• What do we see the Cosmos made of?
  • People, Rocks, Stars
• What else is there?
  • Dark Matter
• Dark Energy
Ordinary Earthly Organisms

For every 10,000 atoms in an average organism, there are:
Ordinary Earthly Organisms

For every 10,000 atoms in an average organism, there are:

- 6500 oxygen atoms
- 1800 carbon atoms
- 1000 hydrogen atoms
- 300 nitrogen atoms
- 150 calcium atoms
- 100 phosphorus atoms
- 25 potassium atoms
- 25 sulfur atoms
- 15 chlorine atoms
- 15 sodium atoms
- 5 magnesium atoms
- 65: traces of other stuff...
The Earth’s Crust

For every 10,000 atoms in Earth’s crust, there are:

- 4640 oxygen atoms
- 2820 silicon atoms
- 830 aluminum atoms
- 560 iron atoms
- 410 calcium atoms
- 230 sodium atoms
- 230 magnesium atoms
- 210 potassium atoms
- 60 titanium atoms
- 10 hydrogen atoms
What is the Sun Made of?

For every 10,000 atoms in the Sun, there are:

- 9149 atoms of hydrogen
- 779 atoms of helium
- 62 atoms of oxygen
- 6 atoms of carbon
- 3 atoms of neon
- 1 atom of nitrogen

and even less of everything else.

Hydrogen is the most common element in the universe!
BARYONS

“Baryonic Matter” is generally taken to be matter made of atoms. Protons and Neutrons are the most common baryons
• Astronomers being what they are, kept looking around.

• In 1933, Fritz Zwicky looked at the motion of galaxies in the Coma Cluster

• He found there are not enough stars in the cluster’s galaxies to hold the cluster together – 90% of the mass was missing!

• The cluster should have flown apart a long time ago!

• There is some matter holding the galaxies together that we can’t see
• Astronomers being what they are, kept looking around.

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Gravity & Orbits

- Kepler’s Laws state if I am farther from a source of gravity, my orbital speed gets slower.

- The farther from the center of the galaxy, the slower you must move.
In the 1970s, **Vera Rubin** measured the speed of stars as a function of distance from the center of galaxies.

She found that far from the center, the stars move faster than they should. This is known as the galaxy rotation curve problem.
This is known as the **galaxy rotation curve problem**

The explanation: there is matter we cannot see providing enough gravity to make the stars move faster

**Matter we can't see. Sound familiar?**

**DARK MATTER**
SCIENTIFIC NAMES?

SURE. SCIENTISTS COME UP WITH GREAT, WILD THEORIES, BUT THEN THEY GIVE THEM DULL, UNIMAGINATIVE NAMES.

FOR EXAMPLE, SCIENTISTS THINK SPACE IS FULL OF MYSTERIOUS, INVISIBLE MASS, SO WHAT DO THEY CALL IT? "DARK MATTER"! DUHH! I TELL YOU, THERE'S A FORTUNE TO BE MADE HERE!

I LIKE TO SAY "QUARK". QUARK, QUARK, QUARK! INSTEAD OF MAKING AN IDIOT OF YOURSELF, WHY DON'T YOU GO FIND ME SOME SCIENTISTS?
• Dark Matter evidence comes from observing the behaviour of galaxies (clusters stick together, rotation curves, etc.). To explain this galactic **Dark Matter** there are two competing possibilities:

  • **MACHOs (Massive Astrophysical Compact Halo Objects).** Ordinary black holes, neutron stars, or other “dark star-like object” swarming around the galaxy in a vast cloud (“halo”)

  • **WIMPs (Weakly Interacting Massive Particles).** Exotic subatomic particles that are difficult to see with experiments, swarming around the galaxy in a vast cloud (“halo”)

• **MACHOs vs. WIMPs** — who will win? Only more observations will tell us!
Halo Dark Matter

- We don’t know what all the dark matter in the halo is, but some of the dark matter is MACHOs.

- A microlensing search toward the Magellanic Clouds detected MACHOs!

- Microlensing occurs when gravity focuses light like a magnifying glass; it brightens a star.
Microlensing
HALO DARK MATTER

DARK MATTER HALO

Milky Way

MACCHO

Large Magellanic Cloud

Target Star
MACHO Results

- The MACHO Collaboration photographed the LMC for 5.7 years
- Detected enough MACHOs to account for 20% of the dark matter in 0.5 solar mass MACHOs
- Other groups did not detect such high rates
- The matter is still under debate, and new observations are being done.
White dwarfs can suck gas from a companion star. Enough matter falls on the white dwarf to initiate an uncontrolled explosion, completely destroying it. Type Ia supernovae are standard candles – they all have the same intrinsic brightness and can be used to determine distances.
In astronomy these are called **standard candles**

A standard candle is an object whose **intrinsic brightness** is known

If you observe standard candle and measure its brightness, you can tell how far away it is. **Farther away is dimmer!**
• Distant supernovae are dimmer than expected because they are farther away than expected

• The Cosmic expansion is accelerating due to a new (previously unknown) repulsive force in Nature, important on large scales

• The repulsive force is caused by Dark Energy.

• There is NO CONNECTION between dark matter and dark energy; this is an unfortunate name

• We have NO IDEA what dark energy is...

• ...but I can tell you what some of its properties are because it has to explain what we see.
Properties of Dark Energy

- Dark Energy fills all of space
- The Dark Energy produces a repulsive force between points in space
- The greater the distance between points, the greater the repulsion (e.g. important between galaxies, but not planets)
- When the Cosmos was about half its current size, the expansion changed from slowing down to speeding up.

- We have no idea what the Dark Energy is, though many speculations exist
  - Maybe our observations are wrong, and the expansion is not accelerating!
  - A funny form of Einstein’s Cosmological Constant
• Dark Energy **fills all of space**

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• **Maybe our observations are wrong, and the expansion is not accelerating!**

• A funny form of **Einstein’s Cosmological Constant**
What the Cosmos is Made of

- The census of the Cosmic Content now looks like this:
Why are we interested?

- The Ultimate fate of the Cosmos in the distant future depends on the total matter content.
- There is just enough stuff (including dark matter and dark energy) so that gravity can slow the expansion of the Universe.
- Current CMB observations indicate that the Universe is close to Flat — it is slowly coasting, but never recollapsing.
Last Thoughts...

• We have no idea what Dark Matter or Dark Energy are (though we have some ideas)

• 96% of the known Universe is composed of stuff we have next to no knowledge of

• The Ultimate Fate of the Cosmos depends on what is out there!