Cosmology – The Origins of the Universe

Here, we want to examine the scientific story of the origins of the Universe.

We saw in the video last class that Hubble's discovery of an expanding Universe confirmed Lemaitre's solution of Einstein's equation implying that the Universe had an origin, and that, according to Hawking, the origin had to be a singularity.

Cosmology is one arena in which science and religion are in apparent conflict.
We should pause and discuss this apparent conflict:

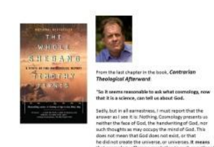
Story &Music

- In many ways Science and Religion ask the same questions; for example:

What is the Origin of the Universe?

- But, their answers are very different – not just in what the answers say, but, even more importantly, in how the answers are framed.

- Consider a paragraph from the science writer Timothy Ferris' 1997 book **The Whole Shebang A State-of-the Universe(s) Report**.



Cosmology: Science and Religion

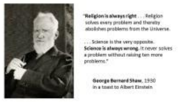
- **In Religion, The Question of Origins is answered in the language of religion, i.e. in a very definite and certain way; for example, the first lines of Genesis:**

  1 In the beginning God created the heaven and the earth
  2 And the earth was without form, and void; and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the waters
  3 And God said, Let there be light: and there was light (King James Version)

- **In Science, The Question of Origins is answered in the language of science, i.e. based on observations and currently understood theories. As in all of science, new observations can always come to light, and more complete theories can be found. Therefore, the answer that Science provides is always tentative; for example:**

  "Our observations indicate that the state of the Universe as we observe it today is consistent with all spacetime and matter/energy originating from a singularity sometime between 12 to 15 billion years in the past. Our theories of the Nature of Matter applied to the conditions that existed in the early history of the Universe allow us to predict how the Universe evolved into its present state. Our predictions agree well with observations. Recent observations (e.g. the acceleration of the cosmic expansion) and new theories (e.g. the long-hoped-for quantum gravity) may require revisions to our model." (SGA version ☺)

- **The Irish writer George Bernard Shaw summed up this idea this way.**



- **Jacob Bronowski, a Polish-born British mathematician and writer, in a defense of science, warns us about absolute knowledge and dogma in his series The Ascent of Man** ➡

<u>Cosmology: Science and Religion</u>

When Science and Religion seem to come into conflict, **it is frequently wise to keep two ideas in mind:**

> **If you seek answers from Science that are as definite and as certain as those given by Religion, you will be disappointed.**

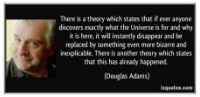
And,

> **If you seek answers from Religion that are as measurable and as verifiable as those from Science, you will be disappointed.**

Perhaps **Georges Lemaitre**, the Catholic priest, physicist, and mathematician and founder of what we today call Big Bang Cosmology put it best:

"To search thoroughly for the truth involves a searching of souls as well as spectra."

And, let's not forget ***Douglas Adams***
(we can't lose our sense of humor!)



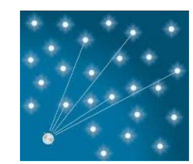
. . . Oh no, I've said too much

The Science of Cosmology: Some History

Isaac Newton believed that a static Universe had to be uniformly populated with stars to infinite distances.

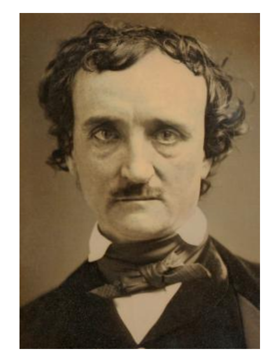
If it wasn't:
Gravity would cause the Universe to collapse.

But then, **Why is the night sky dark? ("Olbers Paradox" c. 1820s)**



Every direction we look should ultimately intersect a star, and the night sky should be bright.
The simple fact that the night sky is dark tells us something profound: (LC)

The Universe must be finite in Space (size)
or Time (age) – or both.



Edgar Allan Poe

What famous American writer was one of the first to correctly interpret this paradox. **(LC)** *(. . . . do you want a clue?)*

Cosmology: Some History

- In **1916, Albert Einstein** applied his new General Theory of Relativity (remember, a new theory of gravity) to the entire Universe with the following assumptions: **At the largest scales, the Universe is:**

  - **Homogeneous**, the same distribution of mass/energy
    (**LC**, what do you buy that's been homogenized?)
  - **Isotropic**, i.e. the Universe looks the same in every direction.
  - **Universal and Rational**
    The "*Laws of Physics*" are the same at all places in the Universe and and at all times (*i.e. Universal*), and we are capable of understanding them (*i.e. Rational*)! *(Note: this does not say that we know these laws!)*

- With these assumptions, Einstein solved the field equations of General Relativity:

$$G_{\mu\nu} = -8\pi G T_{\mu\nu}$$

- He expected to find a steady-state or **Static Universe** – the same today as in the past and the future.

- But the only solutions that came out mathematically were for an **Expanding Universe or a Contracting Universe – it could not stand still!**

Cosmology: Some History

- To make his equations produce a static Universe, Einstein added a term to his field equations called the **"Cosmological Constant"**

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = -8\pi G T_{\mu\nu}$$

- In the 1920's, Georges Lemaitre proposed that the original equations were correct, and when Hubble discovered the expansion of the Universe, even Einstein abandoned his Cosmological Constant. (we also saw an excellent discussion of this in the Stephen Hawking video.)

- However, as we'll see in the next few classes, in **1998**, the use of white dwarf supernovae as distance indicators revealed that:

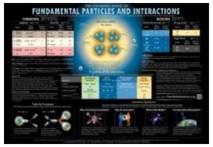
Not only is the Universe expanding, but the expansion is accelerating!

The source of this acceleration has been named **"Dark Energy,"** and one treatment of it puts it into Einstein's equations exactly where the Cosmological Constant is (. . . but not for the same reason).

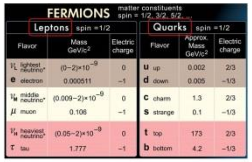
The Standard Model of Particle Physics

To understand many of the current ideas of the origin of the Universe, we have to briefly examine the **Standard Model of Particle Physics** – *our last dive into the structure of matter:*

- Although not complete, it is our **best understanding to date of the fundamental particles and forces in the Universe**. This chart is from The Contemporary Physics Education Project (CPEP); we will go over some of it.



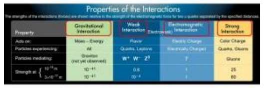
- Matter is made of two fundamental types of particles, **Leptons and Quarks** (quarks feel the strong nuclear force, leptons don't)



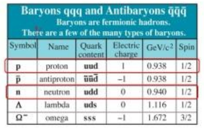
FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin =1/2			Quarks spin =1/2		
Flavor	Mass GeV/c²	Electric charge	Flavor	Approx. Mass GeV/c²	Electric charge
ν_L lightest neutrino*	$(0-2)\times10^{-9}$	0	u up	0.002	2/3
e electron	0.000511	–1	d down	0.005	–1/3
ν_M middle neutrino*	$(0.009-2)\times10^{-9}$	0	c charm	1.3	2/3
μ muon	0.106	–1	s strange	0.1	–1/3
ν_H heaviest neutrino*	$(0.05-2)\times10^{-9}$	0	t top	173	2/3
τ tau	1.777	–1	b bottom	4.2	–1/3

- The fundamental particles, Leptons and Quarks, interact through **Four Fundamental Forces**: (see narrated figure in the study area)



- Quarks combine through the Strong Force to make **Baryons**, two familiar ones are the **proton and neutron** (there are many other types)

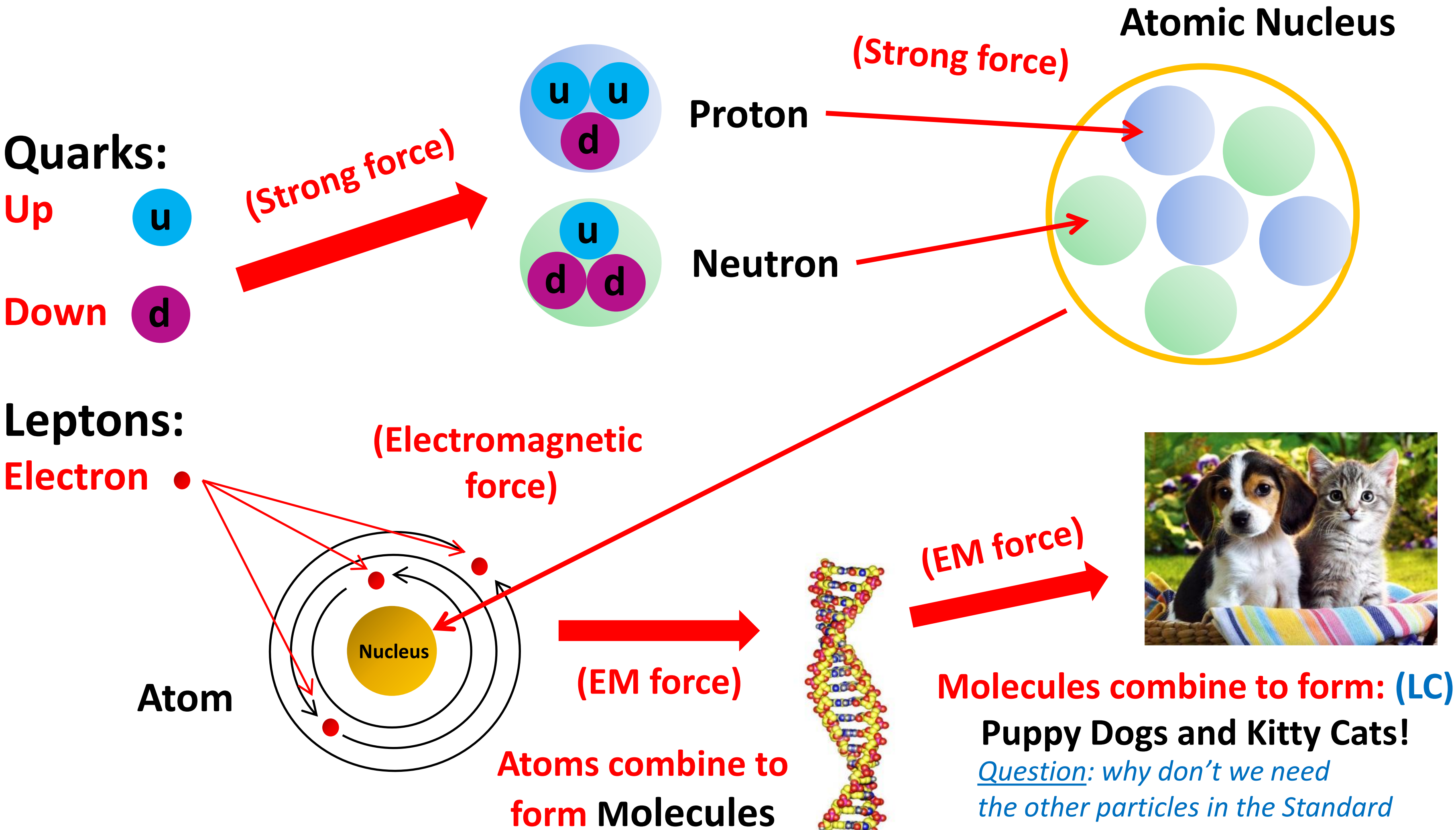


Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$
Baryons are fermionic hadrons.
There are a few of the many types of baryons.

Symbol	Name	Quark content	Electric charge	GeV/c²	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	antiproton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	–1	1.672	3/2

The Structure of "Normal Matter"

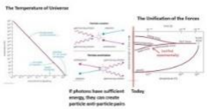
How do you make "Normal Matter" out of the Standard Model Particles?



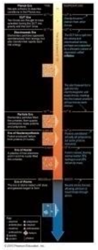
<u>Question</u>: why don't we need the other particles in the Standard Model to make "Normal Matter"?
We don't know.

The Standard Model and Big Bang Cosmology

To understand how the Universe changed and evolved, we run the clock backwards, and use the Laws of Physics (as we understand them) to predict how the Universe behaved during certain epochs.



As the Universe expanded, it cooled, and several aspects of particle physics can be important (see the narrated Figure 17.4 in the study area & HW)



Your author goes through the important processes step-by-step in Figure 17.5 (narrated in the study area & HW) and Figure 17.6.

Two of the most important predictions made from Big Bang Cosmology are: (LC)

- **The Cosmic Abundance of Helium**
- **The Cosmic Microwave Background** (existence and fluctuations)

We've seen a discussion of these in the video, and your text covers them well.

Cosmological Inflation:

In the 1980's, it was proposed that early in its history, the Universe went through a **rapid expansion called Inflation**. (See Figure 17.5) This solves two problems, the **Horizon Problem** and the **Flatness Problem**.

What are we leaving out? **Dark Matter and Dark Energy – next classes**