COSMOLOGY

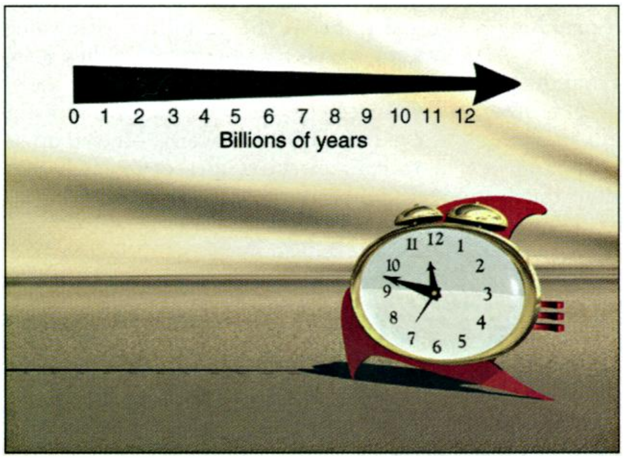
Cosmic Age Controversy Is Overstated

Eric J. Chaisson

Debate continues to swirl around the vexing issue of the age of the universe. Teams of researchers joust in heated argument, and not with just a little acrimony. Clear-cut biases are evident, and reputations of some astronomers are on the line. The media, too, has caught on, viewing this issue as another kind of "Hubble wars" while claiming all sorts of dire consequences for our cherished Big Bang cosmology. Yet mostly everyone seems unaware that long-standing age problems of this sort have plagued science off and on for well more than a century.

In two paragraphs, here is a statement of today's problem. The age of a uniformly expanding universe is $t = H_0^{-1}$, where the Hubble constant H_0 expresses how fast objects in the universe are receding versus their distance from an observer. For a popular average value of the Hubble constant at the current epoch (H_0 = 70 km s^{-1} Mpc^{-1}), t equals nearly 15 billion years. This age is correct only if the cosmic density is much lower than the critical density of a barely unbound universe whose space balloons marginally to infinity—in fact, it is strictly correct only for an unreal universe devoid of all matter. If, however, the density equals the critical value, then the universe decelerates with time, and the true age must be less than 15 billion years; this is the so-called Einstein–de Sitter case of a perfectly balanced (and flat) universe, for which $t = 2/3H_0^{-1} \sim$ 10 billion years. Astronomers have observationally detected (but not yet measured well) a slight deceleration in the recession of the galaxies; because we also have some theoretical reasons (mostly having to do with the concept of inflation in the early universe) to take the cosmic density to be close to critical, we do suspect that the value of H_0^{-1} must be an upper limit for the age of the universe (*1*).

By contrast, a key component of the universe appears to be older than 10 billion years. These are the ancient stars of the globular clusters, tight-knit groups of many thousands of stars strewn throughout the halos of galaxies that are probably as old as the galaxies themselves. Astronomers estimate such stellar ages on the basis of the rates at which stars undergo nuclear fusion, in particular, according to the turn-off point of a cluster of stars plotted on a Hertzsprung-Russell diagram of luminosity and surface temperature. In short, the theory of stellar evolution tells us when bright blue, main-sequence stars should begin to change into swollen red giants; the fewer the number of bluish stars as compared with the number of reddish stars, the older the cluster. Many such globular clusters have been studied in this way, and most of them show ages of 15 ± 3 billion years (*2*). Hence, the paradox at hand: Some stars seem older than the universe itself, a clear embarrassment to astronomy if not resolved.



Cosmic ages determined from the arrow of time of the Hubble expansion and from the evolutionary nature of the oldest stars seem to be converging at about 12 billion years. [Image courtesy of D. Berry]

Actually, this problem is not new; it has existed in one form or another for well more than a century. For example, when, in the early 19th century, the pioneers of geochronology sought to assess Earth's age on grounds other than religious or philosophical, they essentially made two assumptions: that the Earth probably formed at the same time as the sun, and that the sun shone by the burning of some known chemical, like the wood or coal commonly used during the Industrial Revolution. The answer they got for the age of the sun, and hence the age of the Earth, was a few thousand years, a value less than that of recorded history (*3*). So an age controversy developed, not so much heated than merely amusing to most theologians of the time, who thought unwell of science: How could Earth be younger than the duration of human existence?

The first assumption of early Victorian science was a good one (indeed, we today consider the birth of Earth and the sun to have occurred at the same time), but the second one was most definitely not; the sun, assuredly, is not made of wood or coal. Kelvin, von Helmholtz, and others later revised these calculations in the second half of the 19th century, taking the sun to be made of an incandescent liquid mass (such as gasoline or kerosene) and allowing for some energy generation by means of gravitational infall (including meteors crashing into the sun), yet they were unable to increase the age estimate for the sun to much more than 100 million years, a value surely older than recorded history but much less than that needed by Darwin to explain the fossil record in terms of biological evolution by natural selection (*4*); at the time, long-dead life forms seemed to be at least several hundred million years old (and we now realize they are even older). Kelvin got similarly low values when trying to estimate the rate of cooling of Earth itself, largely because he overlooked the poor thermal conductivity of the rocky interior, all of which put geological evolution into conflict with biological evolution. Thus, the age controversy continued, dominating scientific circles about a hundred years ago, some of the debate (then as now) being quite vehement: How could life on Earth be older than the planet itself?

These early age discrepancies eventually went away. As radioactivity became better understood by Becquerel, the Curies, and Rutherford around the turn of the 20th century, geologists could then measure the age of Earth directly. And what they found was a planet a few billion years in age, which was then fully enough to provide the long time scales needed to explain Darwin's fossils. (We now know that biological evolution has occurred over the course of some 3.5 billion years, yet there is no problem here, because modern studies using similar radioactive methods date Earth at 4.6 billion years.)

Alas, in the 1930s, a version of this prob-

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lem resurfaced. At issue then was the first measurements of H_0 by Hubble and Humason (5). Owing to observational uncertainties in the brightnesses of the galaxies and especially to calibration errors in the analysis of the acquired data (from Cepheid variables), they found $H_0 \sim 500$ km s^{-1} Mpc^{-1}. This value meant that $H_0^{-1} \sim 1$ to 2 billion years for the age of the universe, and suddenly the general problem was back: How could Earth be older than the universe?

In turn, this problem gradually faded away as many astronomers (especially Baade) undertook, over decades, better observations and data analyses of the brightnesses and distances of the galaxies. By the 1950s, the value of H_0 had decreased fivefold, and H_0^{-1} had therefore equally lengthened to nearly 10 billion years. Hence, the universe was safely older than Earth, and the age problem went away again, for a while. To be sure, it has resurfaced in more recent years, as noted above. Thus, by the 1980s and into the 1990s, we have the modern version of a recurring age discrepancy: How could some stars within the Milky Way be older than the universe itself? Well, they can't be. It's as simple as that. Something is awry, again.

The most likely outcome is that the current age controversy will simply fade away, just as better observations and improved data analyses caused similar glaring contradictions to evaporate throughout the past century. Indeed, several recent developments favor the dissolution of this problem altogether. For example, today's astronomers (6), even the ones polarized from decades of infighting, seem to be converging on smaller values of H_0, implying that some of us may have been recently underestimating the age of the universe; furthermore, unless more dark matter is actually found, then the universe could be an open one, the further consequence being that the universal age is indeed closer to H_0^{-1}, the upper bound of which, say for $H_0 = 60$ km s^{-1} Mpc^{-1}, would then be in accord with the lower bound of the most ancient stellar ages, namely about 12 billion years. What's more, recent reanalyses of some globular-cluster data [especially enhanced helium abundances, which can raise the brightnesses of such stars (7), and recent results from the Hipparcos satellite, which revise upward the brightnesses of several key variable stars (8)] suggest that the globular clusters might have had their ages overestimated by nearly 20%. If true, then the above-noted average age of 15 billion years for the oldest stars needs to be readjusted to about the 12-billion-year value toward which many current studies seem to be headed.

We need not be overly concerned about the current age controversy, other than to note it as an active area of research that seeks to specify a number (the value of H_0) to an accuracy of better than a factor of 2 when many other cosmologically significant numbers (including those on which it depends, such as the cosmic density) are known only to within a factor of about 10. Frankly, it is remarkable that the ages of the cosmos, stars, and life are so close and that together they seem to be stacking up so well along an ordered arrow of time. As for our cherished notions of cosmic evolution, the subject is hardly affected by this lingering age controversy; the arrow of time itself can be contracted or expanded, a little like an accordion, to match the true age of the universe, whatever it turns out to be. It is the sequence of events along that arrow that is more important than the magnitude of the arrow itself.

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PROTEIN BIOPHYSICS

Stretching Single Protein Molecules: Titin Is a Weird Spring

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The giant protein titin, which provides most of the elasticity of relaxed striated muscle, can stretch to at least four times its 1-μm resting length. Now, on pages 1109 and 1112 of this issue and in this week's *Nature*, three laboratories report their measurements of the elastic forces generated during stretch and relaxation of single titin molecules (1–3). They find an exotic mix of entropic springs, sawtooth waves, and hysteresis, unlike the properties of any familiar elastic material. And, at higher forces, we see for the first time what happens when protein domains are unraveled by applied force.

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Titin is primarily a string of 300 immunoglobulin (Ig) and related fibronectin type III (FNIII) repeats (4). Each immunoglobulin repeat folds into a globular domain about 2.5 nm in diameter and 4 nm long, producing a filament 1.2 μm in length. It was proposed earlier that stretching titin must unfold the immunoglobulin domains, each domain extending from 4 to 30 nm as it unravels (5, 6). However, the complete sequence revealed a new domain called PEVK (for Pro-Glu-Val-Lys) in the middle of the I-band segment of titin (4). Unfolding and straightening this PEVK domain, as well as the partially collapsed immunoglobulin segments, could account for the passive elasticity of skeletal muscle, at least at the forces the muscle usually experiences (7). At higher forces, which can occur in extreme stretch and in the stiffer cardiac muscle, immunoglobulin domains too may unravel (7, 8). Now both of these mechanisms are demonstrated in the stretching of single titin molecules.

Two of the groups tethered an individual titin molecule to a plastic bead and used laser tweezers to pull the bead, stretching the titan molecule (1, 2). At lower stretch, force is generated by a mechanism termed here an entropic spring (see figure, upper panel). The entropic spring works because a randomly coiled chain will tend to maximize its configurations as it is buffeted by thermal fluctuations (kT in the figure). A force is required to counteract these thermal forces and extend the chain. Tskhovrebova *et al.* (1) resolved two entropic springs in series, one corresponding to the somewhat flexible native immunoglobulin domains and the other to the more flexible denatured PEVK segment.

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