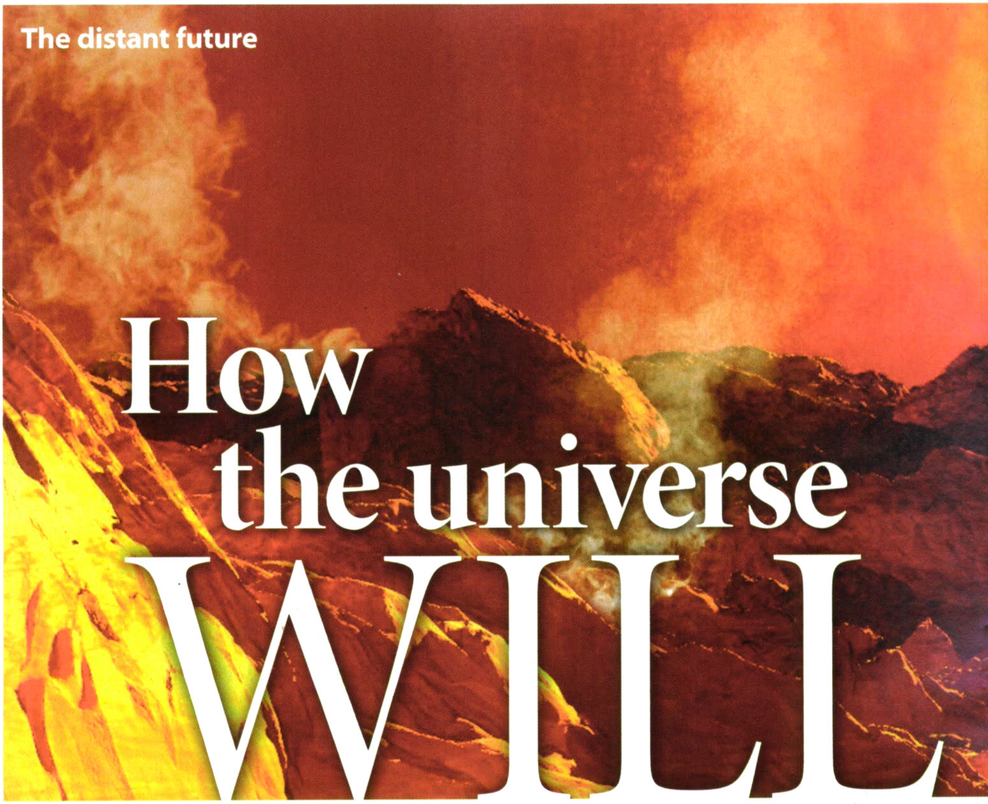
How the universe WILL END
Reddy, Francis
Astronomy; Sep 2014; 42, 9; ProQuest Research Library
pg. 38

The distant future

How the universe WILL



First, Earth becomes uninhabitable, and then our galaxy collides with its neighbors. Beyond that, the fate of the cosmos becomes fascinating guesswork.

by Francis Reddy

Two of the most compelling and provocative questions humans can ask are, "Where have we been?" and "Where are we going?" We can't help ourselves from taking these questions to their logical extremes — extending them to the smallest and largest scales imaginable by pondering the origin and fate of the entire universe. Observations made in the past several decades have given astronomers a good handle on the Big Bang and its immediate aftermath. But the destiny of the universe is a tougher nut to crack. Will the cosmos eventually collapse in a Big Crunch, fly apart in a Big Rip that destroys space-time itself, or expand forever until the stars and all other energy sources fade away?

Let's cut to the chase. At the present state of knowledge, scientists can't determine which of these scenarios will play out because they don't understand the nature of the universe's two largest constituents: dark energy, a negative pressure that appears to be speeding up the expansion of space, and dark matter, an unknown substance that forms the framework of cosmic structure. In fact,

Francis Reddy *is the senior science writer for the Astrophysics Science Division at NASA's Goddard Space Flight Center in Greenbelt, Maryland.*

A bloated red giant Sun looms over Earth's scorched landscape some 5 billion years from now. The Sun's impending death is but an early milestone in the universe's ultimate fate. RON MILLER

no cosmological observations of the past or present will ever be sufficient in and of themselves to reveal the ultimate fate of the universe. For that, scientists will need to combine observations into a theoretical framework that marries Albert Einstein's general relativity, which rules the cosmos at the largest physical scales, to quantum mechanics, which governs the very small.

Although a definitive big picture eludes science, plenty of interesting phenomena will play out on the road to our cosmic destiny, especially closer to our own time. For example, astronomers are confident that the Milky Way Galaxy will collide with its galactic neighbors and that Earth's days are truly numbered. As the saying goes, getting there is half the fun.

Past is prologue

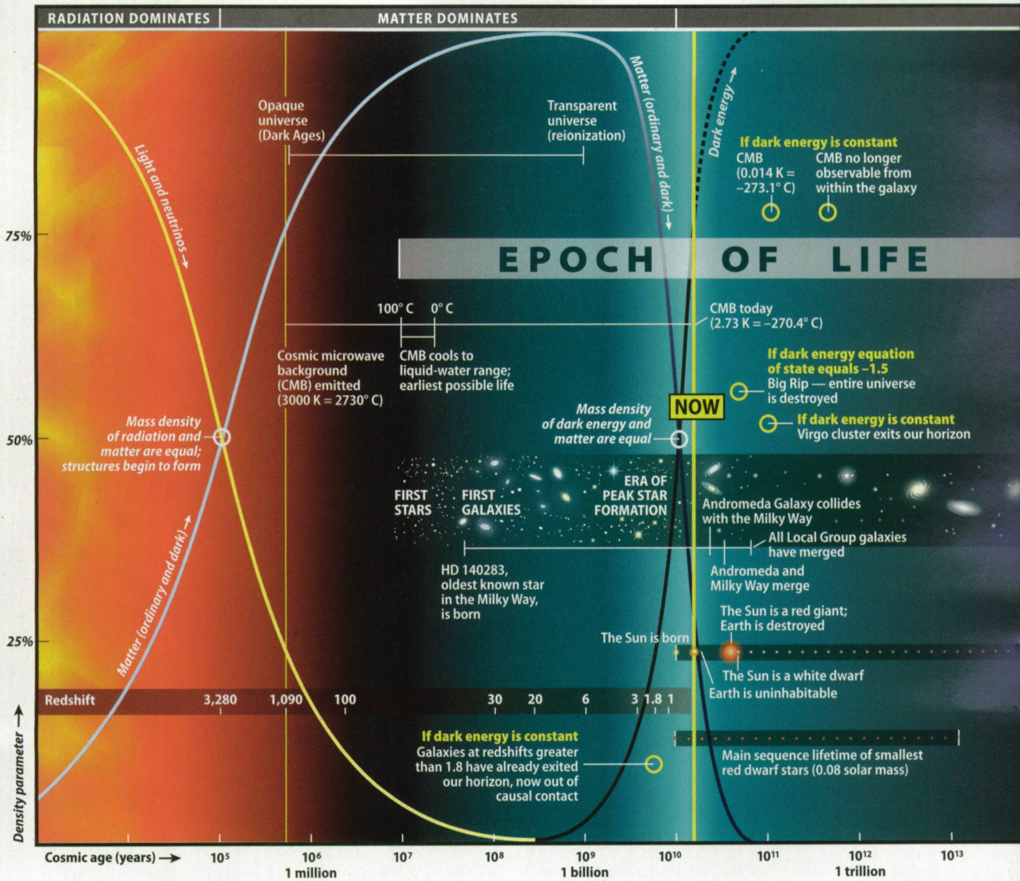
According to the best measurements so far, provided to better than 1 percent accuracy by the European Space Agency's Planck satellite and NASA's Wilkinson Microwave Anisotropy Probe, we live in a universe that has been expanding for the past 13.8 billion years. This information comes from detailed studies of the cosmic microwave background (CMB) radiation, the oldest light astronomers can see, emitted when the universe was around 380,000 years old.

Before that time, most of the light in the cosmos was tied up with interactions between particles, especially electrons. Like a car in the middle of a demolition derby, photons just couldn't travel far before striking one of these particles. At about the time the universe reached its 380,000th birthday, the cosmos had cooled enough that protons could capture electrons and form the first neutral hydrogen atoms, which greatly reduced the number of free electrons that photons could crash into.

The result, cosmologists say, is that the first light of the universe "decoupled" from matter and finally was free to traverse unimpeded. This is the light scientists see in the CMB, now stretched and cooled into microwaves by the subsequent expansion of space.

The CMB has almost exactly the same temperature everywhere in the sky, which presents a problem for theorists. Points on opposite sides of the universe were too far apart when the CMB light was emitted to ever have been in contact.

As a way to solve this and other problems, physicists think the universe's size ballooned tremendously during the first fractions of a second of its existence. Prior to this epoch, appropriately called inflation, the cosmos was small enough that opposite regions were connected causally — close enough that they could interact — and their physical



properties could even out. When the observable universe was a trillionth of a trillionth of a trillionth (10^{-36}) of a second old, it abruptly expanded from something billions of times smaller than a proton to about the size of a fist, thereby locking in its near-uniform properties.

Long after inflation but well before decoupling, matter of both ordinary and dark kinds dominated the universe. Although physicists don't yet understand what dark matter is, their best guess is that it consists of massive particles that interact with other matter only through gravity. Scientists think dark matter created the initial foundations for the structures we see, amplifying the small density differences remaining from inflation so that dense areas became more compressed and rarified regions thinned out.

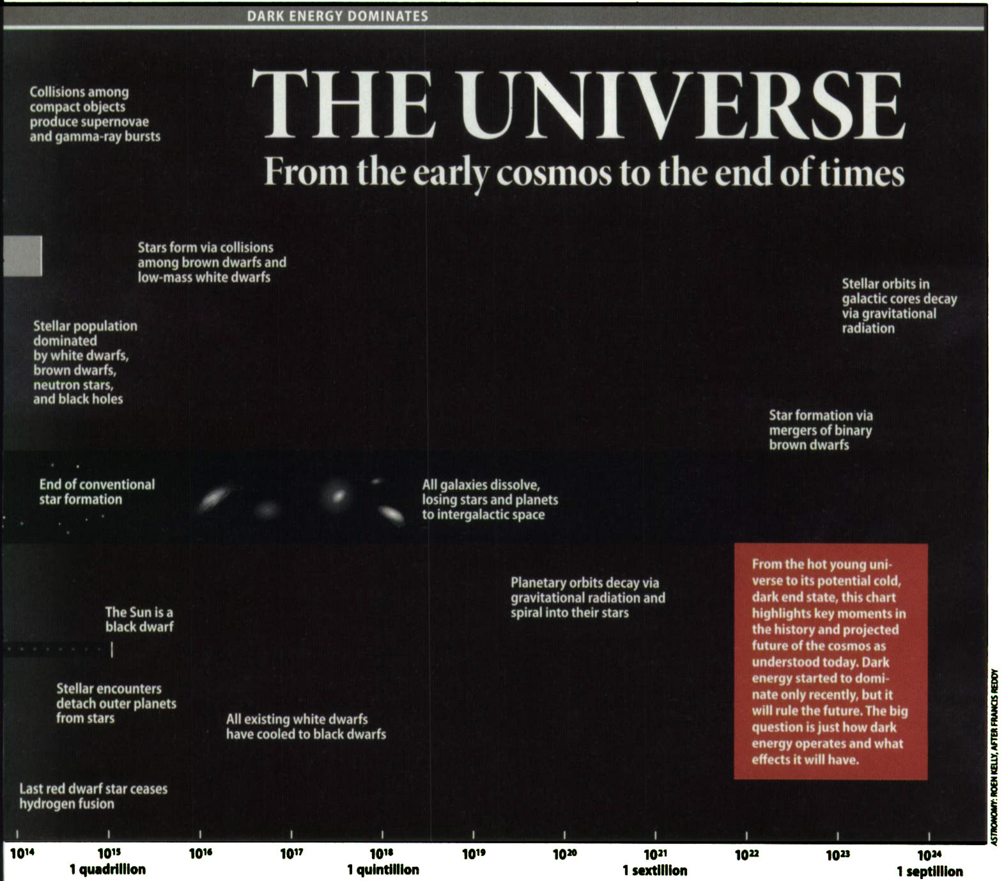
After decoupling, the universe went dark. It cooled steadily as space expanded, and this expansion slowed continuously thanks to the combined gravity of all the matter in the cosmos. Dark matter halos corralled normal matter to form stars, bringing light to the universe. The first stars produced ultraviolet light that ionized the ever-present neutral hydrogen gas, starting feedback processes that transformed a simple cosmos into today's highly structured universe.

Then, about 5 billion years ago, the universe began acting bizarrely. Against all expectations, cosmic expansion sped up, and it appears to have been doing so ever since.

Tales from the dark side

Astronomers discovered this cosmic acceleration while mapping the distant universe using a certain class of exploding star. Type Ia supernovae signal the total destruction of white dwarf stars. Because these explosions produce similar amounts of energy, astronomers know their intrinsic luminosity. It's similar to knowing the wattage of a light bulb. "You know how bright that light bulb is, and by measuring the flux you see, you can figure out its distance," explains David Spergel, an astrophysicist at Princeton University in New Jersey. But distant supernovae appear less luminous, and therefore more distant, than those nearby.

Scientists call the culprit dark energy, a negative pressure that steadily pushes the cosmos apart. As the universe expands, gravity (which can be thought of as a positive attractive pressure) works to slow its growth, and this effect diminishes over time as matter



spreads over a larger universe. But dark energy's negative "force" seems to remain constant independent of expansion, so its importance increases relative to matter and accelerates the cosmos. Today, dark energy makes up about 68 percent of the universe, and all signs point to it increasing in the future.

Three different possible values exist for what cosmologists call the dark energy equation of state (*w*), which relates its pressure to its energy density. "If *w* is equal to –1, then the universe will continue to expand," says Spergel. "If *w* is greater than –1, then as the universe expands, dark energy decreases with time and becomes more dilute." The acceleration would slow, then stop, and the universe would expand ever more slowly until matter again holds the reins.

And there's a third, particularly unpleasant, option. If *w* is less than –1, the pressure of dark energy will increase with time and the cosmos will accelerate at an ever faster clip until, eventually, space and time themselves are shredded in a "Big Rip." If *w* turns out to be as small as –1.5, for instance, the universe would end just 22 billion years from now. A billion years before then, galaxy clusters would dissolve. About 60 million years before the deadline, our galaxy would be torn apart. The solar system would survive until about three months before the end, and the planets themselves would endure to about half an hour before the end of time.

"Right now, we know that *w* is close to –1," adds Spergel, "but we have enough uncertainty in the values that we don't know which one of those three possibilities best describes our universe."

INFLATION VS. DARK ENERGY

"Superficially, dark energy and inflation do seem to have some similarities," says Fermilab's Dan Hooper. Scientists say that the universe is expanding at an accelerated rate today because of something called dark energy and that for a fraction of a second shortly after the Big Bang, the universe expanded at a tremendously accelerated rate during the inflation epoch. Might dark energy be a contemporary version of what physicists call the inflaton field, which they suspect drove inflation? "They're not exactly the same thing," explains Hooper, "but they might have some similarities that would lead us to think of them as analogous physical phenomena." — *F. R.*

The planetary nebula IC 2149 in Auriga doesn't look spectacular because it formed from a relatively low-mass star. Astronomers suspect our Sun will face a similarly anemic fate. PATRICK A. YOUNG, DONALD W. McCARTHY, CRAIG KULESA, KAREN A. KNIERMAN, JACQUELINE MONKIEWICZ (STEWARD OBSERVATORY)/GUIDO BRUSA, DOUGLAS MILLER, MATTHEW KENWORTHY (CENTER FOR ASTRONOMICAL ADAPTIVE OPTICS)

Because scientists don't actually know what dark energy is, it could turn out to be a self-limiting phenomenon, something akin to inflation that persists for a while but ultimately varies, maybe even fading away entirely (see "Inflation vs. dark energy" on p. 41). Or perhaps it could ramp up in the future instead, turning the expanding universe into a contracting one destined for a fiery end in a Big Crunch. "It is completely plausible that sometime in the distant future, dark energy could start behaving in a different way that would change the endgame of the universe's history, but it's probably something we will never really know," says Dan Hooper, an astrophysicist at Fermilab in Batavia, Illinois.

Or perhaps dark energy is a phantasm, an illusion created by the breakdown of general relativity at enormous scales. Either way, what we learn about dark energy in the next decade or two will reverberate throughout physics and fundamentally alter our concepts of space and time.

THE END OF COSMOLOGY

One consequence of our current picture is that cosmology itself may one day be obsolete, according to a 2007 study by physicists Lawrence Krauss, then at Case Western Reserve University in Cleveland, and Robert Scherrer of Vanderbilt University in Nashville, Tennessee. If dark energy continues its constant push, the descendants of today's cosmologists will lose all observational cues about the universe's origins in a time significantly shorter than the age of the longest-lived stars.

Within 100 billion years from now, galaxies that are not gravitationally bound to the Local Group will exit our horizon, moving out of causal contact with us and gradually fading to invisibility. If future cosmologists can't observe distant galaxies, they won't be able to detect the expanding universe or the presence of dark energy.

In the same time frame, the peak light from the cosmic microwave background (CMB), which universal expansion currently has stretched into microwave energies, will have shifted to 300-megahertz radio waves. Before the universe is 50 times its present age, ionized gas within the merging remnants of Local Group galaxies will scatter this signal and effectively erase all evidence of the CMB.

The final pillar of modern cosmology rests on the abundance of light elements. In the first few minutes after the Big Bang, fusion reactions produced a 3-to-1 ratio of hydrogen to helium. Scientists can detect relic abundances of deuterium — a heavy flavor of hydrogen — in distant quasars even today, and the amount of primordial helium has been only slightly "polluted" by helium produced within and scattered by stars.

Fast forward 100 billion years. Quasars are undetectable, processing in stars has destroyed deuterium, and the byproducts of stellar fusion reactions have overwhelmed the initial helium abundance.

Based on observations alone, astronomers will conclude that the universe consists of their own galaxy set within an infinite and unmoving void. — *F. R.*

Approximately 3.9 billion years from now, the merger of the Milky Way (right) and the Andromeda Galaxy (left) will be well underway. At this stage, tidal forces have started to warp the outer spiral arms of both galaxies. NASA/ESA/Z. LEVAY AND R. VAN DER MAREL (STScI)/T. HALLAS/A. MELLINGER

Back to the future

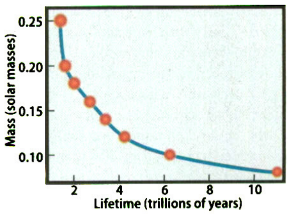
Despite the uncertainty, astronomers can talk confidently about a few events coming in the next several billion years. After that, "new physics" — interactions fueled by particles and processes scientists can only guess at today — may dominate.

First off, Earth will be cooked. At present, the Sun's average luminosity is growing about 1 percent every 110 million years. In a billion years, the increased energy will push outward the solar system's habitable zone — the region where liquid water is stable on a planet's surface — and Earth will roast on the zone's hot inner boundary.

In about 5 billion years, as the Sun transitions into its red giant phase, Mars will nestle in the middle of the habitable zone. At this point, prudent real estate investors may be buying up future oceanfront property on the solar system's icy moons. During the next couple of billion years, the Sun will evolve into a full-fledged red giant, bloated to roughly 200 times its present size. Pluto and its Kuiper Belt brethren will then play host to the habitable zone's inner boundary. Earth will be engulfed by the Sun's outer atmosphere and spiral into it, undergoing the same immolation that destroyed Mercury and Venus during the preceding few million years.

On a grander scale, the "big three" galaxies of our Local Group — the Milky Way, the Andromeda Galaxy (M31), and the Pinwheel

The lifetime of red dwarfs



The smallest stars — dim red dwarfs — live the longest because they burn through their fuel at a miserly rate. The tiniest of them possess only 8 percent of the Sun's mass and will survive for approximately 11 trillion years. *ASTRONOMY*: ROEN KELLY

After Andromeda and the Milky Way make their first close pass, both galaxies will have been stretched almost beyond recognition. They'll meet again in about 2 billion years. NASA/ESA/Z. LEVAY AND R. VAN DER MAREL (STScI)/T. HALLAS/A. MELLINGER

Galaxy (M33) — will begin to collide and merge around the time Mars starts basking in the habitable zone and Earth becomes a hot cinder. According to recent simulations, M31 will make its first close approach to our galaxy about 3.9 billion years from now. The massive galaxies will pass through each other, and strong tidal forces will distort them both, transforming their orderly disks and beautiful spiral arms into chaotic splashes of stars and gas. They finally will merge into a single galaxy astronomers have dubbed Milkomeda about 5.9 billion years hence, likely orbited for a while by M33 before it, too, joins the fray. All galaxies gravitationally bound within the Local Group eventually will merge, although the process could take tens of billions of years.

And every other galaxy simply will fade away. An accelerating universe is one with an "event horizon" analogous to the boundary of a black hole. Once the expansion of space pushes galaxies apart at speeds greater than that of light — which does not violate physical law — we lose causal communication with them. Even if we could send a spaceship or radio signal racing toward one of these galaxies at the speed of light, neither would ever catch up. Right now, all galaxies at redshifts greater than 1.8 — whose light has taken nearly 10 billion years to reach us — are inaccessible. What we see now are frozen images that ultimately will redden and fade away.

Astronomers will never be able to study the evolution of a galaxy beyond some finite age in its own frame of reference. And the more distant the galaxy, the earlier its image will freeze and the less information will be available to us about the way it ages. If dark energy remains constant, the vast Virgo cluster of galaxies that now lies some 50 million light-years away will move beyond our horizon within 100 billion years and gradually fade from view (see "The end of cosmology" on p. 42).

From what we know today, the cosmos of the far future will be a cold and isolated place. All stories have a beginning, a middle, and an end. And at this stage of the game, it's entirely possible that the story of the universe will end with a twist no one expects.

After the Milky Way and Andromeda galaxies merge some 5.9 billion years from now, they will form a single giant elliptical galaxy, perhaps similar to NGC 2937 (bottom). Then, several billion years later, the merged object will pull in spiral galaxy M33, creating an interacting pair that might look similar to this view of Arp 142. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

READ ABOUT NASA'S PLANNED WIDE-FIELD INFRARED SURVEY TELESCOPE AND ITS ROLE IN DARK MATTER STUDIES AT **www.Astronomy.com/toc.**