Two Big Unanswered Questions in Physics

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- A **little** about me
- A Look at Two of the Big Questions in Modern Physics
- Some Reflections on Science & Physics

My Education (So Far)

- Did Leaving Cert. Honors Physics in CVS (now Breifne College)
- Got a Double Honors Degree in Experimental Physics & Computer Science in NUI Maynooth
- Studying for a PhD in Computer Science in NUI Maynooth. Work involved cooperation with:
  - NASA GEST Center in Goddard Space Flight Center
  - Telescopes In Education foundation at NASA JPL
  - Also got to play with the Faulkes Telescopes

Some Other Stuff

- Associate Member of the Institute of Physics
- Fellow of the Royal Astronomical Society
- Founded Astronomy Society in NUIM (Astro2)
- Webmaster for Irish Federation of Astronomical Societies (IFAS) - www.irishastronomy.org
- Produce a monthly Podcast for IFAS
- Avid Blogger and Photographer - www.bartbusschots.ie

Two Big Questions

- There are many questions scientists are striving to answer. Today we will look at just two:
  - What makes up most of the universe?
  - How can we unite Quantum Mechanics and Relativity?

Where's The Rest of it?

"The crux... is that the vast majority of the mass of the universe seems to be missing" - **William J. Broad**

The "Missing Mass Problem"

- 1930s - Fritz Zwicky (Caltech) measures galaxy dynamics in the Coma Cluster of galaxies - finds it must have 400 times more mass than could be observed - Astronomers don't take him seriously

- 1970s - Vera Rubin & Kent Ford (Carnegie Institution of Washington) measure rotation curves of galaxies. Curves require more mass than can be observed - Many Astronomers scoff again

- 1980s - other astronomers repeat the experiments - they verify the result over and over again

- Recently - gravitational lensing measurements again show that there is more mass in galaxy clusters than we can see

- These results have stood the test of time. Current research shows about 95% of the mass of galaxies is 'missing'

Gravitational Lensing

- As predicted by Einstein's relativity - light is bent by large masses
- The amount of bending is related to the mass of the intervening object

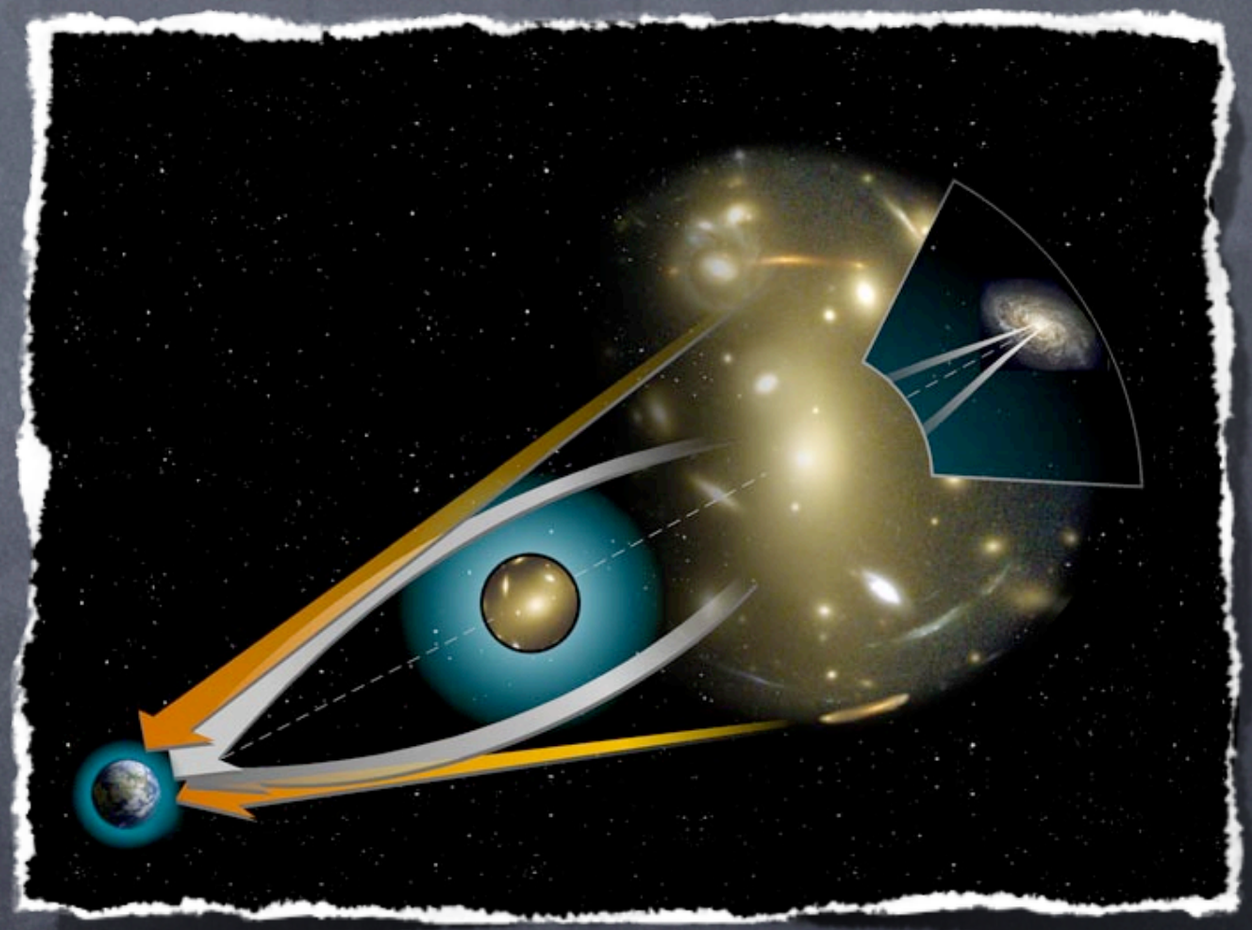
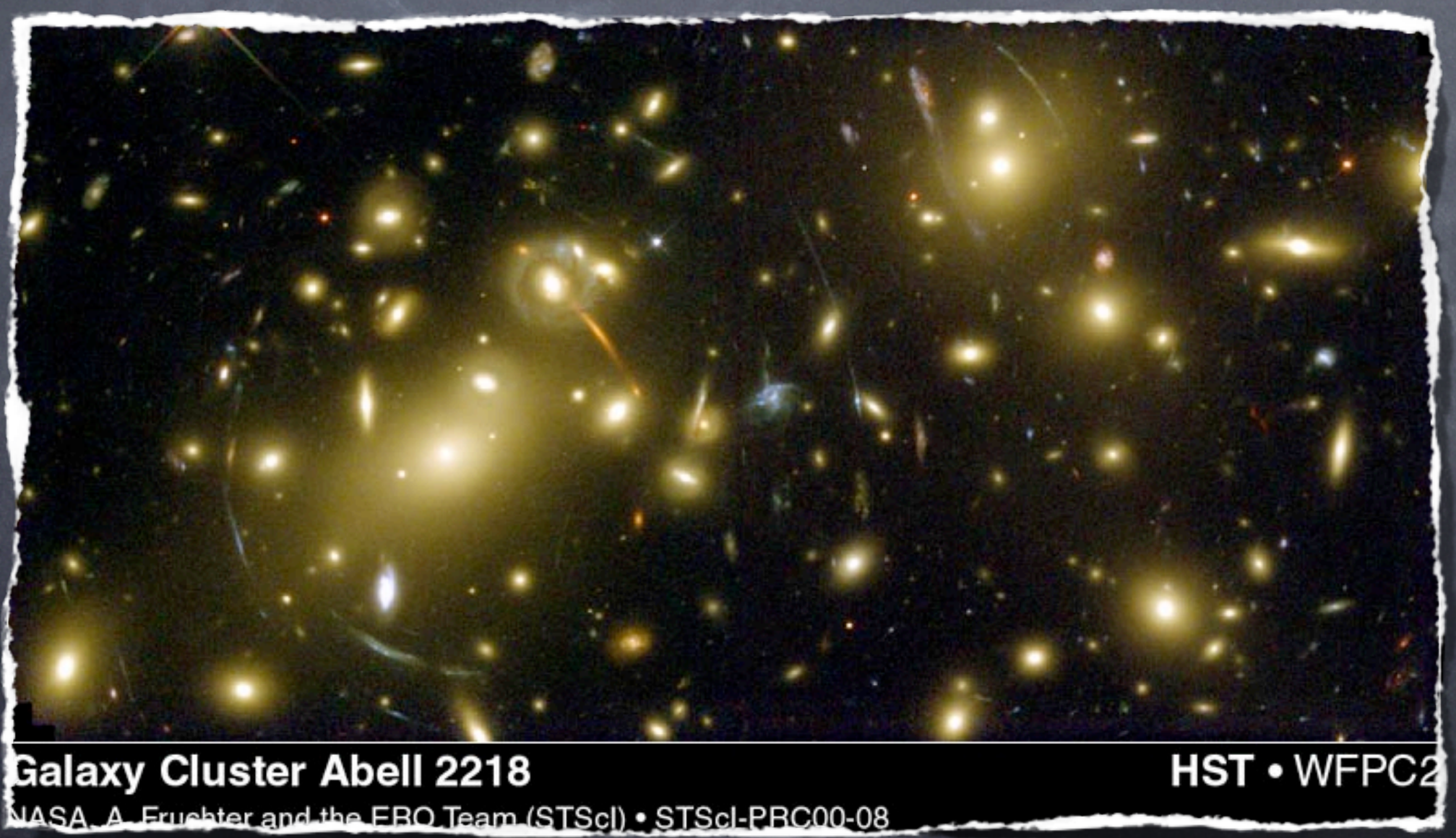


Image Credit: NASA & ESA

Gravitational Lensing as Seen by the HST



What's Going On?

- Two things could be going on:

1. The observed discrepancies are the result of a flaw in our understanding of gravity
    - **MoND** is the leading theory in this area. It still requires some dark matter and its current predictions do not match the results of gravitational lensing observations well

2. The observed discrepancies are caused by matter that we cannot see - we call this **Dark Matter**

- It is also possible that it's a little of both but current observations and theoretical work support Dark Matter

What Could Dark Matter Be?

- There are two accepted theories of Dark Matter:

  1. Hot Dark Matter (e.g. Neutrinos)
  2. Cold Dark Matter (e.g. Black Holes, Neutron Stars, Brown Dwarfs 7 WIMPs)

- Cosmological theories combined with observations of the 'echo' of the Big Bang, the Cosmic Microwave Background Radiation, seem to imply that both kinds are present in the universe

Our Expanding Universe

- 1910s
  - Vesto Slipher and later Carl Wilhelm Wirtz use red-shift measurements to show that 'spiral nebulae' are receding from the Earth - they didn't realize the importance of their findings
- Einstein's General theory of relativity predicts a non-static universe. Einstein invents the 'cosmological constant' as a 'hack' to force a steady-state universe

Our Expanding Universe

- 1922 - Alexander Friedmann discovers an expanding-universe solution to general relativity field equations without using a cosmological constant
- 1927 - Belgian Catholic priest Georges Lemaître proposes his "hypothesis of the primeval atom"
- 1929 - Edwin Hubble's observations show a universe expanding according to Hubble's law:

$$v = HD$$

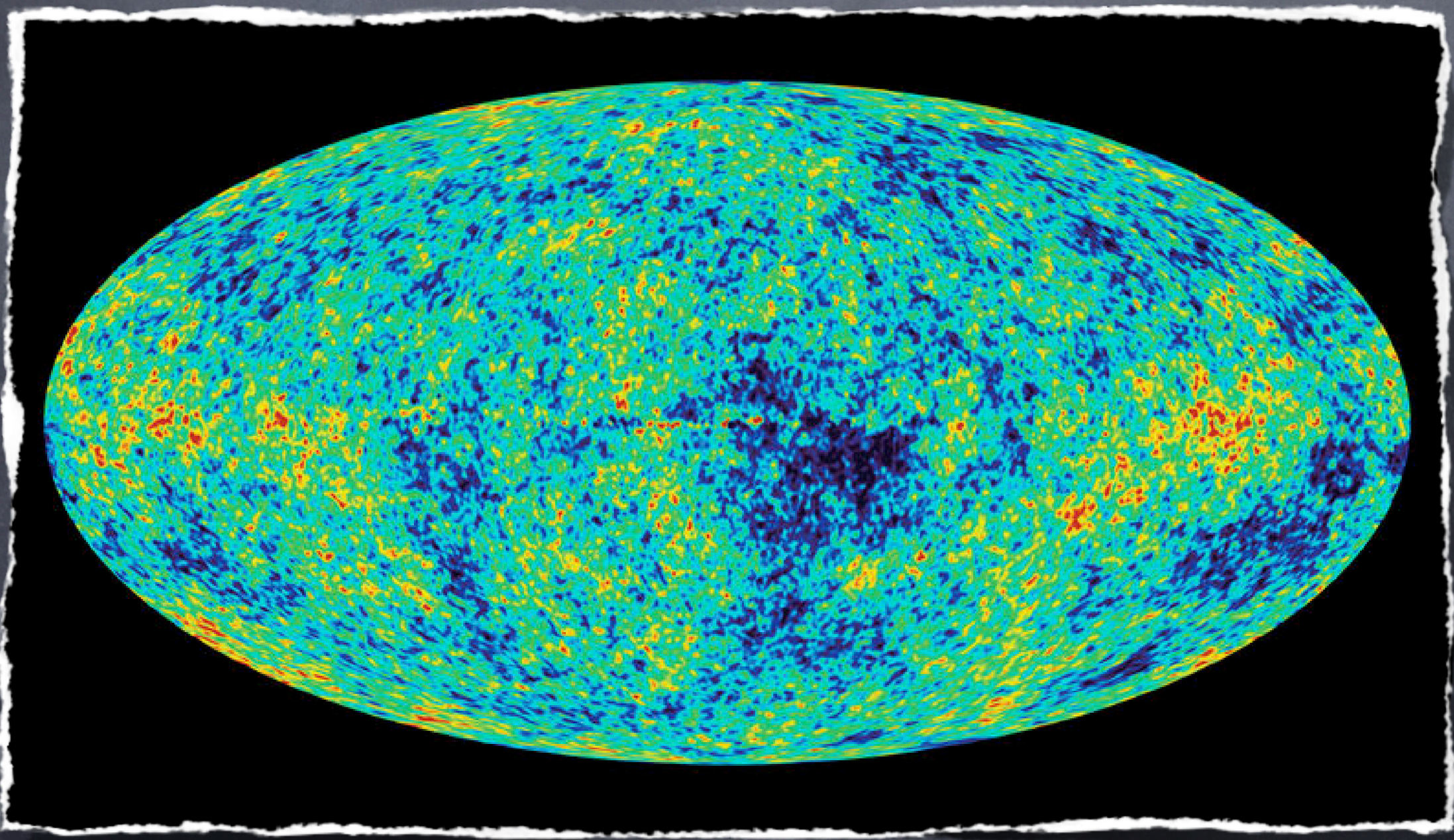
The Big Bang

- When you put everything on the previous slides together you get a theory where the universe starts as an infinitely small point with infinite density and mass and then expands out to form the universe
- This view was ridiculed by many including Fred Hoyle who coined the phrase "Big Bang" as an insult - it stuck!

The Cosmic Microwave Background Radiation

- Although Hubble's observations supported the Big Bang theory more evidence was needed
- According to the Big Bang theory the universe is closed so the heat from the Big Bang cannot escape. It must still exist as background radiation getting ever more stretched as the universe expands
- In 1964 Arno Penzias and Robert Wilson **accidentally** discovered the CMBR

The CMBR Observed



The Cosmic Microwave Background Radiation as observed by the WMAP probe

Who Has Their Foot on the Gas?

- It was starting to look like we'd soon have all of cosmology figured out but then two rather large flies landed in the ointment

- The CMBR is too uniform to allow for Galaxies to form - unless you include cold dark matter in your equations that is

- The rate of expansion is SPEEDING UP - not slowing down as expected - BIG problem!

Dark Energy

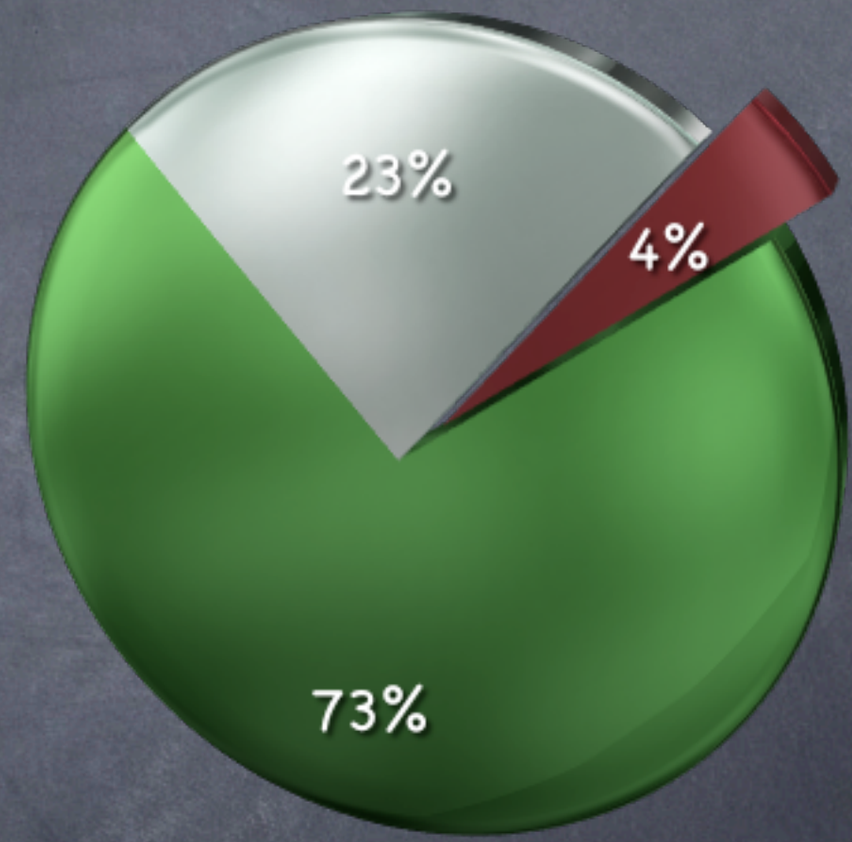
- We have no idea what the mystery force is that is driving this increase in rate of expansion but we call it Dark energy
- It seems to be a force that exists in the very fabric of space-time itself - some form of Zero-Point-Energy
- Ironically, the properties of this Dark Energy are very like Einstein's Cosmological Constant!

The Composition of Our Universe

- Dark Matter & Dark Energy make up the majority of our universe

- And we have no idea what they are!

- We only know what 4% of our universe is made of!



Relativity

"When you are courting a nice girl an hour seems like a second. When you sit on a red-hot cinder a second seems like an hour. That's relativity" - **Albert Einstein**

Special Relativity

- Published in 1905 by Albert Einstein it was an extension of a principle proposed by Galileo
- Based on two very simple postulates
  - The laws of physics are the same in all inertial frames of reference
  - The speed of light in a vacuum is a universal constant

Special Relativity - The Consequences

- The Effects of Special Relativity are summed up by the so-called Lorentz Transformations:

1. Time Dilation - the twin paradox

2. Relativity of Simultaneity - events which seem simultaneous in one reference frame won't in others

3. Lorentz Contraction - different observers will measure different lengths

4. Composition of Velocities - speeds don't add linearly

5. Inertia & Momentum - as you approach c your mass becomes infinite so you can't get to the speed of light

6. Mass and Energy are related by $E=mc^2$

General Relativity

- Special Relativity does not work in accelerating frames of reference
- Special Relativity does not deal with gravity and breaks down in strong gravitational fields
- To deal with these problems Einstein published his theory of General Relativity in 1915/6. It not only works in the presence of strong gravitational fields but explains gravity and works in accelerating frames of reference

General Relativity

- General Relativity explains the workings of a 5 dimensional universe - our regular three spacial dimensions and time are referred to as space-time which can be curved in a fifth dimension to produce gravity
- General Relativity is the first theory to properly explain the motion of Mercury
- Predicts gravitational Lensing & Black Holes

Quantum Mechanics

"Anyone who is not shocked by Quantum Theory has not understood it" - **Niels Bohr**

Quantum Theory - The Early Years

- 1900 - Max Plank solves the black body problem by assuming energy is quantized
- 1905 - Einstein explains the photoelectric effect by quantizing light
- 1913 - Neils Bohr develops the first working model of the atom by quantizing electron orbits
- 1924 - Louis-Victor de Broglie formalizes Wave-Particle Duality
  - Sub-atomic 'particles' have properties of both waves and particles
  - Electron 'wavelength' explains the quantization of electron orbits in the Bohr atom

The Birth of Quantum Mechanics

- 1925 - Werner Heisenberg develops the first complete quantum theory - Quantum Mechanics is born (Max Born transformed Heisenberg's original theory to a simpler form using matrices)
- 1925 - Erwin Schrödinger produces the famous Schrödinger Wave Equation
- 1926 - Erwin Schrödinger proves that his wave equations are completely equivalent to Heisenberg's matrix mechanics - they are two ways of expressing the same theory

QM 'Spookiness'

- QM theory has Electrons jumping instantly from one orbit to the next without passing through any position in between
- 1927 - things get even weirder when Heisenberg discovered the Uncertainly principle. The more certain you are about the momentum of an object the less you can know about it's position and vica-versa
- QM is a probabilistic Theory - all you can get is probabilities of which state a particle will be in when observed
- Superposition - when not observed particles are in all their possible states at once!
- Quantum Entanglement - "spooky action at a distance"

QM Goes Sour for Albert

"God does not play dice" - **Albert Einstein**

- Einstein was deeply disturbed by the probabilistic nature of QM - He was sure particles must contain an internal state that could provide a way around the probabilistic nature of QM

- John S. Bell's 'Bell Inequalities' provide an experimental way to test the Bell Theorm "No physical theory of local hidden variables can ever reproduce all of the predictions of quantum mechanics" - The experiments have been done - Bell was right, Einstein was wrong

- Quantum Entanglement violates Special Relativity

The Big Gap

- When you scale QM up it approximates to Newtonian Physics
- When you scale down Relativity it approximates to Newtonian Physics
- HOWEVER, QM is not compatible with Relativity
  - Fundamental incompatibilities in treatment of Gravity
  - Quantum Entanglement violates Special Relativity

The GUT

- Einstein founded the field of Relativity and was instrumental in the early work on Quantum Mechanics
- He spent the latter part of his life in a failed attempt to come up with a Grand Unified Theory that would unite the two
- The GUT is the "Holy Grail" of modern physics - no one has found it yet but many are looking
- The best current candidate for a GUT is M-Theory - a derivative of String Theory

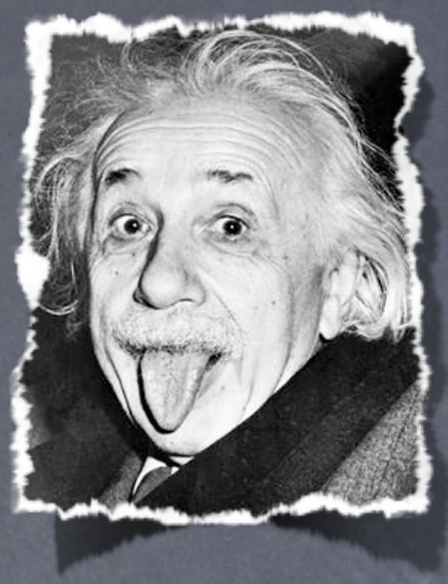
M-Theory

- Unites the five Super-String Theories
- Requires 11 dimensions!
- M-Theory is not yet complete - anyone here think they could finish it off?

Reflections on Science

- In science it's not possible to prove anything right, only to add support for a theory, or prove it wrong - "Falsify-ability"
- Science is based on repeatable observation
- Science is our current best approximation of how the universe works
- Science is not static nor set in stone
- Science is ever changing and adapting

Some Final Thoughts From Albert



- "As far as the laws of mathematics refer to reality, they are not certain, and as far as they are certain, they do not refer to reality"
- "I am enough of an artist to draw freely upon my imagination. Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world"
- "If A equals success, then the formula is: A = X + Y + Z, X is work. Y is play. Z is keep your mouth shut"
- "Common sense is the collection of prejudices acquired by age 18"
- "Only two things are infinite, the universe and human stupidity, and I'm not sure about the former"

Some Final Final Thoughts

- "I have not failed. I've just found 10,000 ways that won't work" - **Thomas Edison**
- "Research is what I'm doing when I don't know what I'm doing" **- von Braun**
- "The most exciting phrase to hear in science, the one that heralds new discoveries, is not 'Eureka!' (I found it!) but 'That's funny ...'" **- Isaac Asimov**

That's It Folks

Any Questions?