PARADIGM SHIFTS

THE GREATEST STORY NEVER TOLD
PARADIGM SHIFTS: A COMET TALE

**Paradigm Shift — When science changes the way we think about nature**

- **Science changes the way we think about nature.**
- **Sometimes the resulting world view is dramatically different than one that came before.**
- **When such a change in thinking occurs, it is called a paradigm shift.**
- **In this lecture we will investigate important paradigm shifts and why they happened.**
- **We will begin our discussion about paradigm shifts in the context of a tale about comets.**
PARADIGM SHIFTS: A COMET TALE

WHAT ARE COMETS

• Comets are cosmic snowballs of frozen gases, rock and dust roughly the size of a small town.

• We know these things about comets because scientists have studied them in ingenious and amazing ways.

• Here are a couple of examples:
PARADIGM SHIFTS: A COMET TALE

THEY HAVE SampleD A COMET

• 2/2000 NASA flew a probe through the tail of a comet.
• They collected some samples of dust and gas.
• The probe returned the samples to Earth on 1/15/2006.
• NASA: STARDUST Mission
PARADIGM SHIFTS: A COMET TALE

THEY HAVE SMASHED INTO A COMET


• The Deep Impact probe recorded the impact as the small craft hit the target.

• NASA wanted to know what would “pop out” of the comet.

• NASA: Deep Impact
PARADIGM SHIFTS: A COMET TALE

THEY HAVE LANDED ON A COMET

• On 3/11/2014, NASA and ESA landed a small probe on Comet-67P

• The mother ship remains in orbit around Comet-67P taking pictures of the comet as it travels around the Sun.

• NASA/ESA: Rosetta Mission

• ESA Comet Viewer
WHERE DO COMETS COME FROM?

- Comets come from two places, the **Kuiper Belt** and the more distant **Ort Cloud**.
- The Kuiper belt lies just beyond the orbit of Neptune.
- The animation shows the discovery of Kuiper Belt objects appearing in the order that they were discovered during the last 10 years.
- Some of the objects are comets, other are dwarf planets similar to Pluto.
PARADIGM SHIFTS: A COMET TALE

THE ORT CLOUD

• The Ort Cloud is the second and more distant place from where comets originate.

• The Ort Cloud is an icy debris field that contains the leftover remains from the creation of our solar system.

• It lies about half-way to the nearest star.

• Consist of billions of individual objects.
A COMET TALE: …THE ORT CLOUD

THIS ICY DEBRIS FIELD CONTAINS THE REMAINS OF THE PRIMORDIAL DUST CLOUD THAT COLLAPSED AND GAVE BIRTH TO OUR SUN.

- THROUGH A PROCESS CALLED ACCRETION, STARS ARE FORGED, AND PLANETS CONSTRUCTED.

- ALL OF THE STUFF IN OUR SOLAR SYSTEM ORIGINATED FROM THIS STELLAR NURSERY.

- THE ORT CLOUD CONTAINS THE LEFT-OVER RAW MATERIALS USED IN THIS CREATIVE PROCESS.
A COMET TALE: THE ORT CLOUD

Our star (the sun) generates a solar wind containing charged particles and other gasses.

- Solar wind interacts with interstellar gas and dust creating a “bow shock”

- The bow shock region of space is considered the “city limit” of our solar system and the beginning of interstellar space.

- The ort cloud and everything in it lies beyond the bow shock region of space.
Occasionally a nearby star disturbs the Ort cloud, sending objects hurtling toward our sun.

- Ort cloud objects are disturbed by the gravity of a neighboring star. Some fall toward our sun.

- As these objects come closer to the Sun, its solar wind will heat the object and cause it to melt.
A COMET TALE: …THE ORT CLOUD

As object melts, a tail of gas and dust develops.

- A comet forms as a result of debris emitted by the object as it melts.

- Solar wind pushes the debris away from the object forming a tail.

- Tail can extend for hundreds of millions of miles and is often visible from Earth.
A COMET TALE: …MESSENGERS OF THE GODS.

A COMET LIGHTS THE SKY…

• Once every ten years on average.
• Some can be seen in daylight
• Tails can fill the sky
• They seem to suddenly appear and disappear

Our modern understanding of comets tells us that they are basically dirty snowballs.

But to the ancients, comets were mysterious and unpredictable.

Often comets were viewed as supernatural, they were messengers of the gods.
THE COMET OF 1066

- William the Conqueror saw a comet in the year 1066.
- He believed that the comet was a sign that God was on his side.
- He invaded England and overthrew the Anglo Saxon king.
- He commemorated his success in an elaborate tapestry called the Bayeux Tapestry.
THE COMET OF 1222

- Genghis Khan saw a comet in 1222.
- He believed that the comet was a sign that his gods were on his side.
- He waged a war that changed the world forever.
- It is estimated that his actions resulted in 50 million deaths over a period of 3 years.
THE COMET OF 1456

- Mehmed the conqueror saw a comet in 1456.
- He saw it as a sign from a god to move west and expand his kingdom.
- Mehmed was the king of the Ottoman Empire which lasted until the early 20th century.
THE COMET OF 1680

• **Isaac Newton** saw a comet appear in late 1680.

• The comet remained visible until December that year.

• Another comet appeared in the sky in January 1681 and it remained visible until March of that year.

• **Newton did not believe the comets were supernatural** but he was curious about them.

• **Newton wanted to know if these two events were caused by a single comet or two of them.**
FROM SUPERNATURAL TO NATURAL

• **Isaac Newton** assumed that both comet appearances were caused by a single object.

• He believed that a single comet might appear twice if it were in orbit around the sun.

• He plotted the apparent path that the comet took around the sun.

• But he noticed something weird about it.
A MYSTERIOUS NEW FORCE

- **Newton understood the comet was in orbit around the sun.**
- **He used the Copernican laws of motion to predict where the comet should reappear on the horizon.**
- **When the comet reappeared in January 1681 it did not appear in the place predicted by his calculations.**
- **Newton knew that some other force much be acting upon the comet.**
- **He called this new force “Gravity”.**
A COMET TALE: NOW FOR SOMETHING COMPLETELY DIFFERENT

PREDICTING THE COMETS RETURN

- Newton understood that in order to prove his discovery, he had to conduct an experiment.

- Newton calculated the force of gravity by analyzing the path that the comet took around the sun and comparing it to the path predicted by the Copernican laws of motion.

- Newton determined that the orbital period of the comet was 74-75 years.

- He predicted that the comet would return again in 1758.

- In 1758, the comet appeared exactly as predicted by Isaac Newton.
A COMET TALE: \textit{...now for something completely different}

\textbf{BUT THERE IS MORE TO THIS STORY}

- Newton knew that he wouldn’t live to see the comet return in 1758 so he got one of his colleagues to help him do some research.

- Newton enlisted the help of a man named Edmund Halley to see if there were historical reports of comets that appeared in the records every 75 years.

- What Halley discovered was that the comet appeared like clockwork.

- The comet was named “Halley’s Comet” after Edmund Halley who was the first to see the pattern in the historical records.
A COMET TALE: ...AN OLD AND FAMILIAR FRIEND

THE HISTORICAL RECORD

• **What Halley had discovered was truly amazing.**

• **When William the Conqueror saw the comet in 1066, it wasn’t a message from God, it was Halley’s comet.**

• **When Genghis Khan saw a comet in 1222, it wasn’t supernatural, it was Halley’s comet.**

• **When Mehmed the Conqueror saw his comet in 1456, it was not a sign from God foretelling his victory, it was Halley’s comet.**
WHAT MAKES SCIENCE DIFFERENT

- **Prediction and Control** of nature.
- **Error Correction** built in by design:
  - Replication and multiple observation
  - Publicly available and verifiable evidence
  - Peer Review
- **Knowledge Production**
  - Knowledge is belief that is both true and justified by evidence
- **Anomalies** are discovered and explained:
  - Anomalies are scientific observations that seem to violate the laws of nature as they are currently understood.
- **Paradigm Shifts**
  - Science changes the way we think about nature
  - Comets as: messengers of the gods vs dirty snowballs
Thinking Errors

• Your brain is in the construction business:
  • We are good at finding patterns in nature, so good in fact that we are often misled by false positives:
  • There are two types of thinking errors:
    • Type I: detecting a pattern when there isn’t one.
    • Type II: failing to detect a pattern when there is one
  • Humans mostly make Type I thinking errors.

• This bias for Type I thinking errors is technically called “Patternicity”.
  • Patternicity was not an insignificant intellectual hurdle for humankind to overcome
  • The answer to the Patternicity problem was science and its methods.
TYPE I THINKING ERRORS

• If you were born in ancient times, it would have seemed as if nature was sometimes out to get you.
  • Xerxes, the great Persian king, was reported to have sentenced the sea to 300 lashes for destroying his pontoon bridge.

• Xerxes made a Type I thinking error.
  • Xerxes had a gap in his knowledge of how oceans and weather work.
  • Xerxes made a type I error by assuming that the sea had intentions and could feel pain.
TYPE I THINKING ERROR: GOD OF THE GAPS

- God of the Gaps:
  - Where there is a gap in scientific understanding people have often appealed to the supernatural as an explanation.
  - This is called a “God of the Gaps” argument
TYPE I THINKING ERRORS &
GOD OF THE GAPS

• God of the Gaps vs the Weather
• The ancient Greeks thought that the faces they saw in the clouds were real.
• The god could cause water to fall from the sky.
• The god could throw lightning bolts.
• The god controlled your harvest.
• The ancient Greeks had gaps in their knowledge of weather and climate.
• Their god of the gaps was named Zeus.
• God of the Gaps vs Epilepsy

• To witness someone having an epileptic seizure is a disconcerting experience. To the ancients, it was terrifying.

• Today, science tells us that epilepsy is the result of misfiring neurons in the brain and we have treatments for it.

• To the ancients, epilepsy was caused by demonic possession.

• In ancient times, people were tortured and killed over this medical condition.
  • There was a gap in their knowledge of how the brain works.
  • The god of the gap was the devil.
EMERGENCE OF COSMOLOGY

- The ancients weren’t always wrong!
- Some of the patterns detected by the ancients were real:
  - Examples:
    - The ecliptic
    - The retrograde motion of the planets
    - Phases of the moon
    - Seasonal changes
  - Many of these beliefs are as ancient as Babylon, but it wasn’t until about 100 CE that someone took the time to sit down and put everything together.
THE PTOLEMAIC REVOLUTION

• 100 CE – The Emergence of Astrology
  • Claudius Ptolemy is the man credited with “putting it all together”.
    • He published his theory in book titled, "Almagest" and from it, astrology was born.
    • His astrological paradigm was the gold standard explanation for the cosmos for about 1500 years.
THE PTOLEMAIC REVOLUTION
&
PTOLEMAIC COSMOLOGY

- Ptolemaic (Astrology) World View
- Ptolemy's world view had the following characteristics:
  - Geocentric (earth centered)
  - Geostationary (earth did not move)
  - Heavens were arranged in perfect concentric spheres.
  - Heavenly bodies were perfect.
  - Planetary motion was explained with epicycles.
The Mystery of Retrograde Motion

• The way that planets appeared to move against the backdrop of stars made them a source of great mystery, even Ptolemy appealed to a god of the gaps when thinking about it:

• Ptolemy, in his work, Almagest, in the margins next to his epicycle explanation, he wrote the following:
  • *I know that I am mortal by nature and ephemeral, but when I trace at my pleasure the windings to and fro of the heavenly bodies, I no longer touch earth with my feet. I stand in the presence of Zeus himself and take my fill of ambrosia.*
Epicycles to explain retrograde motion

- Ptolemy attempted to explain the mysterious motions of planets by appealing to the concept of “Epicycles”.
  - This was an improvement over the historically supernatural explanations for this phenomena.
- Perfect circles were fundamental in his cosmology
- The illustration on the right demonstrates how he used circles within circles (epicycles) to explain the retrograde motion.
- The Ptolemaic world view would remain dominant for the next 1500 years.
THE COPERNICAN REVOLUTION

• 1543 CE - Astrology to Astronomy

• In 1543, Nicholas Copernicus published his work “De revolutionibus orbium coelestium” (On the Revolutions of the Celestial Spheres)
  • Copernicus is credited with being the first to create a model of the cosmos with the sun at the center.
  • He published this work on his death bed to avoid torture and execution for heresy.
  • His death marks the beginning of a paradigm shift from Astrology to a new science called Astronomy.
The Copernican Model (Astronomy)

- The Copernican model did a better job at explaining nature because it was simpler.
  - Copernicus was able to explain retrograde motion without using epicycles by placing the sun at the center of the cosmos.
- The new paradigm was not accepted at first:
  - Initially, there was little in the way of evidence to support the model so people were reluctant to adopt it.
  - Additionally, the threat of religious inquisition played a role in suppressing these ideas.
- Copernican ideas began to gain widespread acceptance with the invention of the telescope.
THE COPERNICAN REVOLUTION &
THE TELESCOPE

• 1610 CE - Galileo and his Telescope

• Galileo is the first astronomer to use the telescope to study the heavens and he published his findings in a book called, Sidereus Nuncius (Starry Messenger)

• What Galileo observed through his telescope was not predicted and could not be explained by the Ptolemaic model of the cosmos.

• Galileo went to publish his work and in response catholic church ordered that:
  • He be shown the instruments of torture
  • He be forbidden to publish any other book,
  • He could not speak about his work ever again to anyone,
  • He was ordered to remain on house arrest for the remainder of his life.
Anomalies Observed by Galileo

- Galileo saw through his telescope three anomalies that directly challenged the geocentric (Ptolemaic) world view.
  - He saw that the sun was not perfect but had spots
  - He saw that some planets had phases and others didn’t.
    - Challenging the notion of a perfect celestial body
    - No prediction or explanation in the Ptolemaic model for some planets having phases and others not having them.
  - He saw that Jupiter had its own moons in orbit around it.
    - This challenged the notion that the Earth is special and unmoving.
THE COPERNICAN COSMOLOGY

**Key Features of the Copernican Model**

- Zodiac used as a celestial coordinate system
- Heliocentric (Sun Centered)
- Geomobile (Earth moves)
- Planets orbit the sun in **perfect circles**.
- Retrograde motion was explained by placing the sun at the center, no epicycles needed.
During the Copernican revolution, Johannes Kepler developed the laws of planetary motion that described how planets orbit the sun using equations.

When comet Halley appeared in 1680, Newton wanted to see if he could use his modified version of Kepler’s laws to predict the path of the comet.

Newton’s discovery of gravity was like finding the missing piece to a cosmic mystery.

- Kepler’s laws explained how celestial bodies move
- Gravity explained why celestial bodies move.

When two or more branches of science combine to create something new, this is a special kind of paradigm shift called a synthesis.

- This particular synthesis is called Classical Physics.
NEWTON’S GOD OF THE GAPS

• Newton’s God of the Gap

• Newton was interested in explaining all of the celestial bodies as a single system, unfortunately his work stopped just short of this goal.

• The law of universal gravitation worked really well when used to predict how any two celestial objects would behave relative to each other.

• But his laws failed him when he tried calculating all of the known celestial objects as a coherent system.
  • According to his calculations, the solar system should be unstable, and planets should be flying every which way.
  • This was a gap in his knowledge about celestial mechanics.

• Newton reasoned that it must be god’s hand keeping it all together.
  • This was Newton’s god of the gap argument.
  • It would take another 100 years for someone to demonstrate that Newton’s god of the gaps was nothing more than a type I error.
DISCOVERY OF URANUS

• 1781 CE – Discovery of Uranus
  - William Herschel discovered what he thought was a comet though his telescope.
    - Eventually he realized that what he was observing was not a comet but a new planet! Uranus.
  - Herschel recognized the discovery as an opportunity to test Newton’s laws of gravitation.
    - He predicted what the orbit of Uranus should be.
  - It took another 70 years of observation before the orbit of Uranus could be verified against his prediction.
  - The orbit of Uranus didn’t appear to match the predictions made by Newton’s laws of gravitation (Anomaly).
1846 – Discovery of Neptune

Uranus’s orbit was anomalous

Unlike Newton, his contemporaries did not make a god of the gaps arguments to explain the anomaly. Instead, they looked for alternative natural explanations:

- One possibility was that there might be another source of gravity that was influencing the orbit of Uranus.
- Urbain Le Verrier used Newton’s laws to calculate the possible orbital path that this mysterious new object might take.
- When astronomers looked at the predicted location via telescope, they found a new planet, just as predicted.

The discovery of Neptune proved the accuracy and utility of Newton’s laws and demonstrated the power of Newtonian physics as a natural science.
THE MYSTERY OF MERCURY’S ORBIT

The Last Anomaly (or so they thought)

• The discovery of Neptune occurred by using only physics.
  • In the past, all discovery had been based on previous observation, this was the first time that a
    new discovery was made using predictions derived only from scientific theory.
  • This represents a significant event in the history of science, one that set the standards of proof for
    all future scientific discoveries.

• Many astronomers boasted at the time that they were on the verge of discovering everything
  there was to know about the cosmos.
  • At the time, there was one anomaly known to astronomers that had yet to be explained so they
    tried using the same approach that led to the discovery of Neptune to see if they could explain the
    anomalous orbit of Mercury.
THE MYSTERY OF MERCURY’S ORBIT

The Anomalous Orbit of Mercury

- Mercury’s orbit does something quite strange; it precesses; meaning, the orbit changes slightly each time the planet passes closest to the sun.

- They assumed that the anomalous orbit must be from an unseen source of gravity:
  - Astronomers suggested that it might be an undiscovered asteroid belt that lies between the sun and Mercury
  - One astronomer reported that he had seen a new planet transiting the sun that was between Mercury and the sun.

- What astronomers were left with was an unexplained anomaly

- The mercury anomaly remained a mystery until the beginning of the 20th century.
THE ANOMALOUS ORBIT OF MERCURY
The Anomalous Properties of Light

Mercury’s orbit was not the only anomaly that needed explaining.

Light has its own mysteries to explore. E.g. is light a wave or a particle?

Newton assumed that, like other waves in nature, light must require medium to propagate through.

The anomaly arises from the fact that space is a near vacuum and so there is no obvious medium through which light propagates.

Newton and others assumed that the medium was there but remained undiscovered.

They called this hypothetical medium the “Aether”.

CLASSICAL PHYSICS & THE AETHER
• In 1887, Michelson & Morley devised an experiment that could in principle detect the presence of an ether if it exist.

• The Michelson & Morley experiment was considered to be the most expensive scientific investment ever made at that time.

• The logic of the experiment was to measure any variations in the speed of light that occurred as a result of the earth orbiting the sun.

• The outcome of the experiment measured no changes of any kind to the speed of light no matter which direction they looked.

• This experiment confirmed that there was no Aether and that the speed of light is constant.

• How light propagates through a vacuum and why the speed of light is constant remained a perplexing mystery until the beginning of the 20th century.

• [LINK]
THE NEWTONIAN REVOLUTION
(CLASSICAL PHYSICS)

Key Features of the Newtonian Revolution
(Classical Physics)

• Zodiac remained in use as a celestial coordinate system.
• Heliocentric
• Newton’s version of Kepler’s laws described how planets orbit the sun, and Newton’s laws of gravity described why they orbit the sun.
• Orbits are no longer considered perfect circles; rather, they are ellipses.
• Newton’s laws couldn’t explain the anomalous orbit of Mercury.
• Newton’s laws could not explain why speed of light was constant and how light could propagate through a vacuum without a medium.
ELECTROMAGNETISM

◊ The synthesis of electricity & magnetism (electromagnetism) made it possible to explain how light could propagate in the absence of the Luminiferous Aether.

◊ The discovery of electromagnetism made possible the invention of:
  ◊ Radio communications
  ◊ Transistors
  ◊ Integrated Circuits

◊ 1864 – James Clerk Maxwell developed the electromagnetic theory of light.
  ◊ Light was made of electric & magnetic waves occurring at right angles (or perpendicular) to each other.
  ◊ Occurring together, each wave reinforced the other via a continuous feedback loop, allowing these waves to propagate without a medium.
  ◊ This discovery set the stage for Albert Einstein to usher in the age of modern physics in the early 20th century.
THE THEORY OF RELATIVITY

1913 – Einstein wrote a paper explaining his new theory of gravity.

This was Einstein’s attempt to solve the remaining anomalies of classical physics:

Why is the speed of light constant in a vacuum?
Why does Mercury’s Orbit precess at the perihelion?

To explain these anomalies, Einstein had to reimagine the force of gravity and he named his theory, the theory of relativity.

Einstein’s theory makes some interesting predictions, most of which have been since verified by experiment.
EINSTEIN’S FOUR GREAT INSIGHTS

- EQUIVALENCY OF SPACE & TIME
- EQUIVALENCY OF MASS & ENERGY
- UNIVERSAL COSMIC SPEED LIMIT
- EINSTEIN’S CONCEPT OF GRAVITY
EQUIVALENCY OF SPACE & TIME

❖ Einstein’s first great insight was that space and time are two aspects of the same thing.

❖ This insight constitutes a synthesis that he called “Spacetime”.

❖ This insight has some interesting implications that we will discuss further in the coming slides.
EQUIVALENCY OF MASS & ENERGY

◊ Einstein’s second great insight was that mass and energy are two aspects of the same thing.

◊ Einstein described this relationship with the famous equation ”$E = MC^2$”

◊ The equation is deceptively simple, but its implications are not.
  ◊ $E$ represents energy
  ◊ $M$ represents mass
  ◊ $C^2$ represents the speed of light (300,000 kms) squared

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<tr>
<td>mass</td>
<td>kg</td>
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<tr>
<td>speed of light</td>
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UNIVERSAL COSMIC SPEED LIMIT

◇ Einstein’s third great insight was that the speed of light in a vacuum is the maximum speed limit for objects with mass.

◇ This means that objects with mass, at best, may only approach the speed of light but can never meet or exceed it.

◇ $E=MC^2$ demonstrates why this must be the case.

◇ Because Mass and Energy are equivalent…
  ◇ The more energy ($E$) used to approach the velocity of light,
  ◇ The greater your mass ($M$) increases.
    ◇ The greater your mass ($M$) becomes,
      ◇ The greater the curvature of spacetime.

◇ Only light can travel light speed because light has no mass.
EINSTEIN’S CONCEPT OF GRAVITY

- Einstein’s fourth great insight was that gravity is not an attractive force between two objects (like Newton thought).
- Gravity is an emergent phenomenon resulting from the interaction of mass & energy with spacetime.
- Einstein’s concept of gravity can be broken down into two components:
  - The presence of mass-energy causes the geometry of spacetime to curve.
  - The curved geometry of spacetime determines how mass-energy can move.
- It was this insight that explains the anomaly of Mercury’s orbit.
EINSTEIN’S CONCEPT OF GRAVITY

- Mass-Energy cause spacetime to curve around it.
EINSTEIN’S CONCEPT OF GRAVITY

- The curved geometry of spacetime determines how mass-energy moves.
- https://www.youtube.com/watch?v=MTY1Kje0yLg
TESTING EINSTEIN’S PREDICTIONS

◊ **GRAVITATIONAL LENSING**

◊ Einstein predicted that the curvature of spacetime around massive objects might be detected by light bending around it.

◊ Einstein called this effect gravitational lensing (Cowen 2019).

◊ Einstein devised an experiment that would use the light from background stars to detect gravitational lensing caused by the sun’s gravity.

◊ A total solar eclipse in 1919 provided an opportunity to test Einstein’s predictions.

◊ Observations during the Eclipse matched his predictions, making him famous overnight.
TESTING EINSTEIN’S PREDICTIONS

✧ SPACETIME DILATION

✧ Because space and time are two aspects of the same thing (spacetime), what happens to one must also happen to the other.

✧ This means the greater the curvature of spacetime, the slower time will pass relative to an outside observer.

✧ In 1971, Joseph C. Hafele and Richard E. Keating devised an experiment where three cesium-beam atomic clocks (see Fig. 9) would be synced so that each reflected the same time on the ground.

✧ Two of these clocks then were placed on commercial airliners and flown around the world twice.

✧ One clock was flown to the east the other flown to the west, the third remained on the ground.

✧ The differences between these clocks matched exactly what Einstein's theories predicted.

✧ The ground clocks ran faster than the clocks on the airplanes.
THE GENERAL THEORY OF RELATIVITY & SPACETIME DILATION

**Spacetime Dilation**

- Einstein predicted that time speeds up and slows down depending on mass and acceleration; this is called Spacetime dilation.
  - The closer you are to the center of a mass the slower time passes for you relative to someone else standing farther away from it.
  - The greater the mass, the more space will curve and the slower time will go.
  - At infinite mass, time stops all together!

- It is possible to time travel into the future only, if the person accelerates close to the speed of light.
  - The twin paradox will demonstrate what can happen.

- Multiple experiments using atomic clocks and other devices have proven that Spacetime Dilation is real.

### The Twin Paradox

\[
t' = t\sqrt{1 - \frac{V^2}{c^2}}
\]

Where:
- \( t' \) = dilated time
- \( t \) = stationary time
- \( V \) = velocity
- \( c \) = speed of light

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EINSTEIN’S LEGACY

◊ BIG BANG THEORY, COSMIC MICROWAVE BACKGROUND

◊ Einstein’s theories about light, motion, gravity, mass, and energy began a new era of science.

◊ These ideas directly led to the big-bang theory of how the universe was born and led to concepts such as black holes and dark energy (NASA 2005).

◊ There have been many theories put forth to explain the origins of the universe in the last 100 years and one has been left standing after all the tests have been conducted, the Big-Bang theory (Tyson 2017).

◊ While Einstein didn’t come up with the theory himself, the Big-Bang theory is derived from his ideas (NASA 2005).

◊ Currently, scientists are using NASA’s instruments to study some important anomalies.
  ◊ The patterns in the cosmic microwave background.
  ◊ The nature of dark energy.
COSMIC MICROWAVE BACKGROUND
EINSTEIN’S BIGGEST BLUNDER?

◊ THE MYSTERY OF LAMBDA & DARK ENERGY

◊ Einstein derived mathematical formulas to describe the universe, but his formulas only worked if the universe was expanding or contracting (NASA 2005).

◊ Einstein wasn’t comfortable with either option because he believed the universe was constant and would last forever.

◊ To fix this expansion/contraction problem, Einstein added an extra term to his formulas that described the universe.

◊ The extra term made it possible for his model to neither expand nor contract.

◊ Einstein called this term the “cosmological constant” (Tyson 2014).

◊ The cosmological constant is represented by the symbol lambda: $\Lambda$
EINSTEIN’S BIGGEST BLUNDER?

THE MYSTERY OF LAMBDA & DARK ENERGY

Edwin Hubble soon acquired direct observations that proved that our universe was expanding.

In response, Einstein pulled the cosmological constant term from his formula describing the cosmos.

Einstein called the cosmological constant his “greatest blunder” but some recent discoveries suggest that Einstein may have been right.
EINSTEIN’S BIGGEST BLUNDER?

THE MYSTERY OF LAMBDA & DARK ENERGY

Scientists recently discovered that our universe isn’t just expanding, it is expanding at an accelerated rate.

Scientists have speculated about the causes of the expansion rate of the universe and have coined a term for his called, “Dark Energy”.

The effects of Dark Energy have been precisely measured and it’s value matches exactly that of Einstein’s cosmological constant.

These outcomes show that Einstein was so smart that even when he was wrong, he was right.
Was the cosmos made for us?

**FUNDAMENTAL PHYSICAL CONSTANTS**

\( N = 10^{36} \) - Ratio of the strength of electromagnetism to the strength of gravity for a pair of photons.

\( Epsilon (\varepsilon) = .007 \) - The strength of the force binding nucleons to nuclei.

\( Omega (\Omega) = 1 \) - The density parameter, the relative importance of gravity and the expansion energy in the universe.

\( Lambda (\Lambda) = 10^{-122} \) - Ratio of the density of dark energy to the critical energy density of the universe.

\( Q = 10^{-5} \) - Ratio of the gravitational energy required to pull a large galaxy apart to the energy equivalent of its mass.

\( D = 3 \) - Number of spatial dimensions in spacetime.
GOD OF THE GAPS
VS
NATURAL EXPLANATIONS

Lambda ($\Lambda$) = $10^{-122}$

What explains the pattern in the CMB?

What explains the extreme precision of Lambda?