Before the Big Bang

The Origin of the Universe and What Lies Beyond

Laura Mersini-Houghton

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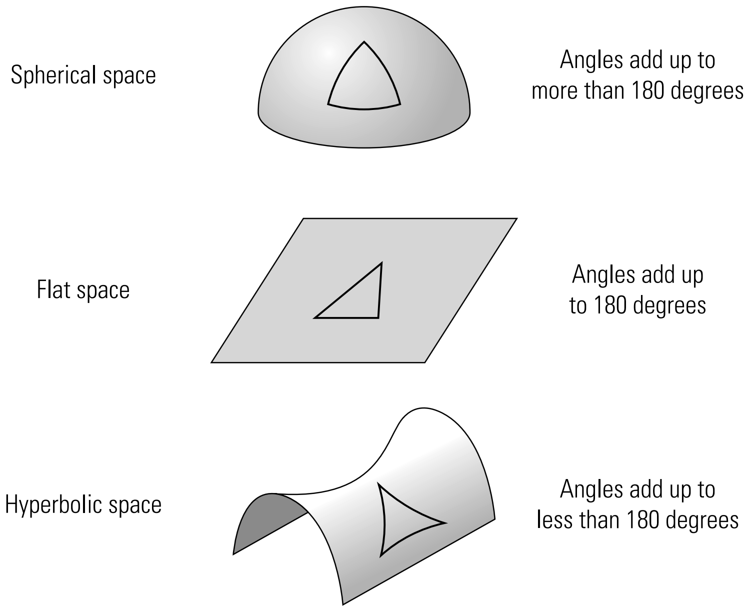

Figure 1. From top to bottom, a spatially closed, flat, and open universe.

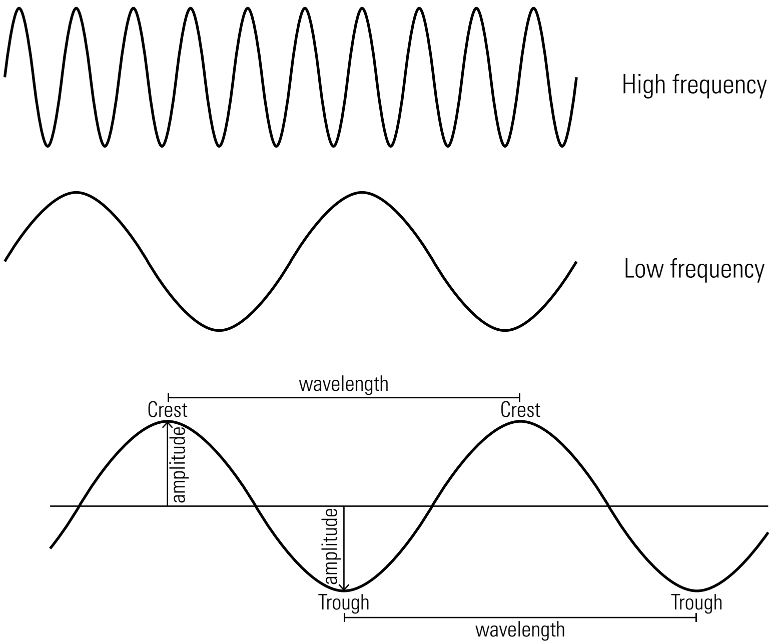

Figure 2. Characteristics of a wave defined by their amplitude, frequency, and wavelength, as shown.

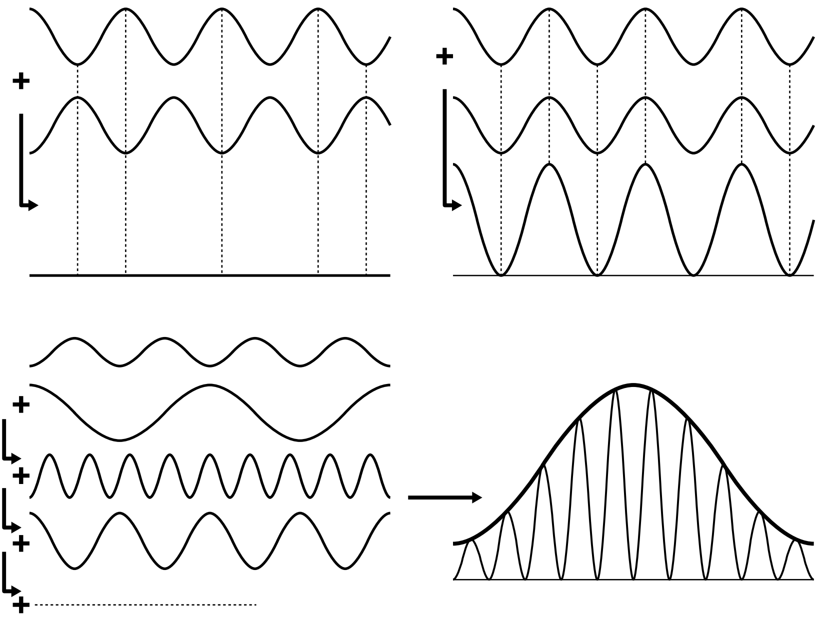

Figure 3. Waves' superposition when they are out of phase (*top left*) and in phase (*top right*). Many of them with different phases, frequencies, and amplitudes add up to a wave packet (*bottom*).

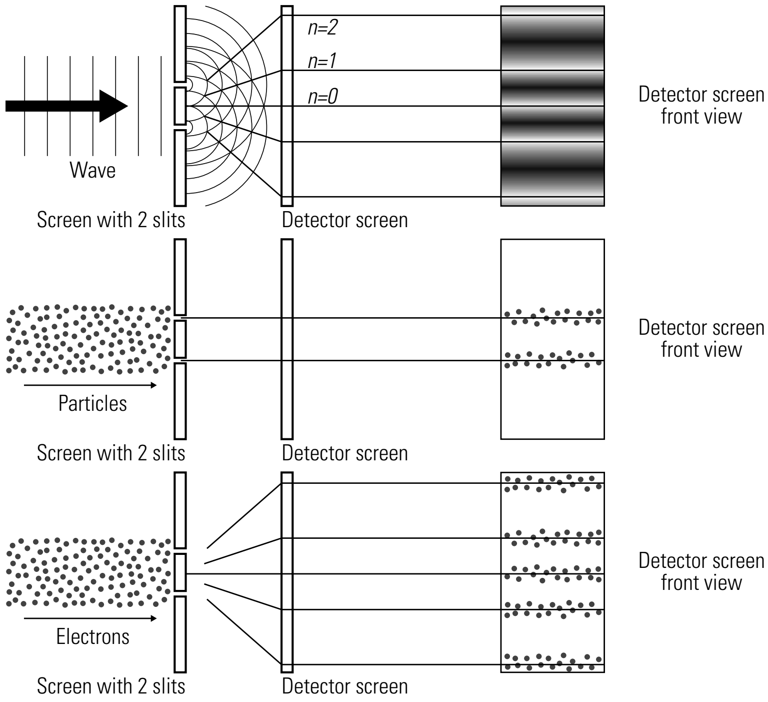

Figure 4. The double-slit experiment. *Top panel:* Light goes through two slits and creates an interference pattern on the screen behind. Middle panel: If electrons were particles, then we would see only two bright spots on the screen behind. *Bottom panel:* Electrons must also be waves because they add up and interfere, just like the light waves do in the top panel; therefore we see many bright and dark spots on the projection screen—the interference pattern of electron waves ("n" simply refers to bands).

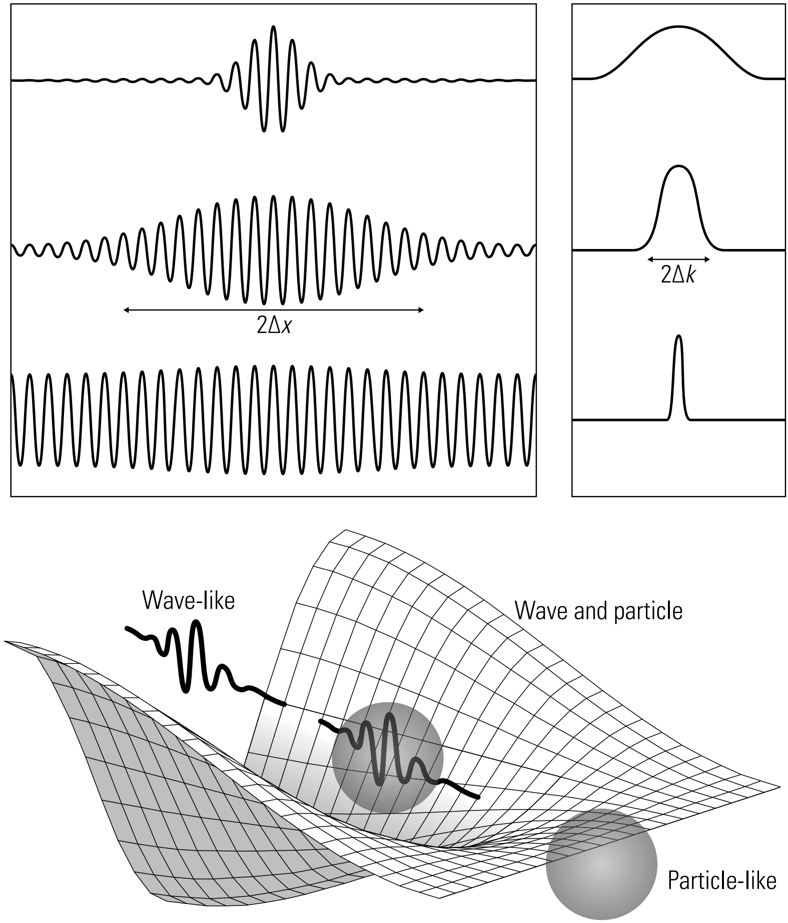

Figure 5. Top: Spreading of the wave and particle when the speed is known to great precision. A narrow wave packet (small Δx) corresponds to a large spread of wavelengths (large Δk); a wide wave packet (large Δx) corresponds to a small spread of wavelengths (small Δk). *Bottom:* An illustration of wave-particle duality set against an imagined space-time background. A particle is equivalent to the wave packet; most of it is “gathered” around the particle’s location, but parts of the wave still stretch out to infinity.

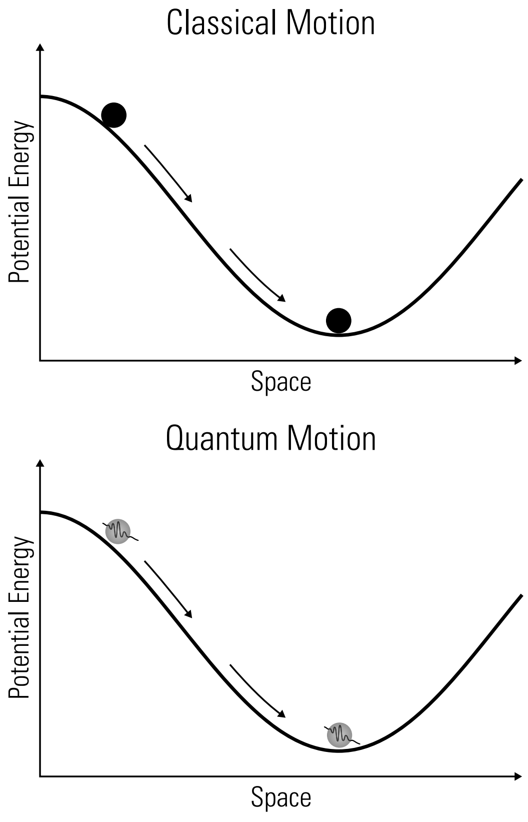

Figure 6. The top graph shows a marble rolling down a mountain under the influence of the Earth's gravitational potential energy. The bottom shows a quantum particle, such as the inflaton, rolling down a potential energy field. Thanks to Schrödinger, we know that this quantum particle is also a probability wave.

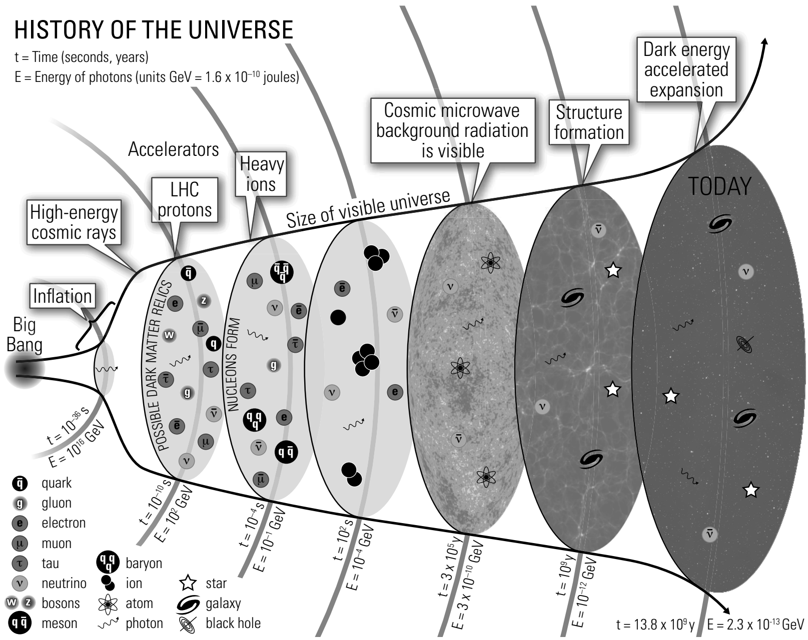

Figure 7. The whole standard model of cosmology is contained in this diagram. Time runs on the horizontal axis from the first moment of Big Bang inflation to present. Space runs on the vertical axis. Note that the universe is growing in time and it is flat in space, as can be seen by taking slices of the universe at each moment in time.
Particle Data Group at Lawrence Berkeley National Lab

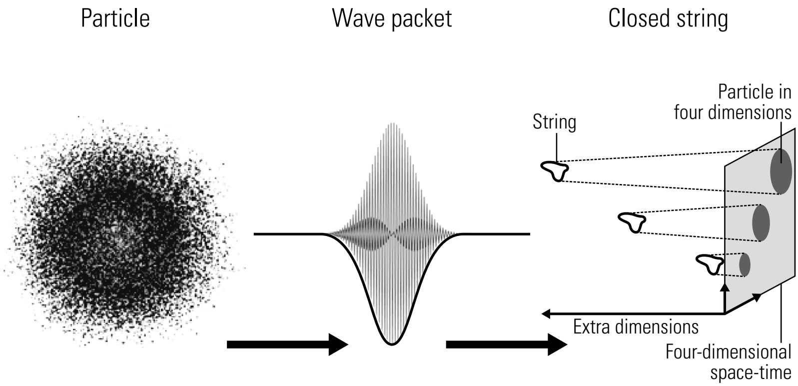

Figure 8. A point particle, in the left panel, is spread into a bundle of waves packed together, shown in the wave packet in the middle panel. But what appears as a point particle to us is, according to string theory, actually the vibration of a closed string, shown in the right panel. The frequency of vibration determines the mass of the particle.

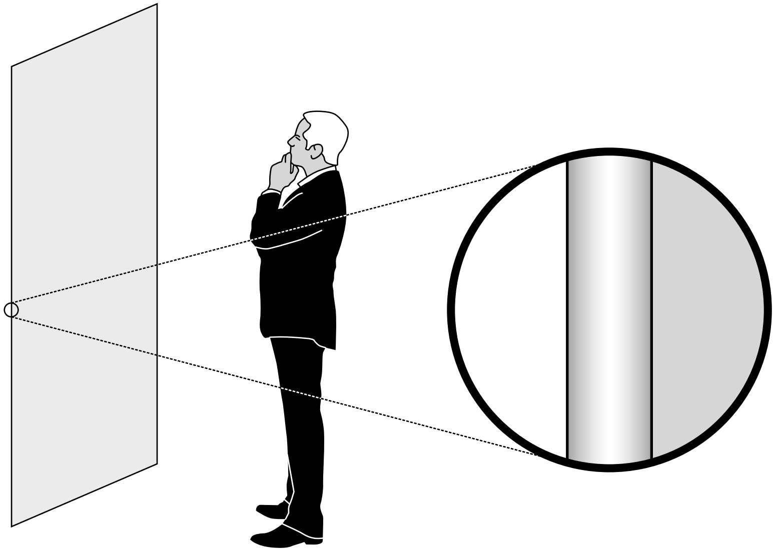

Figure 9. Cartoon illustration of the perspective explained in the adjacent text. The person standing in front the paper can see its length and height but not its depth, and thus he is not aware of the existence of this third dimension. This person would miss out on the existence of additional dimensions and structures if more of these were nested and hidden from view within the depth of the paper.

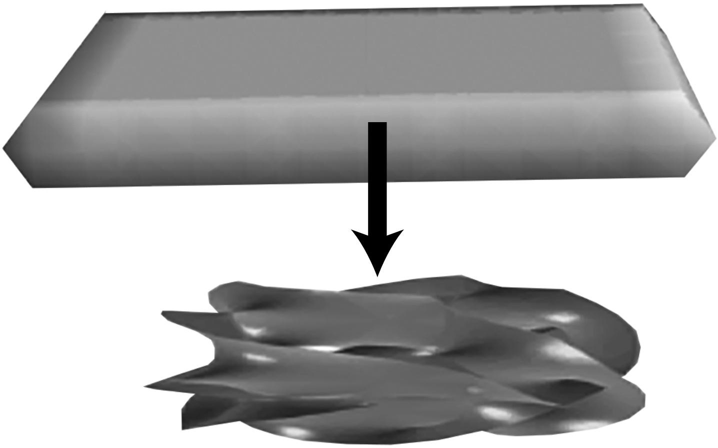

Figure 10. Shown in the picture at the bottom are bundles of strings inside the four-dimensional "compressed spring box," which is what is left after the additional seven dimensions are compactified. According to string theory, pictorially, this is what the space-time of our universe would look like if we could probe scales of, say, 10^(-30) cm. Instead of seeing point particles or empty space-time, we would observe bundles of strings. The volume of the seven additional dimensions of the box at the top is compressed (represented by the arrow) and hidden from view.

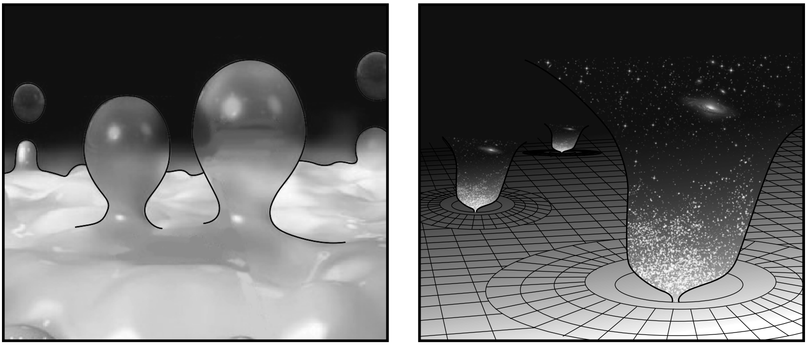

Figure 11. A visualization of the transition from wave-universes settling on the energy vacua of the landscape to inflating physical universes that exist in real space-time.

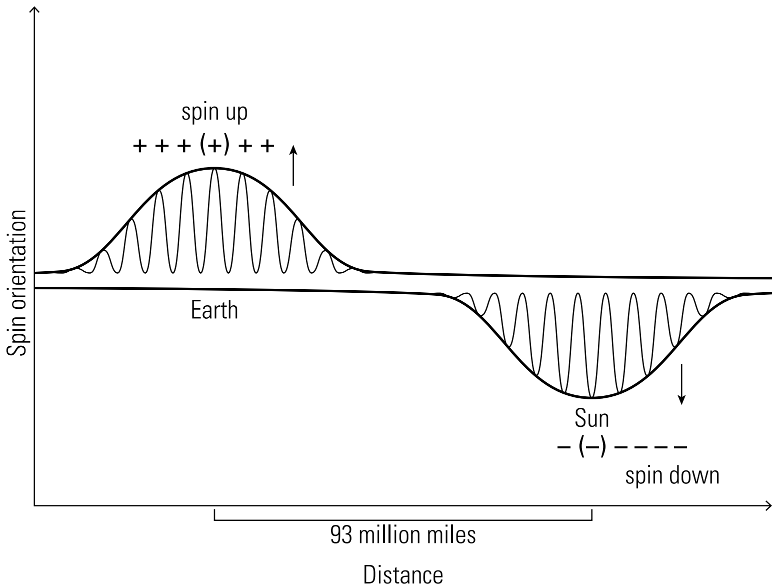

Figure 12. Entanglement of two electrons (one thick line, one double line). As waves, both electrons spread to infinity. If they were point particles, they would need to send light signals across the distance between them—in this case, the distance from the sun to the Earth, which would mean that each signal would take eight minutes to travel from one to the other. But as waves, they are constantly in contact, so there is zero distance they need to travel to communicate and therefore no delay in their exchange of information. Thus, when one goes spin up, the other one knows of it instantly and flips spin down; in the same manner, should one spin go to the right, the other will go to the left instantly. This happens without breaking the speed-of-light limit.

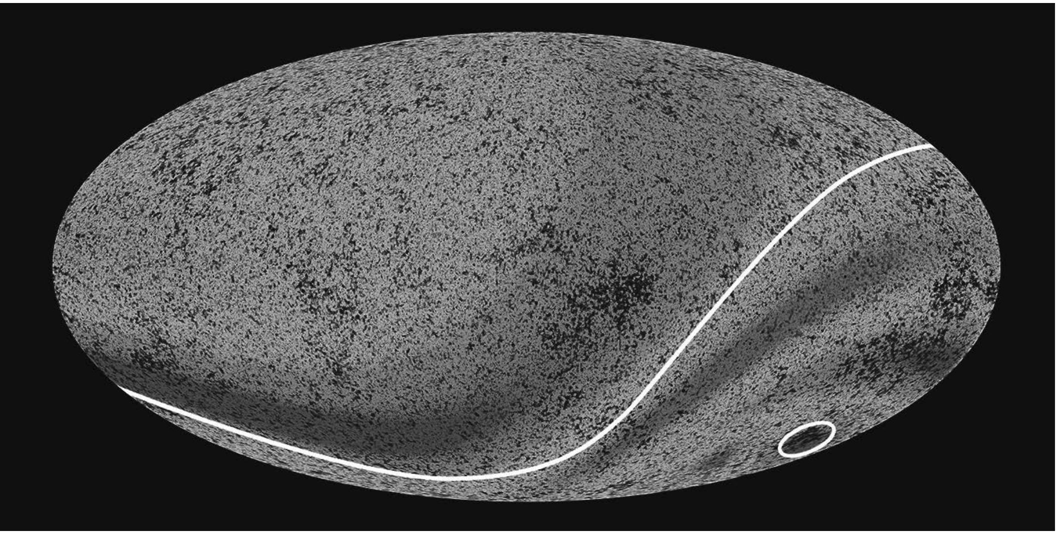

Figure 13. The CMB map observed by the European Space Agency Planck satellite indicating the Cold Spot (circled) and the asymmetry of matter between the two hemispheres (separated by the curving line). When the map was released in 2013, its surprising anomalies were in complete agreement with our predictions about the scars of the universe's birth that should be visible in our own sky.