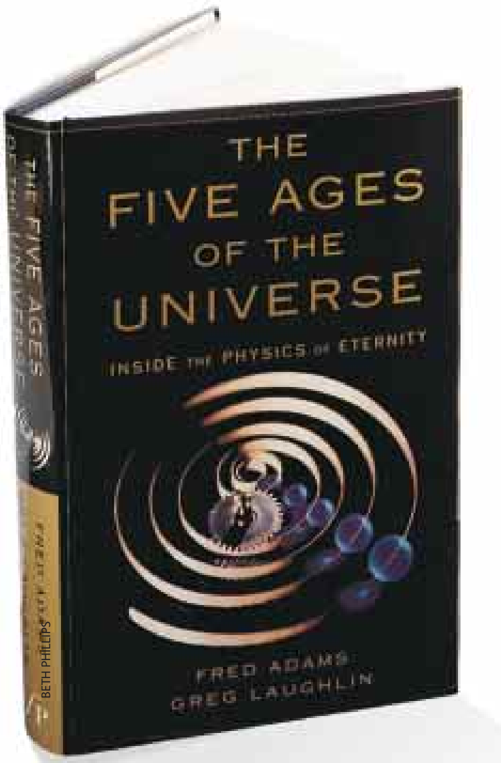
AN ARMCHAIR JOURNEY TO THE END OF TIME

Review by Neil de Grasse Tyson

The Five Ages of the Universe: Inside the Physics of Eternity
BY FRED ADAMS AND GREG LAUGHLIN
Free Press, 1999 ($25)



BETH PHILLIPS

Imagine peering into a crystal ball and watching the laws of nature run their course through all of time and all of space. What exactly would you see? One thing is for sure, the cosmos is destined to expand forever. Regardless of what you may occasionally hear on the street or read in the newspapers, the idea that the universe will one day recollapse has never been supported by reliable data. We've made the observations. We've done the arithmetic. When you add up all the mass contained in the hundred billion galaxies scattered from here to the limits of our most powerful telescopes—the ubiquitous dark matter included—you do not have enough gravity to halt our current state of expansion. Worse yet, recent evidence that compared the observed brightness of distant supernovae with their predicted brightness suggests that the expansion of the universe may actually be accelerating.

This one-way cosmos in which we live may not be philosophically satisfying, but to Fred Adams and Greg Laughlin, co-authors of *The Five Ages of the Universe,* it's a theorist's amusement park. Armed with just the few basic laws of physics and an understanding of the astrophysical behavior of cosmic objects, the authors ride the universe into a formerly unimaginable future. Making the necessary assumption that our knowledge of the laws of physics is accurate and complete, they ask a simple question of their crystal ball: What is the long-term evolutionary fate of all objects in our eternally expanding universe, from its subatomic particles to entire galaxies?

Their answer takes the reader so far into the future that the ordinary reckoning of time swiftly loses its utility. So they use a sensible new clock wherein each tick η (the Greek letter eta) is a cosmological "decade" that lasts 10 times longer than the previous tick. In other words, they reckon time by the exponent when years are measured as a power of 10. A logarithmic timescale is entirely appropriate because the pace of events slows down over time: unimaginably brief intervals in the early universe saw as much astrophysical action as stretches of billions of years do today.

Having anointed themselves with powers of hindsight and foresight, the authors move from the big bang to the indefinite future, characterizing the universe along the way by five basic time periods. First comes the primordial era ($-50 < \eta < 5$), followed by the stellar era ($6 < \eta < 14$). Next is the degenerate era ($15 < \eta < 39$), in which the authors assure us that the name refers to a dense quantum state of bulk matter rather than a state of moral turpitude. The black hole era ($40 < \eta < 100$) follows, and of course they end with the dark era ($\eta > 101$). For reference, the current 15-billion-year age of the universe can be written as 1.5×10^{10} years and falls just above $\eta = 10$.

Yes, we live in the stellar era, where the energy generated within the universe is dominated by starlight. The stellar era also happens to be when all our laws of physics were discovered and tested, so this part of the book will certainly have the longest shelf life. The contents of both the primordial and stellar eras may ring familiar to avid readers of popular literature on astronomy, but the treatment nonetheless represents a compact, if occasionally dry, review of modern astrophysics.

Decay and Degeneration

At the dawn of the degenerate era, all gas clouds have been used up to make stars. All stars, even the "long-lived," low-mass ones, have exhausted their thermonuclear fuel. All that's left is the trinity of degenerate stellar corpses: white dwarfs, neutron stars and black holes.

By the middle of the degenerate era, a single cosmic decade lasts 25 powers of 10 longer than the current age of our universe. Predictions get more and more speculative and more and more fun, because events that were formerly improbable in one decade now become highly likely in another decade. In the stellar era, stars hardly ever journeyed near enough to one another for their gravity to make a substantial difference in their orbital paths, even during head-on collisions of entire galaxies—stars are very small when compared with the distances that separate them. The stars (rather, their corpses) now have close encounters almost continuously and thus undergo "dynamical relaxation," in which low-mass objects are thrust out of the system while high-mass stars descend toward the galaxy center.

While some corpses are cast adrift in the cosmos, the rest of them are eaten whole by the supermassive black holes that lurk in the galactic centers. We have entered the black hole era, where nearly all cosmic energy is now traceable to Hawking radiation as the black holes of the universe evaporate away. When all black holes have disappeared, and there are no sources of fresh energy left, we have entered the dark ages: the temperature of the entire universe asymptotically approaches absolute zero. Only then will the cosmos be dead, by any measure of the word.

Adams and Laughlin deftly invoke all known laws of the universe to spin an entertainingly scary picture of our distant future.

The authors' journey through time continuously engages the imagination as they take the known laws of physics right up to their natural limits. In this intellectual venue, speculation can be justly accused of becoming wishful thinking. Yet sometimes wishes come true. Cosmologists have been describing the early universe ever since physicist George Gamow, in the 1940s, turned the clocks back and predicted the existence of remnant energy from the big bang—the cosmic microwave background radiation.

And today, for example, grand unification theories in physics predict that the proton is unstable and will eventually decay in 10^{30} years—a factor of a quintillion longer than the current age of the universe. Experiments are now being designed to see this happen. Naturally, proton decay factors significantly into the happenings of the degenerate era, as the authors are granted plenty of time to kill every proton in every nucleus of every atom in the entire universe.

In *The Five Ages of the Universe*, Adams, who teaches physics at the University of Michigan, and Laughlin, a postdoctoral fellow at the University of California at Berkeley, deftly invoke all known laws of the universe to spin an entertainingly scary picture of our distant future. During our eternal cosmic expansion, if new laws of physics are revealed, then many (if not most) of their predictions will fail. They admit this obvious shortcoming. But I don't mind, because I enjoyed the journey. When new laws of physics demand it, I will simply ask them to weave an updated scientific tale that takes me back to the future once more.

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THE EDITORS RECOMMEND

ONE RENEGADE CELL: THE QUEST FOR THE ORIGINS OF CANCER. Robert Weinberg. Basic Books, New York, 1998 ($21).

This is the cancer story, told with care and clarity and unfolding like a good detective novel. Skilled detective work is what it has taken to determine the causes and nature of the disease and to bring medical science to a time when it is becoming increasingly possible to prevent or treat cancers. Weinberg, professor of biology at the Massachusetts Institute of Technology and a founding member of the nearby Whitehead Institute for Biomedical Research, is prominent among the detectives. His account starts with the single "renegade cell" that begins an uncontrolled growth in one of the body's tissues, eventually giving rise to a cancerous tumor. But his main focus is on the findings of the past two decades that have yielded an understanding of the disease—among them the role of carcinogens and viruses and the discovery of oncogenes, growth factors and the cell cycle clock. "We have learned much about the invisible forces that create human cancer," he writes. "Knowing the causes of many tumors, we should be able to prevent their appearance, or if they appear, to treat them and achieve permanent cures."

THE SUN, THE GENOME, AND THE INTERNET: TOOLS OF SCIENTIFIC REVOLUTIONS. Freeman J. Dyson. Oxford University Press, New York, 1999 ($22).

Dyson, who gained eminence in physics at the Institute for Advanced Study, is also sure-footed in other areas of science and in examining the social implications of scientific achievements. He displays all those talents in this book, which is based on lectures he gave at the New York Public Library in 1997 "to show to an audience of nonscientists how science could be important in their lives." His aim in the book is to suggest developments that might be significant in the 21st century and to show how, "either along this road that I describe, or more probably along some other road, we have a chance to reach a happier and more equitable world." The major developments he foresees are in genetic engineering, the Internet and solar energy. He discusses these and many related subjects in his characteristically limpid prose. "I am looking," he writes, "for ways in which technology may contribute to social justice, to the alleviation of differences between rich and poor, to the preservation of the earth."

FROM THE SUN, THE GENOME, AND THE INTERNET

FINDING THE WALLS OF TROY: FRANK CALVERT AND HEINRICH SCHLIEMANN AT HISARLIK. Susan Heuck Allen. University of California Press, Berkeley, 1999 ($35).

Received wisdom has it that Heinrich Schliemann, a German businessman turned archaeologist, discovered the remains of ancient Troy at Hisarlik in modern Turkey in 1868. That tradition, according to Allen (visiting scholar and guest lecturer in the classics department at Brown University and visiting lecturer at Smith College), arises from Schliemann's self-promotional writings. "But there is another claim to be staked," she writes, "both to some of Schliemann's treasures and to the honor of actually having found the site of Troy. That claim belongs to the man who owned half the land on which Troy eventually was found, the man who informed and educated Heinrich Schliemann about the site and persuaded him to dig there."

That man was Frank Calvert, an Englishman who served for 34 years as a U.S. consular agent at the Dardanelles, all the while steeping himself in Trojan archaeology. Allen describes the contributions of Schliemann and Calvert to the Troy work and brings the story of archaeological activity at the site up to the present, illustrating the tale with many maps, photographs and drawings. Calvert's role has been obscured, she says, because—in contrast to Schliemann—he was "a self-effacing, private person," and "only the occasional letter offers details of his unpublished achievements, the manuscripts for which rarely have been found."

THE HUNTING APES: MEAT EATING AND THE ORIGINS OF HUMAN BEHAVIOR. Craig B. Stanford. Princeton University Press, 1999 ($24.95).

Eight hunters in East Africa, followed by Stanford, have had a good day. They sit about, feasting on the meat, and they "politick throughout the meal" over ways of sharing the catch. Members of a hunter-gatherer group? No, chimpanzees. "I argue that the origins of human intelligence are

FROM *THE HUNTING APES*

linked to the acquisition of meat, especially through the cognitive capacities necessary for the strategic sharing of meat with fellow group members," Stanford writes.

Stanford, who is associate professor of anthropology at the University of Southern California, sees meat "not only as a nutritionally desirable food item but also as a social currency that is controlled by males and therefore is a tool for the maintenance of patriarchal systems." He discusses the residual effects of this heritage in human societies, thereby risking attack from feminists. His main focus, however, is on what meat sharing by our primate ancestors meant for human intelligence: "The intellect required to be a clever, strategic, and mindful sharer of meat is the essential recipe that led to the expansion of the human brain."

THE OSTRICH FACTOR: OUR POPULATION MYOPIA. Garrett Hardin. Oxford University Press, New York, 1998 ($22).

The ostriches Hardin sees are the people who think that continued growth of the human population is no problem—even a good thing. "Perpetual growth has become a secular religion built on the assumption that *growth = progress*." Hardin (professor emeritus of human ecology at the University of California at Santa Barbara) thinks population growth is definitely a problem. Finite resources, he holds, cannot support infinite growth. "Ask yourself this question: what features of your daily life do you expect to be *improved* by a further increase in population?" Hardin tends to shout and wave from his pulpit, and he acknowledges that most of his argument will be "abhorrent to large numbers of Americans (as well as to many other modern people)." But his challenges to widely held assumptions are bound to stir the reader's thoughts and probably emotions.

SKYWATCHERS, SHAMANS & KINGS: ASTRONOMY AND THE ARCHEOLOGY OF POWER. E. C. Krupp. John Wiley & Sons, New York, 1999 ($17.95).

"Through calendar, ritual, symbol, and myth, shamans, chiefs, and kings invest the landscape with magical power from the meaning they extract from the sky. Through such transfers of power, they guide and govern the lives of those who reside on earth." That is the way it was in ancient societies, says Krupp, an astronomer who directs the Griffith Observatory in Los Angeles. His interest in the connection between astronomy and earthly power has led him to visit more than 1,300 sites where relics of reliance on celestial signs remain. In this book (a paperback edition of the 1997 hardback), he takes the reader to many of the sites and provides numerous photographs of what one sees there. And although social structures no longer rest on what people see in the stars, he says, belief in the miraculous lingers on, as evidenced by tales of flying saucers and sightings of Elvis.

THE ILLUSION OF ORDERLY PROGRESS. Barbara P. Norfleet. Alfred A. Knopf, New York, 1999 ($20).

It is a slender book of stunning photographs, part serious science and part whimsy. Norfleet has posed many colorful insects, most of them dead, in more or less natural settings and photographed them. She presents a five-inch by seven-inch photograph on each right-hand page. The whimsy is in the brief caption on each facing page and often in the related photograph. For example, the caption that also serves as the book's title accompanies a photograph of 13 shining leaf chafer beetles (*Chrysina macropus*) forming a vertical triangle around a piece of clay in what appears to be almost military precision, but they are in fact circling forever and

FROM *THE ILLUSION OF ORDERLY PROGRESS*

going nowhere. At the end of the book, Norfleet identifies the insects in each photograph insofar as their identity is known. "There exist between 10 and 30 million insects," she notes, "and only about 1 million have names." Norfleet is founder, director and curator of the photography collection at Harvard University's Carpenter Center for the Visual Arts. She has done herself proud with this, her seventh book.

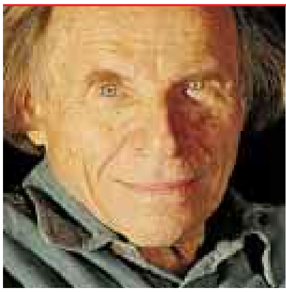
LIFE'S OTHER SECRET: THE NEW MATHEMATICS OF THE LIVING WORLD. Ian Stewart. John Wiley & Sons, New York, 1998 ($16.95).

Life's first secret, Stewart says, is the molecular structure of DNA. The other secret, he believes, is mathematical control of a growing organism. (Mathematician Stewart's activities include conducting this magazine's Mathematical Recreations department.) Arguing that "life is a partnership between genes and mathematics," he embarks on an absorbing study of what life is, how it originated and how the search for mathematical laws that underlie the behavior of living organisms will illuminate those deep questions.

Along the way, he examines mathematical patterns in flowers, bird feathers, animal locomotion and many other features of life. But he hopes for much more profound findings in biomathematics. "A full understanding of life depends on mathematics," he writes. "At every level of scale, from molecules to ecosystems, we find mathematical patterns in innumerable aspects of life. It is time we put the mathematics and the biology together."

FROM *LIFE'S OTHER SECRET*

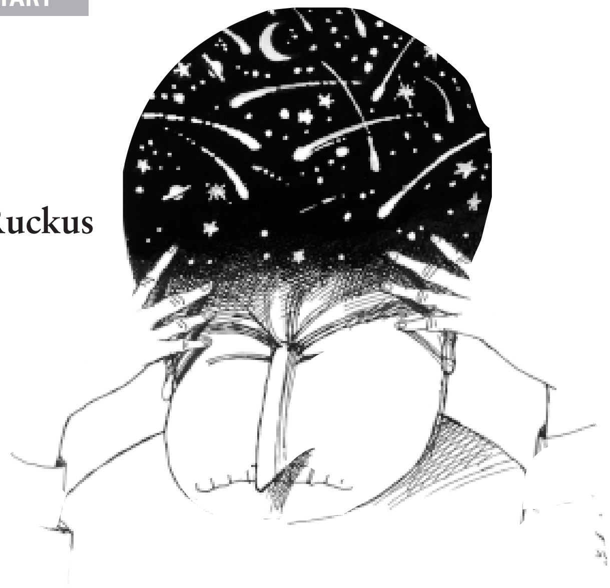
COMMENTARY



WONDERS

by Philip Morrison

The Hidden Cosmic Ruckus



DUSAN PETRICIC

The sun and its planets share the universality of the building blocks of our quantum world: electrons, nucleons and photons. But it comes as a bit of a surprise that the solar system and distant planetary systems have another distinctive modular origin all their own. Those planetary "bricks" are not tiny identical particles; rather they are roughly built out of dust, rock, tarry organics and ice, somewhat like a Boston street gutter in winter. They were postulated around 1900 by two University of Chicago professors, geologist T. C. Chamberlain and astronomer F. R. Moulton. The fine old word "infinitesimal" had long expressed a vanishingly small quantity, so they coined "planetesimal"—the smallest object that might be thought of as an orbiting planet.

In abundance, such modules of matter—estimated to be about a mile in diameter—will attract, collide and merge to become progenitors of full-scale planets. As planetesimals grow ever more massive, their gravitational attraction to the sun and to one another becomes more effective than the collisions they encounter as they move in the solar nebula.

Here a savvy reader might well object. If a final Earth sphere is to be formed by the merger of many planetesimals, it will require 10,000 of them aligned along each of the three dimensions—the length, the depth and the width—amounting thus to about one trillion planetesimals. A few more numbers may serve to orient. The cosmic space we can survey offers us a view of fewer than a trillion galaxies and of fewer than half a trillion stars that make up our own galaxy. Our human cohort numbers only six billion heads; even the census of all our ancestors summed up over the entire history of our species amounts to a tenth of one trillion.

Can we grant so bold a postulate, at once invoking trillions of unseen planetesimal modules? Should not old Occam's razor cut them off, as fine specimens of hypothetical "entities multiplied beyond necessity"? We certainly should—*except* that we have evidence for trillions of their counterparts even today.

Comets arrive nearby after falling in as far as a light-year to approach the sun. New comets have straggled sunward from remote darkness every year for five billion years. In itself that would imply tens of billions stored, thereby allowing for losses. Long study of the orbits of comets shows that the gravitational disturbances from passing stars and clouds of gas only rarely nudge a comet out of the cold attic, so the original comet inventory must rise to many trillions. That comets come in trillions verifies the planetesimal idea, for comets are but a species of planetesimal from uncrowded icy orbits. The densely pockmarked faces of the moon and the airless planets, moreover, record the waning barrage that closed the curtain on planet formation, a process that is now all but extinct.

Accept that trillions of mile-size chunks formed in plenty, growing from gas and grains through sticky collisions, at best tentatively understood. The chemistry of contact as binding agent gradually gave way to gravitation as the objects grew. Planetesimals can interact without contact. Slowly their orbits simplify as countless gravitational energy transfers space out, circularize and flatten the initial thick-braided cloud of orbits. Planetesimal collisions flourish; some partners chip; more cohere by gravity. Eventually, large composites aggregate out of the pell-mell collisions, until at last the biggest runaway clumps sweep up most residual surrounding orbiters unto themselves. Simulations of this sequence by powerful computations yield a result resembling the solar present, where well-spaced planets revolve in near-circles within a thin, flat disk amid a complex but dilute cloud of lesser bodies.

Has our well-ordered solar system grown orderly merely by aging?

Although gravity is indifferent to the chemical composition of matter, chemical bonds determine many features of the planets. Where close-in planetesimals feel the sun's heat, few will be icy; far out, ice (the most common of molecular solids) will dominate, and the rest will be mere contaminants. Close in there is less room, and collisions will be fast and furious. Far away, space is ampler, and slower orbital collisions will be less frequent. Thus, comets mostly remain icy individuals. The cool region of massive Jupiter and its gas giant kin lies between; there ice and gas abound, and strong planetary gravity can even hold on to the free helium and

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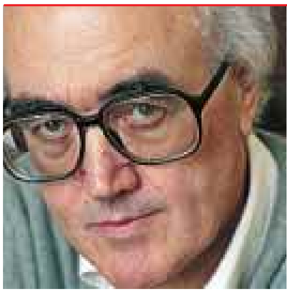
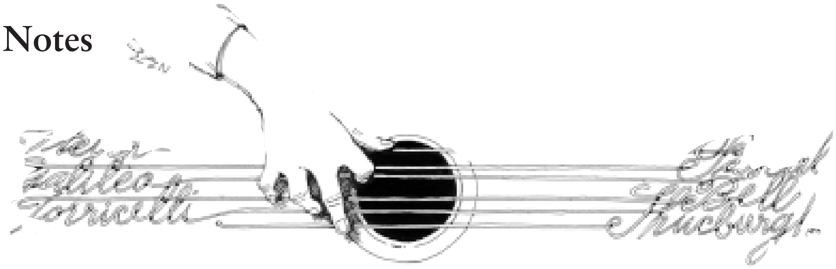


CONNECTIONS

by James Burke

A Few Notes



DUSAN PETRICIC

One of the things I do to relax (it has the opposite effect on all within earshot) is to play the classical guitar badly, and the other day I warmed up by accompanying myself to a whistled rendition of "Yankee Doodle." Then, just as I was getting down to the serious matter of scales, before attempting yet another failed attack on "Recuerdos de la Alhambra," it flashed upon my inward eye that scales had been mathematically sorted out by that Dutch Renaissance whiz Simon Stevin. Pioneer of decimal fractions, military adviser to Count Maurice of Nassau and builder of sand-yachts. And he who had divided the octave into the semitones I was now plucking.

In 1608 Stevin must have been out to lunch on the day an unknown local optical noodler named Hans Lippershey fetched up at Maurice's place with a new gizmo to help the count in his never-ending efforts to turn the Dutch army into a high-tech force with which to chuck out the occupying Spaniards (which he eventually did). Lippershey brought along a tube with a lens at each end to be used for "looking," as he put it. Maurice is reported to have muttered something about binoculars and sent him off with a flea in his ear. Next thing we hear, it's 1609, and Galileo's got the kit and built one. He is about to change the entire history of everything by revealing that the moon has mountains. And he will go on to prove that Earth isn't the center of the cosmos by showing moons orbiting some other body: the planet Jupiter.

The solar system concept was what Copernicus had been clobbered for nearly 100 years earlier, so surprise, surprise—much the same was about to happen to the big G. One of the other crimes Galileo was also to commit (and which was almost as bad as heliocentricity) was to encourage researchers to do something about nothing. As in the vacuum. Which was not supposed to exist, because any empty bits of the universe were reckoned to be filled by God's presence. It started in 1630, when Galileo was approached on the problem of why suction pumps would not lift water more than about 30 feet. A weighty matter when you were digging wells for water to power ducal fountains in Florence. Galileo kind of passed the puzzle on to one of his acolytes, Evangelista Torricelli (who lived in Galileo's house during the last years of his life and would end up succeeding him as mathematician and philosopher to the duke of Tuscany).

Subsequent Torricellian thoughts led to a column of mercury in a tube being upended in a dish of mercury. During upending, some of the mercury in the tube ran out into the dish, but some remained in the form of a column reaching almost all the way up the tube. The gap above the almost? The impossible and, as you know, heretical vacuum. Over a number of days, Torricelli noticed that the level of the mercury in the tube crept up and down. Had this to do with changing air pressure on the surface of the mercury in the dish supporting the column of mercury in the tube?

A copy of a secret letter about this risky idea, sent by Torricelli to a Roman propeller-head pal named Michelangelo Ricci, got into the hands of the only person who was likely to be able to do anything about it. This was Marin Mersenne, a scientific priest in Paris with the biggest address book in Europe. Mersenne was one of those guys who might not know the answer to something but always knew a man who did. In this case, that someone was going to have to find a glass factory, one of the essentials of vacuum experimental gear being long glass tubes. This was high-end stuff, not readily available back then in your neighborhood mall. Unless you lived among the glassmakers of Rouen, which this fellow did.

Galileo encouraged researchers to do something about nothing—as in the vacuum.

Then came the ticklish matter of mountains. Rouen is pancake-flat, and this chap wanted to take the mercury in the tube up a significant height to see if upness meant lower air pressure and a fall in the level of the column. Fortunately, the city of Clermont-Ferrand in central France had both mountains and his willing and able brother-in-law, name of François Périer. On September 19, 1648, Périer visited the peak of Puy de Dôme and went up and down. And so did the height of his mercury column, making like a barometer. And clinching the reputation of the fellow who had put him up to it all (4,888 feet up, to be exact): his brother-in-law, Blaise Pascal.

Pascal was a mathematical genius who designed the first working calculator and was deeply into gambling and probability. Which may be why he was also in deep doo-doo with Rome over his links with radical back-to-basics Catholic reformers known as Jansenists. These types, followers of Dutch priest Cornelius Jansen, attacked Jesuits for their probabilism (“what you’re thinking about is probably not a sin if a church authority says not”). Jansenists, *au contraire,* were for probabiliorism (“you never know—it’s more probable to be a sin than not, so don’t do it”).

Now, back then, criticizing power-of-thumbscrew Jesuits was a good way to get yourself taken seriously dead. By 1705 a Papal bull required Jansenist priests and nuns to get out of the habit, or to get out of the habit. Which is just what happened to Father Michel de L’Épée, who ended up in Paris, opening a school where he taught sign language to the deaf and mute. Did the job so well that in a test one of his star pupils was able to answer 200 questions in three languages. By 1789 the school head was Roch-Ambroise Sicard, who finished the dictionary of signs L’Épée had started.

In 1815 an American, Thomas Gallaudet, turned up to learn the teaching technique. Two years later he had established the Connecticut Asylum for the Deaf and Dumb in Hartford. In 1872 a Scottish immigrant did a two-month teaching stint at the asylum and then became a professor of vocal physiology at Boston University. It was there, while trying to develop a system to help deaf people to “feel” or “see” sounds so as to imitate them, that the prof took a close look at how the eardrum worked and persevered in finding a way to make a vibrating membrane generate a vibrating electric current that would in turn vibrate another membrane. We call the resultant contraption that Professor Alexander Graham Bell came up with: the telephone. Because Bell was less than qualified to do any of the electrics involved, he wisely took advice from eminent science guru and Smithsonian secretary Joseph Henry.

At one point early in his working life, Henry had been a tutor in the household of the Van Rensselaers, the Dutch patroon family that owned much of New York State from the 17th century. In 1642 in the city of Rensselaer on the Hudson River, just across from the family home, Fort Crailo was built to protect the settlers. Tradition has it that it was in this fort that an English medic, Richard Shuckburgh, composed the tune I was whistling at the start of this column.

Oh, well. Back to my scales.

Wonders, *continued from page 104*

hydrogen atoms that escape little Earth.

The planets began as cold accumulations of solid planetesimals. Their atmospheres are at the surface (or escaped entirely). H_2O, if present, is mainly below. Oxidized rocks are deeper still, then a thick mantle, and deepest down is a dense iron core that must once have rained down from molten slag to collect at the center, just as in a furnace! The clues pointing to the inner planets’ fiery origin are too strong to deny and are supported by detailed study. But of course, the icy planetesimals themselves can kindle and fuel that furnace, if only they cohere rapidly enough. The kinetic energy they bring in by collisions is enough to melt an Earth or a Venus, probably again and again in repeated stages over a few million years. The births of the big boys (Jupiter is as massive as 300 Earths) are less well understood—they may be largely the results of gas accumulations, because they are mostly hydrogen and helium. Or perhaps they are composites, starting out as icier, planetesimal-built cores but capacious enough to draw in cold gas to fill out their bulk. Remember that the main ingredients of the sun and its nebula are hydrogen and helium, more than 98 percent of all the atoms it has.

Has our well-ordered solar system grown orderly merely by aging? Many planets may have come and gone, merged into the sun or out into space, like the gases lost earlier from the sun-forming molecular cloud. The wonderful newly found distant systems show us many “hot Jupiters.” We do not now see how those could form so near their star. It is more plausible that they arose in an outer cool zone, then migrated inward under gravitational interactions, tidally with the star, with nebular remnants or even with a massy rival planet.

Our sketchy idea of planetary origins is about as secure as that of a botanist who would infer a life history from one blossom, the only flower he had ever seen. But at last we are on the way to an enlightening variety of planetary specimens. Someday we may detect signs of distant planet formation under way: a pelting storm of planetesimals, a star engulfing whole planets, even giant planets in collision. Can such a ruckus remain forever hidden?