Cosmology

- Interesting note: When the Big Bang theory came out, many Christians embraced it. Why?

- Because the prevailing scientific view about the Universe in the early 1900’s was:
  - The Universe is infinite in size,
  - The Universe is infinite in age (Eternal)
  - The Universe is static.

Olber’s paradox

- Why is the sky dark at night if the above points are true?

- Obviously one or more of those conditions cannot be right.

- Newton’s ideas helped lead to the above view, along with Aristotelian philosophy.

- Things began to change with Einstein’s theory of General Relativity. (1915)

- Mass warps spacetime, which then controls how matter moves.

- $G_{\mu\nu} = 8\pi T_{\mu\nu}$ (Don’t worry!)

- People began studying what Einstein’s equations would mean.

- Quickly realized that his equations would imply a dynamic universe.

- But to everyone, the universe was static!

- So Einstein made a simple change. He added a cosmological constant (replusive).

- This would offset the attractive force of gravity & keep a Static Universe.

- And there the matter rested (somewhat).

Edwin Hubble

- In 1929 Hubble presented his result about galaxies.

- $v_r = HD$

- If the galaxies are rushing away, then in the past they would be closer together.

- This looked exactly like one of the predictions of Einstein’s theory.
• Meeting at Palomar: Einstein, Hubble and Lemaitre.

• What do the equations imply? Three possibilities, like throwing a ball in the air.
  – Not going very fast-It goes up and then comes back (Closed)
  – Going just fast enough to get away (Flat)
  – Going faster than that (Open)

• But the terms of GR talk about how spacetime is distorted.

• If the amount of mass-energy in the Universe is high enough, gravity will be able to stop the expansion. (Closed)

• If the mass-energy is just right, it will expand and constantly slow down. (Flat)

• If the mass-energy is too low, it will expand forever and not slow down. (Open)

• The critical parameter is the density of matter (or energy). The critical value is $\rho_c = 4 \times 10^{-30}$ gm/cc. (1 H atom in a box 1 meter on a side)

• Typically quoted as a ratio, $\Omega = \rho/\rho_c$.

• $\Omega < 1$ open, $\Omega = 1$ flat, $\Omega > 1$ closed.

• Has consequences for the shape of space. (The puzzle of Math)

• Space itself is expanding.

• Easiest thing for physicist to do is to run the equations backwards in time. (Unraveling a car wreck)

• Earliest views came from George Gamow (Russian). Hot, Dense model. (Hot ball of neutrons)

• Made predictions about what you would observe:
  – Expansion of space time
  – Leftover radiation that would have cooled down.

• Didn’t get much airplay, except with Fred Hoyle.

• He did not like the Hot Dense model and gave it the name “Big Bang” model.

• His model, Steady State. His reason? It looked too much like a Christian model!
• The issues remained mostly philosophical for many years.

• That all changed with Penzias and Wilson.

• Working on communication at microwave frequencies. Problem of noise

• Tried to figure out what was causing it.

• Even there when they aimed their antenna up into space.

• Over period of about 1 year they finally figured that it was real and was coming from all directions of space. Then they heard about Gamow’s prediction (They scooped the Princeton group).

• Gamow’s prediction is that the radiation and matter would be at same temperature until atoms formed ($\approx 5000K$), then the radiation and matter would be independent of each other, and radiation would be fixed and cool adiabatically. As it cools, it moves to lower energy and longer wavelengths. Predictions were that the temp should be very low, down to 10 Kelvin or lower.

• Much work went into studying this radiation (called CMB) First noticed that it obeys the blackbody equation very well.

• So three things Gamow predicted, three things are seen. What does the model actually say?

• Big Bang theory combines several components:
  – General relativity
  – Thermodynamics
  – Study of subatomic particles.

• One of the foundations for it is the Space Time Theorem by Hawking, Penrose, and Ellis.

• IF GR is true, then it must also be true that space and time came into existence when energy and matter did.

• Loophole is that no one thinks GR is true for all length scales. (Down to the Planck length)

• Basic view is that if we run the expansion backwards, galaxies get closer and closer together.

• If we run it back further, stars would begin to un form, going back to swirling clouds of gas and dust.

• Soon we are back to just atoms. Keep running time backwards...
• Now we get into thermodynamics. If I compress a gas it heats up.
• So now this collection of atoms (essentially a gas) as I wind backwards is getting compressed.
• So it would heat up and we can estimate the temperature as it heats.
• IF the clock can continue to be rewound, and the density and temperature continue to increase, then atoms will begin to ionize and you have free electrons and positive nuclei.
• Now you have a Plasma.
• Remember we are running the clock backwards.
• So the question to them is what was present very close to the beginning?
• Temperatures would have been really hot (millions or more degrees)
• As the study of subatomic particles advanced, a better view of what would be present emerged.
• Nuclei are made up of protons and neutrons.
• Proton and neutrons are themselves made up of quarks.
• At present, the fundamental constituents of matter are believed to be
  • Quarks (3 families, 2 in each)
  • Leptons (3 families, 2 in each)
  • And then all the exchange particles for the 4 forces.
• Each of these particles also has an antiparticle (electron has the positron)
• A particle and its antiparticle can combine and turn all their mass into energy.
• So the picture of the big bang’s initial state is pure energy + spacetime expanding.
• Expanding into what? (Problems of language)
• What it is NOT!
• Are we the center?
• Studies concentrate on understanding even further back in time, or on how fluctuations in temperature led to formation of large scale structures.
• Early studies use particle physics data and models to look at the very beginnings.
• Inflation

• One of the current issues is the matter-antimatter asymmetry.

• Superstring theory is one possibility.

• The area of temperature fluctuations has been very much in the news with the WMAP work.

• MAP-Microwave Anisotropy Probe. W is for David Wilkinson, pioneer in CMB.

• Probe put into orbit at the L2 point. Data.

• What is this telling them? It connects to theories on how spacetime expands and cools.

• Connection between temp fluctuations and large scale structure today.

• Present work on type IA supernova.

• Corrections due to special relativity.

• Is the universe speeding up?

• Could Einstein have been right?

• What is Dark Energy???

• Entropy Discussions a la Penrose.

• Why didn’t it just remain a black hole? Rate of expansion, initial temperature situation. Same equations, so no contradiction.