A FAIRY TALE

Children's [and professors'] guide to cosmology:

The story of an odd couple that lived long ago, their parents, their grandmother, and their weak and strong, strange and colorful offspring

> [Carl Anderson's observation in 1936 of the muon, a kind of heavy electron with mass 206.768 times the electron mass, came as a surprise to physicists. "Who ordered *that*?" asked Isidor Isaac Rabi. Some 40 years later, the tauon, which is a superheavy electron with mass 16.8 times the muon mass, was discovered. Still another 30 years later, in his book *Fundamental Forces of Nature — The Story of Gauge Fields* (2007), Kerson Huang of MIT writes: 'We have no idea why there is more than one family. We hear Rabi's question, "Who ordered them?" ']

Suddenly, grandmother Tau was there. She came from nowhere in a small bubble of space and time—her private little universe. Grandma Tau was cool [1]. She came alone, because only one can be the first. And Grandma Tau was the only being that was able to live all alone without a supporting family surrounding her [2].

> [1] Pressure and temperature arise when molecules or particles bounce off each other. Therefore, a universe consisting of a single particle can have no temperature.
> [2] The neutral spinless primordial particle was a kind of tightly coupled "spinless-tauon" pair described by Paul Dirac's "new equation," which Dirac published in 1971.

When a baby is born, we start counting its age from zero. But in reality it's about 9 months old. Similarly, when Grandma Tau was born, she and her bubble were 1 time unit old [3].

> [3] In other words, the universe wasn't born as an infinitely dense singularity, but as a four-dimensional volume with nonzero space and time dimensions.

Grandma sucked energy [4] and prospered, until suddenly she died, still very young, at the age of 10. At the instant of her death, she gave birth to two children she never saw: the little Mu twins. Fortunately, the memory of Grandma Tau didn't die with her. Today we may still glimpse her features in virtual Tauon couples dancing around for a brief moment.

> [4] When the small universe expanded, identical copies of the initial massive particle appeared on the horizon. One after one, the particles decayed into pure radiation (photons). Energy conservation made the remaining massive particles gain energy as the expansion of space caused the radiation to stretch and lose energy (redshift). When the last massive particle decayed, its rest energy had increased about 17 times.

Grandma Tau was no ballet-dancer and didn't know how to make pirouettes. Her children, the Mu twins, also didn't know how to dance [5]. But they kept in touch with each other, which was a dangerous thing to do, because the Mu twins didn't get along very well. Rather, they were like fire and water—or matter and antimatter.

> [5] The Mu twins were spinless muons, that is, spin-0 bosons. They are described by scalar QED, which resembles ordinary spinor QED. Spinor QED (or QED for short) describes the spinning electrons (spin-$\frac{1}{2}$ fermions)—successors of the spinless muons.

And so, after growing up (sucking energy and increasing in weight), the twins finally crashed into each other and simply annihilated each other. However, in the process they gave birth to

Mr. and Mrs. Electron—he a negative type, and she his positive opposite. The Mu twins died at time 33, only 23 time units old (since they were born at the same instant that Grandma Tau died). Even though the Mu twins died a very long time ago, their memory still lives. Today we are reminded of them by virtual Muons that, in contrast to the Mu twins, know how to pirouette, and occasionally show up for a moment only to again quickly disappear.

Unlike their predecessors (the Mu twins), the Electron couple knew how to dance and make pirouettes. Their dance tended to keep them young-looking and slender, and to keep them apart from each other. But also their dance was risky. It came to an abrupt end at time 37 325 when they annihilated each other and gave birth to new offspring. This time, however, the delivery led to complications. This is what happened:

The annihilating Mr. and Mrs. Electron were reborn as Mr. Antiproton and Mrs. Proton, with a crowd of children flocking around them. But, the couple didn't get on any better than they had done in their previous life as Mr. and Mrs. Electron. Fact is, they were still antimatter and matter! However, with so many children to support, they felt they couldn't simply annihilate each other and leave their children without parents. There was only one simple solution: the couple had to divorce. But how? Mrs. Proton was needed by her many children and couldn't leave them. But she could take care of them without her husband's help. In other words, Mr. Antiproton was dispensable. So, Mr. Antiproton threw away his newly acquired weightiness [6], retook his previous identity as Mr. Electron, and moved away from the rest of the family.

> [6] Proton decay is a process predicted by some grand unified theories (GUTs). When the antiproton decayed back into an electron, it released the energy $m_p c^2 - m_e c^2$, which gave the universe the high temperature that caused big-bang nucleosynthesis (BBN) to take place.

Today, many billion years later, we still see them living separated and in complete harmony, the tiny Mr. Electron dancing around the weighty Mrs. Proton at a safe distance from her.

But what about their offspring? Some colorful and more or less strange or charming children [7] were never really delivered, but still live in the belly of their Mom, Mrs. Proton.

> [7] The up (u), down (d), charm (c), strange (s), top (t), and bottom (b) quarks coming in red (R), blue (B), and green (G) colors. Plus eight gluons (g_1,...,g_8). The proton (p) is made up of u and d quarks (uud). Other quarks only exist virtually in the proton. Quarks cannot exist as free particles.

Other children immediately left the care of their mother. Most of these children we can see, but only with difficulty [8]. Some of them are so tiny that they until recently were thought to weigh nothing [9]. Others were born much heavier than their mother [10]. A strange bunch, indeed!

> [8] The Higgs boson (H) hasn't yet been detected with certainty.
> [9] The tauon, muon, and electron neutrinos (ν_τ, ν_μ, and ν_e) and their antiparticles ($\bar{\nu}_\tau$, $\bar{\nu}_\mu$, and $\bar{\nu}_e$).
> [10] The charged weak bosons (W^+ and its antiparticle W^-), the neutral weak boson (Z), and the Higgs (H).

But what happened next? How were the stars and planets and black holes created? And what does the dark matter consist of? In a universe initially without an immensely high temperature, is there any need for an inflationary phase? Does dark energy really exist? Is the universe really accelerating?