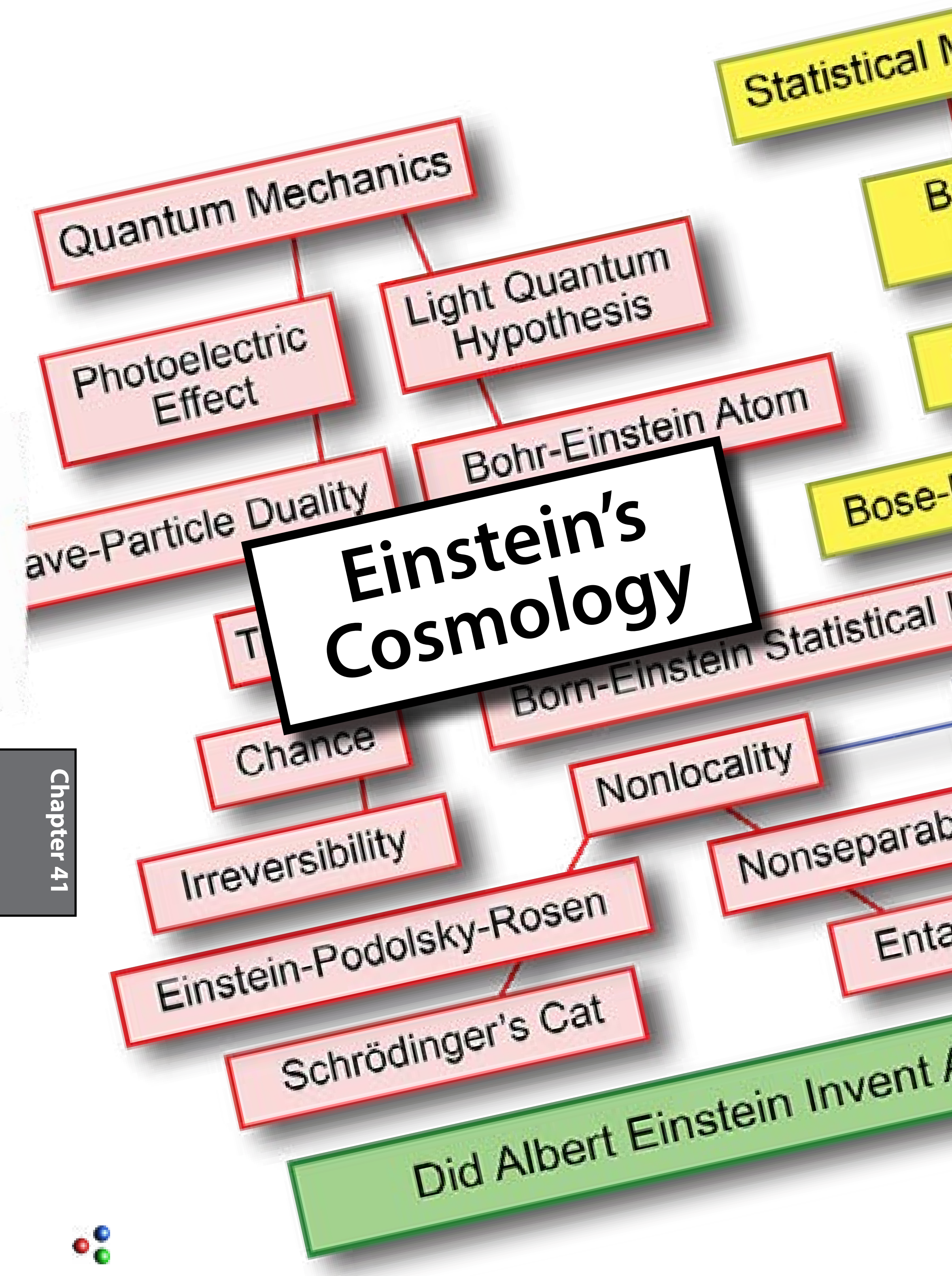
Einstein's Cosmology



Chapter 41

Einstein's Cosmology

The Cosmological Constant

When Albert Einstein was completing his work on general relativity in 1916, it was said that he asked some astronomers whether the stars were falling towards us or perhaps expanding away from us. "Oh, Dr. Einstein, it is well known that the stars are 'fixed,' in the celestial sphere." Since his new equations suggested otherwise, Einstein added a small term called the cosmological constant that would prevent expansion or contraction.

One very simple way to understand expansion in non-relativistic terms is to compare the amount of gravitating matter in the universe, whose mutual attraction would collapse the universe, to the motion energy seen in the distant galaxies.

The positive "kinetic" energy of the motion is either larger or smaller than the negative "potential" binding energy. We can distinguish three cases.

K.E. < P.E. The universe is said to be *positively* curved. The self-gravitating force will eventually slow down and stop the expansion. The universe will then collapse in a reverse of the "Big Bang" origin.

K.E. > P.E. The universe is said to be *negatively* curved. The self-gravitating force will be overcome by the motion energy. The universe will expand forever. When galaxies are infinitely apart, they will still be moving.

K.E. = P.E. The universe is flat. Average curvature is *zero*. The geometry of the universe is Euclidean. The expansion will stop, but only when the distances between remote galaxies approaches infinity after an infinite time.

By just adding a cosmological constant to achieve a result, Einstein masked the underlying physics for time.

The Flatness Problem

The universe is very likely flat because it was created flat. A flat universe starts with minimal information, which is fine since our cosmic creation process can create all the information that we have today. Leibniz' question, "Why is there something rather than nothing?" might be "the universe is made out of something (matter energy) and the opposite of that something (motion energy)."

When I was a first-year graduate student in astrophysics at Harvard University in 1958, I encountered two problems that have remained with me all these years. One was the fundamental problem of information philosophy - *"What creates the information structures in the universe?"* The other was the flat universe.

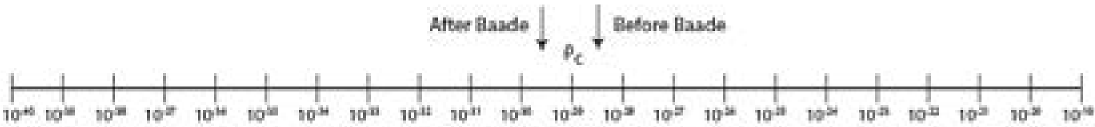
At that time, the universe was thought to be positively curved. Edwin Hubble's red shifts of distant galaxies showed that they did not have enough kinetic energy to overcome the gravitational potential energy. Textbooks likened the universe to the surface of an expanding balloon decorated with galaxies moving away from one another.

That balloon popped for me when Walter Baade came to Harvard to describe his work at Mount Wilson. Baade took many images with long exposures of nearby galaxies and discovered there are two distinct populations of stars. And in each population there was a different kind of Cepheid variable star. The period of the Cepheid's curve of light variation indicated its absolute brightness, so they could be used as "standard candles" to find the distances to star clusters in the Milky Way.

Baade then realized that the Cepheids being used to calculate the distance to Andromeda were 1.6 magnitudes brighter than the ones used in our galaxy. Baade said Andromeda must be twice as far away as Hubble had thought.

As I listened to Baade, for me the universe went from being positively curved to negatively curved. It jumped right over the flat universe! I was struck that we seemed to be within observational error of being flat. Some day a physicist will find the reason for perfect flatness, I thought.

I used to draw a line with tick marks for powers of ten in density around the critical density ρ_c to show how close we are to flat. Given so many orders of magnitude of possible densities, it seemed improbable that we were just close by accident We could increase the density of the universe by thirty powers of ten before it would have the same density as the earth (too dense!). But on the lighter side, there are an infinite number of powers of ten. We can't exclude a universe with average density zero, which still allows us to exist, but little else in the distance.



In the long run we are approaching a universe with average density zero. All the non-gravitationally bound systems will slip over our light horizon as the expansion takes them higher than the velocity of light. At that time, we will be alone in the universe with the nearby, gravitationally bound members of our "local group" of galaxies, the Milky Way, Andromeda, the Large and Small Magellanic Clouds, and a few dozen dwarf galaxies.

Beyond them will be ghostly images of galaxies, quasars, supernovae, and other objects with whom communication will never be possible at the speed of light.

But note that we may always be able to see back to the cosmic microwave background, all the same contents of the universe that we see today, all extremely red-shifted to the point of no visible energy in the photons!

The Problem of Missing Mass (Dark Matter)

Given our assumption that the universe is exactly flat, the missing mass problem is that there is not enough observable material so that in Newtonian cosmology the gravitational binding energy can exactly balance the kinetic energy. The visible (luminous mass) accounts for only about 4-5 percent of the needed mass. Studying the rotation curves of galaxies and galaxy clusters reveals an invisible mass (called dark matter) contained inside the galaxies and clusters that amounts to perhaps 6 times the visible matter, which accounts for about 30 percent of the critical mass density needed to make the universe exactly flat. Current theory accounts for the balance by "dark energy," an interpretation of the cosmological constant Einstein considered adding to his equations as a pressure to keep it from collapsing (known as "vacuum energy"). But the missing mass could just be more dark matter between the galaxies and clusters. About 3 times the estimated dark matter would do.

And I am delighted that observations are within a factor of three of the critical density ρ_c.

When Baade showed the universe was open in the 1950's, we needed ten times more matter for a flat universe. Now we need only three times more. More than ever, we are obviously flat!

Dark Energy (Is the Expansion Accelerating?)

Finding the missing mass can close the universe and explain its flatness. But it would not explain the apparent accelerating expansion seen in Type 1a supernovae. This might be an artifact of the assumption they are perfect "standard candles." Recent evidence suggests that distant Type 1a supernovae are in a different population than those nearby, something like Baade's two populations.

It seems a bit extravagant to assume the need for an exotic form of vacuum energy on the basis of observations that could have unknown but significant sources of error. Fortunately, the size of this problem is only another factor of between 3 and 4, well within observational error.

String theorists claim conditions at the universe origin must have been "fine tuned" to within 120 orders of magnitude to produce our current universe. This seems to be nonsense.

The Horizon Problem

The horizon problem arises from the perfect synchronization of all the parts of our visible universe, when there may never have been a time in the early universe that they were close enough together to exchange synchronization signals.

We propose a solution to the horizon problem based on Einstein's (mistaken) insight that in the wave-function collapse of entangled particles, something is "traveling" faster than the speed of light.

Einstein said that events in a spacelike separation cannot interact, That would violate his special theory of relativity. He described it as the "impossibility of simultaneity." But something can simultaneously change great disstances. That something is *information about possibilities*.

When the "universal wave function" Ψ collapsed at t = 0, parts of the universe that are outside our current light horizon may have been "informed" that it was time to start, no matter the distance.

This radical idea is consistent with RICHARD FEYNMAN's path integral (or "sum-over-histories") formulation of quantum mechanics. In calculating the probability of a quantum event, the path integral is computed over all the possible paths of virtual photons, many traveling faster than the speed of light.

The Information Paradox

Can we speculate about what Einstein might have thought about the black-hole information paradox?

Perhaps not. For Einstein, entropy is defined by Boltzmann's principle. $S = k \log W$, where W is the number of phase-space cells.

Since the size of the black hole is smaller when matter is added, we can see that STEPHEN HAWKING and Jakob Bekenstein were correct that the information content of physical objects falling into a black hole will be lost forever. More particles are now distributed in a smaller number of cells

In 1997, John Preskill made a bet with Hawking, claiming that information must be preserved, according to quantum theory.

In fact, neither quantum nor classical theory requires the conservation of information. Being simply the arrangement of material particles in phase space, information is not a conserved quantity like energy and momentum, as Einstein would have known.

The idea of conserved information comes from mathematical physicists who want a deterministic universe in which all the information existing today was present at the origin of the universe.

In 2004, Hawking published a paper showing how some information might escape from a black hole, and he conceded his loss of Preskill's bet. Hawking is right that particles emerge from pair production at the black hole horizon, but the idea that it is the same information that was destroyed when information structures fell into the black hole is simply absurd.

Hawking may have told us this when he quipped that he should have burned the baseball encyclopedia he gave to Preskill and pay off the lost bet by sending him the ashes!

Once again, it was Einstein's phenomenal imagination that first conceived of extraordinary ideas only recently confirmed, like gravitational waves, gravitational lensing, and of course black holes, though like many of his insights, he doubted their existence.