"Wouk's questions are pure, his exploration heartfelt, and his remarkable lifetime of experience couldn't be more relevant or necessary." —JONATHAN SAFRAN FOER

THE LANGUAGE GOD TALKS

On Science and Religion

HERMAN WOUK

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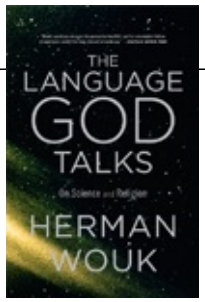

To the memory of our fathers

ABRAHAM ISAAC WOUK

MELVILLE FEYNMAN

who emigrated from Minsk

and gave us our lives in America

It doesn't seem to me that this fantastically marvelous universe, this tremendous range of time and space and different kinds of animals, and all the different planets, and all these atoms with all their motions, and so on, all this complicated thing can merely be a stage so that God can watch human beings struggle for good and evil—which is the view that religion has. The stage is too big for the drama.

—RICHARD FEYNMAN

Remember, Herman Wouk, we are storytellers. Stories, pictures, people! No thoughts!

—S. Y. AGNON

The Language God Talks

More years ago than I care to reckon up, I met Richard Feynman. I was then out to write a sort of *War and Peace* of World War II, and early on in the moonstruck enterprise I realized that if I were at all serious about it, I had to learn something right away about the atomic bomb. Tolstoy could not consu Kutuzov, the general who drove Napoleon out of Russia, because the canny old one-eyed field marsh was long since dead; but when I started to work on my unlikely notion nearly all the men who had created the bomb were alive, and several of them were at the California Institute of Technology, including Feynman. President Truman, who had been an artilleryman in World War I, said of the bomb, "It was a bigger piece of artillery, so I used it," a striking remark which shows up in my *War and Remembrance* but surely something less than the whole story. So I went to Caltech to talk to thos who knew the whole story.

This may seem monstrously pushy, and no doubt it was. Like many novelists I have spun my book out of my own experiences when I could, but in attempting work far outside my own relatively jog-trot existence I have had to pick other men's brains. My World War II service, three years on destroyer-minesweepers in the Pacific, gave me the substance of *The Caine Mutiny*, but taught me nothing at all about the world storm that had swept me from Manhattan to the South Pacific like a driven leaf. When the bomb fell on Hiroshima my ship was a bobbing speck on picket duty in the rough waters off Okinawa, and we had just survived a kamikaze attack unscathed; so I joined heartily in the merriment aboard ship, very glad that I had survived the war and would soon go back to my fre civilian life and marry my sweetheart. As to the larger issues of dropping a whacking new bomb mad of uranium on a Japanese city, I was innocent and indifferent. The radio said that our scientists had "harnessed the power of the Sun," and that was quite enough for me and for all of us aboard that old four-piper, halfway around the world from home.

The Caltech scientists received me cordially, and talked freely about their adventures in working on the bomb. I remember one physicist telling me, for instance, how he drove to the Trinity test site i New Mexico with the dread plutonium core in the back seat of his car. But to a man, one after anothe they warned me so earnestly not to try to see Richard Feynman, that I began to think of him as a human plutonium core. However, I had nothing to lose so I did try, and somehow I found myself in h office, talking to a lean guy in white shirtsleeves, with long hair and a sharply humorous countenance calling to mind a bust of Voltaire. It didn't go well at first. "You know," he said, as I groped to expla my purpose, "while you're talking, you're not learning anything." So I blurted out baldly, any old wa my vision of a fiction work throwing a rope around the whole global war. As I spoke an enigmatic look came over that strong face, something like remote tolerant amusement. "Well, that's the sort of thing genius reaches out for," he said, and he took over the conversation.

In swift strokes Feynman brought the entire Manhattan Project to life, the excitement and the peri alike, mentioning that once in a laboratory corridor he passed uranium materials stacked so carelessl that a chain reaction was within a whisker of going off. His main point was that the whole enterprise was gigantically messy, and that the atomic bomb was by no means at a frontier of science. He put it

so: “It wasn’t a lion hunt, it was a rabbit shoot.” There was no Nobel Prize, that is to say, in the concept or the calculations; it was just a challenge, if a huge one, to audacious innovative technology and brute industrial effort. This formidable fellow walked out of the building with me, and said as we were parting, “Do you know calculus?”

I admitted that I didn’t.

“You had better learn it,” he said. “It’s the language God talks.”

Calculus

I never forgot Feynman’s admonition, promising myself that I would get at calculus once I had writte my big war novel, which I thought might take four or five years. It became two novels, each about a thousand pages long, and the task engulfed my life from my late forties well into my sixties, the bett part of two decades. Toward the end I had a strong sense of racing the calendar to finish it before I died. All that while, the language God talks had to wait.

After that I did make several separate attempts to learn calculus, all recorded in a loose-leaf notebook which I still have. I tried self-teaching out of books with titles like *Calculus Made Easy*. I picked up and skimmed freshman texts in college bookstores, hoping to come across one that might help a mathematical ignoramus like me, who had spent his college years in the humanities—i.e., literature and philosophy—in an adolescent quest for the meaning of existence, little knowing that calculus, which I had heard of as a difficult bore leading nowhere, was the language God talks; or as one noted Jewish microbiologist, also a Torah scholar, commented to me with a grin, “His other language.” I even engaged a tutor, an Israeli, figuring to improve my spoken Hebrew while learning calculus. A dumb idea, and I advanced in neither. Lastly, desperately, I got permission to audit a high school course in calculus. I actually hung on with the teenagers for a couple of months, but I fell too far behind and had to withdraw, with a few farewell words to them about the preciousness of knowing calculus. As I was walking out of the classroom, a patter of applause surprised me; a sympathy hand, in showbiz parlance, for the defeated departing old codger.

In short, calculus remains a thick glass wall between me and most truths in Feynman’s world where he hears God talk.

Gell-Mann

The Nobel laureate Murray Gell-Mann, Feynman’s colleague and rival at Caltech, was no man to mince words, and he once observed that the gap between a person who understood quantum mechanic and one who did not was arguably wider than the difference between a human being and a great ape. On the other hand, Feynman is on the record as having said, “Nobody understands quantum mechanics.” We have here what is called in Talmudic discourse, which I know pretty well, a sort of *Plugta d’tanoi*, that is, a standoff of the sages. Obviously I have to hope that the weight is with Feynman. As it happens, I know Murray Gell-Mann, and we have chatted some in a social vein. I did try once or twice to raise serious matters with him, but gave up. His responses, while not impolite, hinted that an orangutan was getting a bit too familiar.

Feynman was kinder. We met one summer years later at the Aspen Institute, a think tank high in the Colorado Rockies, and we took to lunching together and going on long walks. He did most of the talking: about his own work in physics, about quantum mechanics (making it seem momentarily almost understandable), and about philosophy, of which he was acidly scornful. His father, a dealer i

uniforms, evidently a man with a restless inquiring mind, had greatly influenced him. Not much interested in novels or novel-writing, he perked up when I mentioned that I studied the Talmud daily. Feynman respected the Talmud as a "wonderful book," though he knew little about it. So I laid out for him an obscure abstruse problem that I had just struggled through. He listened keenly, thought for a moment, then rapped out the correct classic solution, and when I said he had hit it he was mighty pleased with himself. Would that Gell-Mann, with his imposing mind, had been inclined to loosen up like that. I treasure the memory of those illuminating lunches and walks.

My library contains whole shelves of science books for the common reader. I have read an amazing amount of the stuff. I may know nearly as much about modern science as one of Gell-Mann's anthropoids can grasp. Gell-Mann himself has written a long generous book in that vein, *The Quark and the Jaguar*, which I have read cover to cover with much interest, and some labor. There is a book by Feynman, too, *Six Easy Pieces*, treating opaque topics like gravitation and quantum theory in his brisk native New York style. These pieces are excerpted from his renowned *Feynman Lectures on Physics*, a three-volume work impenetrable to untrained minds. I know, because I bought the oversize red paperbacks of the *Lectures*, and butted at those stone walls for weeks. *Six Easy Pieces* is deceptively accessible; in some swift turns of the talk one has to hang on for dear life.

Einstein too wrote such books, not very good ones. Explaining himself to the laity was not the forte of this man of the ages. Followers like James Jeans and Arthur Eddington voiced his epochal views in popular books, and scientists can even put out big bestsellers, like James Watson's *The Double Helix* and Stephen Hawking's *A Brief History of Time*. Hawking heeded his editor's warning, "Every equation you include cuts your readership in half," and his book contains only one, $E = mc^2$. Sure enough it sold like hotcakes. I bought a copy myself. The going gets pretty bumpy in Hawking even without equations, and when I slogged through to the end, I wondered how many other book buyers had honestly made it all the way. Still, I had gotten more than my money's worth in hard-won glimpses of the new cosmology.

Science writing is standard newspaper fare today. Science magazines and websites abound, some sober, some jazzy, compacting the latest advances in cosmology and the biosciences into digestible English. It goes without saying that from the Nobel laureate like Gell-Mann who stoops to write a book for plain folk, to the columnist who scavenges *Nature* and *Science* to bang out his or her humble Sunday stint, they all know calculus. One and all, they have the advantage, in that respect, of the author of this little book which, adopting Feynman's metaphor, aspires to suggest that the stage may not be too big for the drama. Clearly I will not be talking down to the reader, not one bit, for by and large I address those like me on the wrong side of the mathematical glass wall.

What I write here is rooted in what I know of God's other language. Like many a Jewish Nobel laureate, Feynman speaks about religion from the wrong side of a very different glass wall, the Bible. There he has most of today's Jewry as company, including Murray Gell-Mann, for the Bible has long been waning as the core of a Jewish upbringing, a way of life once handed from father to son down the millennia, rooted in an epic history and an encyclopedic literature; a practical guide to the insoluble mysteries, brief joys, harsh blows, and everyday workings of a human existence. That upbringing survives here and there among our people, but most Jewish babies—in Israel, in America, in all the diaspora—are born today into the world view of Feynman and Gell-Mann; and a Nobel colleague of theirs, the physicist Steven Weinberg, has written lucid books in which the insoluble mysteries loom especially large, most of all the old agnostic paradox of an orderly universe without seeming purpose.

The world begins for a baby, so says William James, as "a big blooming buzzing confusion," a convincing surmise, though what is really going on in a baby's mind we know mainly by the screaming or the smiling. The baby has to sort out the confusion all by himself, little by little, experience by experience. He is bound to discern, very dimly at first, some kind of order and purpose in things, such as a nearby warm nipple when he feels hunger. This sense of order and purpose deepe and broadens as he picks up the basics of being alive. In time he starts to respond to baby talk. He obeys or balks at commands. The great day comes when he stands erect and takes a few faltering steps, his eyes agleam with wholly human pride which he can't yet express.

Once he does find his tongue, the sorting out process races ahead. He hounds both parents with on word, his prime sorter-out of order and purpose, "Why?" Sooner or later comes the leap to the big, th inexorable *Why,* which occurs to only one animal on earth: "Why am I here?", or in a more usual phrasing, "Where did I come from?" If you are an up-to-date liberated parent you are apt to leave Go out of it, nor will you employ—it goes without saying—the antiquated dodges of stork or cabbage leaf. You will no doubt explain about sperm and ovum, and perhaps about penis and vagina, also abo DNA, and maybe a little about natural selection. All that time your child will be looking you in the eye with a pure trusting gaze, and if you have a truthful bone in your body you will be embarrassed. With all the stunning modern discoveries in cosmology and the biosciences, you really don't know th answer. Nobody does. Not the unbeliever, not the believer. Faith is hope, not fact.

Yet every generation has to make a pass at an answer, and so does every father or mother. Feynman's rejection of religion as an answer to the child's question exhilarates me, and has in fact sparked this book, because I so largely agree with him. He is awed and exuberant, as I am, at the grandeur of the far-reaching universe, full of love, as I am, of our tiny enchanting Earth. He is my kin of agnostic, a votary of Democritus, the laughing philosopher who saw the world as a product only of "atoms and the void," which was quite enough to his Greek taste, because he found the world as it exists so pleasurable and beautiful. Like Democritus, Feynman finds the world as such "fantastically marvelous."

Weinberg

Now Weinberg, in his widely read book, *The First Three Minutes*, has put the bleaker agnostic pictur with stark oft-quoted eloquence: "The more the universe seems comprehensible, the more it also seems pointless…. The effort to understand the universe is one of the very few things that lifts huma life a little above the level of farce, and gives it some of the grace of tragedy."

No laughing philosopher, Weinberg. The human quest for Order and Purpose, which begins with the infant at the comforting nipple, ends for Weinberg in bafflement at the wondrous Order he sees in the universe, and despair at the comfortless absence of Purpose. The wondering child's ultimate sorter-out—WHY?—has haunted and hunted this eminent scientist to a dead end.

In *Facing Up,* a book of his essays, a photo of a granite statue serves as both jacket art and frontispiece.[*] Massive and stiff, the figure stares straight at the sky, head tilted far back, a defiant unshattered Ozymandias. This is Tycho Brahe, the sixteenth-century astronomer, memorialized in stone on the remote Danish island where he worked. The image resonates in Weinberg's spirit, for he calls himself a "devout secularist," and in his sardonic essay "A Designer Universe?" he sets out to inflict mayhem on the Argument from Design, theology's old fall-back proof of God's existence. He

himself has not only discerned the Order in the cosmos, he won his Nobel Prize by more exactly defining it. He knows whereof he speaks, and here is how he concludes the essay: "One of the great achievements of science has been, if not to make it impossible for intelligent people to be religious, then at least to make it possible for them not to be religious. We should not retreat from this accomplishment."

I would shake hands on that accomplishment with Steven Weinberg.

My Lame Paws

As a Columbia undergraduate, imbibing the Greek philosophy, comparative religion, and general humanism of the noted core curriculum, I rode the subway to the Bronx once a week to study the Talmud with my grandfather. The Talmud is a hard grind in Aramaic, and to lighten up things I woul now and then venture an agnostic prod at some tender point of our faith—say, Joshua's stopping the sun and the moon. Grandpa would respond with good-natured scorn, stroking his full gray beard, "Where are you creeping with your lame paws?" It was more pungent in Yiddish, but you get the idea That question has been occurring to me as I write these words. Disqualified as I have described myse for getting into these deep murky waters—no academic credentials to speak of, no mathematics beyond half-forgotten algebra—where am I creeping with this venturesome causerie?

Fair question, reader, so let me invite you into the workshop of an old author still creating stories, my work, my intermittent despair, and my lifelong fun. With a new novel recently published and another on the stocks, I have stepped back from my desk, drawn breath, and glanced around the shop for overlooked items. One folder labeled *A Child's Garden of God* lies to a side, more scuffed than most, in which for years I've been stashing false starts on the answer offered by the Bible (insofar as can grasp it) to the grand *Why* of the child and of stumped agnostics. No wonder I have kept putting i off! A big bite.

Newton summed up his lifework in well-known words:

> I know not what I seem to the world, but to myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell, whilst the great ocean of truth lay all undiscovered before me.

It was this child having fun on the beach who came upon the smoother pebble called the calculus (oddly, the word means "pebble"), enabling thinkers after him to venture far out on that ocean of trut toward a distant shore of final theory which, as they keep learning to their gloomy puzzlement, ever recedes. Isaac Newton not only found Feynman's "language God talks," he also mastered God's othe language, and studied and wrote on the Hebrew Bible, a fact that embarrasses some scientists. Newto put Feynman's dictum on calculus, which he called "fluxions," in plain words suited to his own faith *"God created everything by number, weight, and measure."* An agnostic paraphrase for our day migh be, *"All that is truly knowable is knowable only by number, weight, and measure."* Or as James Jeans put it, *"God is a mathematician."*

God as Irony

A byname for God in Aramaic is *Atik Yomin,* Ancient of Days. Einstein now and then spoke of his

work as wresting secrets from *Der Alter*, the Old One. He was being puckish, of course, and so no doubt was Feynman in calling calculus "the language God talks." Neither savant meant the God of th Bible, the God of Abraham, Isaac, and Jacob, my grandfather's God, and his father's, and my father's and mine, and Pascal's, and Faraday's, and Newton's. The God of modern scientists by and large is a figure of speech, an ironic flourish. Darwin himself sometimes wrote of God in a religious mode, but in the present day such literal usage tends to fade out. Feynman, Gell-Mann, Weinberg, and their pee accept Newton's incomparable stature and shrug off his piety, on the kindly thought that the old man got into the game too early. He did not even know for sure that light travels, for in his *Opticks* he refers to the travel of light as an interesting conjecture, based on the equations of a Danish astronome for the orbit of Jupiter. To the real numbing size of the universe, the naive time-bound giant was blin

Feynman in three lectures on science and religion dances lightfoot around this grand theme, and ends by endorsing the ethics of a papal encyclical while waving off its pious core. As for Gell-Mann, he seems to see nothing to discuss in this entire God business, and in the index to *The Quark and the Jaguar* God goes unmentioned. Life he calls a "complex adaptive system" which produces interestin phenomena such as the jaguar and Murray Gell-Mann, who discovered the quark. Gell-Mann is a Nobel-class tackler of problems, but for him the existence of God is not one of them.

Weinberg is different, a quarreler with God in the vein of Job, who confronts the Lord straight on with that everlasting religious challenge, the existence of senseless evil in the world of an omnipoten Creator. Weinberg goes further and tells Newton's Creator to his face that on the available evidence, he is a figment. Stendhal put the agnostic view so, "The only excuse for God is that he does not exist, but Weinberg is too serious a thinker to let the Creator off with a Gallic witticism. He is angry at the horrible record of fanatic deeds done in God's name down the generations, and he will not tolerate facile philosophizing of God back into existence. Better tell it like it is! Newton's God is not there, s no supernatural being can be blamed for the evils of the meaningless human condition, which rises to tragedy only in mankind's dogged gropings for final truth, as in the Book of Job and in Weinberg's writings.

The Stage and the Drama

In dealing with ultimate mystery, one is thrown back on irony and metaphor: the stage and the drama the quark and the jaguar, the boy and the pebble, the child and the garden. Here is one more metapho that emboldens me, ill-equipped as I am, to take on at last the big bite. Picture a man who has lived most of his working life in exile, say an American mining engineer in Western Australia. He marries Perth lady, and forty years slip swiftly and pleasurably by. Comes time for retirement. On balance he decides to live out his years in his native Nevada, and knowing that he may never look on Australia again, he takes one last tour around this remote island continent he has come to love. For the rest of his days he will cherish his memories of that bittersweet farewell.

This lovely sunlit Earth is an exile all of us must leave, one after the other, to return whence we came. I embark here on a tour of our beautiful little Australia in space, this child's garden of God, at pause in my storytelling, anticipating a sure farewell at an uncertain time. I invite the reader to join me. On the wing as I am, it behooves me to write out these thoughts while I can, and I won't pretend write to please only myself. All my working life I have written for readers, and I do so now, be they many or few.

Is the stage really too big for the drama, as Feynman asserted? I believe it's possible to disagree, and that is the main theme of this book. At the outset, let us take a fresh look at the stage, and start

with a grand moment in the drama.

Outward Bound

The Great Day

When mankind first left the earth I was there. A friendly *National Geographic* executive invited me t witness the liftoff of Apollo 11 from Cape Canaveral on July 16, 1969, a day when the Cape buzzed with the powerful and the famous.

How different it was to watch an Apollo launch at the Cape, rather than on TV! No warm-voiced avuncular Walter Cronkite on the small screen, no space-suited astronauts going off to their fate with waves and smiles, no close-ups of the towering snowy Saturn V shaft wisping vapor, no clueless interviewers killing time by badgering scientists and engineers. None of that, just a long wait under a baking Florida sun on a wooden bench in a crowded stand; the rocket gleaming white and diminutive at a safe distance, Mission Control droning from a loudspeaker overhead: “Five… four… three… two… one…. We have ignition.”

Flames shoot out from under the rocket! White smoke billows, and the faraway colossus rises without a sound on a growing pillar of fire. Tears start to my eyes. A roar comes rolling at us and over us, a roar beyond any I have ever heard, a primal roar out of Genesis, Adam tearing loose from the Garden’s grip, and after the sound the shaking and shuddering of the earth….

The Saturn accelerates, dwindling away up into the blue….

And that was it!

Apollo 11 riveted the world because, for one thing, nobody could then predict what the surface of the moon would be like. Nobody! Sober scientists worried that the first astronaut to venture outside the lander might sink and get swallowed up by the fine space dust accumulated over aeons, and perish as in a quicksand. Four days later, in shadowy live TV pictures, came the reassuring answer—a helmeted man backing down out of the spidery module on a short ladder, planting a Robinson Crusoe footprint on the moon, and sinking in not at all as he declared, “That’s one small step for a man, one giant leap for mankind.”

Neil Armstrong might have uttered instead words less noble but no less apt, when his boot touched the moon: “We win!” For the Apollo program was created to beat the Soviet Union to the moon, nothing else.

Apollo by a Nose

That was the sporting side of the Cold War, the lunatic face-off of the two superpowers during forty frightening years I lived through, rattling rockets with hydrogen-bomb warheads at each other, thirty hair-trigger minutes away from a flameout of civilization. Neither government ever declared the moo race a *race.* Not at all! Rocket engineering now made it possible to get men to the moon and back, an since—as George Mallory said of Everest—the moon was *there,* we were going there. So both sides

feigned, but of course it was just a race, a race for mortal stakes of global preeminence, and the whol world knew that.

The Russians had seized a walloping head start in October 1957 by launching Sputnik, the first man-made space satellite, a metal sphere no bigger than a basketball which went sailing and beeping round and round the globe. Today, when the Soviet Union has long been defunct, when satellites in numbers are up there serving as flying switchboards and surveillance cameras, the magnitude of that surprise half a century ago is hardly imaginable. Yet I well remember what a shocking setback Sputnik was to America's national prestige and sense of security; no Pearl Harbor or 9/11 to be sure, yet a bone-shaking blow. The U.S. military had been pottering with rocketry for years, playing out clumsy failures on TV, and all that time the Russians had been secretly cooking up Sputnik.

President Eisenhower went on the air to pooh-pooh Sputnik as a trivial little stunt, whereupon the Russians forthwith lofted a half-ton satellite with a live dog in it! The giddy American media dubbed this one Muttnik, making sheepish fun of the communist space triumph, while European experts snidely opined that the United States could never catch up to the Soviet Union. The President's assumed calm soothed nobody. Congress appropriated a frenzied billion dollars* to improve the country's scientific education (not specifying how), and still more funds for a new agency, the National Aeronautics and Space Administration—our old friend NASA, that is—to get America the hell up to the moon first.

But a stern chase is a long chase, Navy byword. The humiliation of the United States went on for years. American space efforts publicly fizzled, the frequent Soviet fizzles (as we now know) went unannounced and undetected, and when John Kennedy succeeded Eisenhower the country was still nowhere in the undeclared race. In the spring of 1961 a Russian cosmonaut, Yuri Gagarin, rocketed into orbit clear around the earth in 108 minutes, the first human being in space, an instant world hero A few days later America's first astronaut, Alan Shepard, also shot up into space, and his tiny Mercu capsule plopped down in the Atlantic on schedule, fifteen minutes after it went up.

That probably did it. John Kennedy summoned a special joint session of Congress, to deliver a grave nine-point address on the state of the nation and of the whole world. I heard that speech. Only i point nine did the young president touch on space. Then, with all his casual charm and in that beguiling Boston accent, he remarked, "I believe we should go to the moon," and he proposed fundin a gigantic crash program to send a man there and bring him back within ten years, by mobilizing American science and industry on the scale of the Manhattan Project, this time in full world view. Congress readily complied. The Apollo program sprang into existence. Eight years later, an America stepped out on the moon. No Russian yet has. In short, we won.

But there was more to the success than that. In Apollo 11 a showy actor, half hero and half clown, the primate science calls *Homo sapiens*, made a spectacular debut on Richard Feynman's Big Stage with a leap between two celestial bodies and a great opening line: an instance of what Americans can do when aroused.

Der Fuehrer's Folly

Yet it is pretty well forgotten that both moon programs were in fact spearheaded neither by an American nor a Russian, but by two Germans.

Back in 1945, the Red Army rolling toward Berlin scooped up Hitler's V-2 rocket scientists, engineers, and technicians, some five thousand in all. A project chief, Wernher von Braun, contrived to slip off with some of his key staff to the American side, but his obscure co-chief, one Helmut

Groettrup, was less agile. In virtual Soviet captivity, Groettrup designed engines that powered Sputnik, Muttnik, and in part the moon rockets, while Stalin was retrieving Russian scientists from th gulags where they were rotting away. Once they took over they made a brilliant, heartbreaking effort that might well have won, but blockhead Marxist bureaucrats hampered them and frittered away the long Soviet lead, while Wernher von Braun, riding a surge of all-out American technology in a blaze of publicity, booted home the victor. Incidentally, since von Braun was so useful to our side, the man deaths of slave laborers in his underground rocket factories were soft-pedalled; as when Hitler attacked Russia and forced the Red Army to fight on the Allied side, Franklin Roosevelt soft-pedalled Stalin's mass slaughters, and flooded lend-lease munitions to him. Way of the world.

Big science demands political muscle as well as huge expenditures, and Adolf Hitler had lavished both on his V-2 rockets, a momentously stupid decision. Nazi Germany had started the war with a wide lead not only in rocketry but in nuclear physics. German physicists had achieved fission in 1938 well before anyone else, and even under the Nazis, German science and industry remained formidabl What motivated the Manhattan Project was exactly the fear that the Germans were well along in building an atomic bomb for Hitler. Had he in fact backed the right terror weapon, who can say how history might have gone? Providentially for mankind, Der Fuehrer was not only—in Churchill's picturesque rhetoric—a bloodthirsty maniac, he was a pigheaded maniac. He never saw anything in the German uranium effort, which after the war was discovered to be pathetically puny, and he bet th farm on his darling V-2s, which eventually set random fires in London and killed a lot of civilians. It is a haunting enigma of twentieth-century history that an advanced Western nation adored this grisly madman and obeyed his orders to his last hour, when he shot himself in a Berlin bunker under Red Army artillery bombardment. The victors seized on the dead monster's rocket weapon and improved to run the big race, won by the American team I watched soaring off into space from Florida.

There were six more Apollo missions. Only Apollo 13 attracted any comparable attention, when part of the spacecraft blew up fifty thousand miles from the moon. For a while the astronauts seemed doomed, and that made for a television cliff-hanger; but the crew were rocket engineers as well as space explorers, so they got themselves home, and the happy ending inspired a hit movie. After Apol 17, with more astronaut teams trained and raring to fly and more Saturn Vs ready to go, the mighty project abruptly shut down, out of money and—as the media slang has it—legs.

So the curtain dropped on Act One of the cosmic drama about the creatures that struggle for good and evil: *Homo sapiens, Outward Bound.*

Entr'acte: Armstrong

Sometime after Apollo 11 I happened to catch Neil Armstrong on TV, doing a Chrysler commercial i civvies. Well!! *Homo sapiens*, peak of evolution, American icon, star of the cosmic drama, in the toil of Madison Avenue! I decided that Armstrong did not have to do this, he should write a book instead a sure blockbuster, and I would help him any way I could. Novelists have their nutty side, so next day I actually phoned my *National Geographic* friend, who knew Armstrong well, and asked for a meetin of the three of us.

Encountered on Earth over lunch at the *Geographic*, Armstrong was pleasant, reserved, willing to listen. A Navy man, he may have read *The Caine Mutiny* and wondered what the author wanted of hi In the flesh this handsome rather pale man was still an astral presence, at least to me. Those remote keen eyes, I felt, had looked upon the face of the Lord. But there I was, so I made my lame pitch: a book by the first American to set foot on the moon should be read by youth yet unborn, it would be a

great inspiration, etc., etc., etc. Armstrong heard me out and shrugged off the notion. Apollo was a team endeavor first to last, he said, the engineering achievements were the main thing, and they were on record. As for the rest, the story of the astronauts was well-known, and his personal experiences d not matter. End of my effort to tell a figure of history how to run his life.

In retrospect I can't really regret my brash folly, for I did get to lunch with the actor who played *Homo sapiens* in his cosmic debut. Offstage, as it were, Armstrong was a calm professional with no public relations flair and a striking absence of superstar ego. Masked behind that quiet persona, all th same, were the resolve, tenacity, and moral force of the ace among American aces elected to step firs on the moon. Masked too were the level head and lightning judgment of a pilot who, a quarter millio miles from Earth, with ninety seconds of fuel left, bypassed the designated landing site and glided over the moon looking for a better place to touch down.

Act Two?

So, outer space breached! The conquest of a new frontier brilliantly begun! Moon voyage dream of stargazers, poets, storytellers down the ages come true! Cold chaste goddess of the night ravished by an outward-bound primate, and fled for all time weeping to the dark side of the moon! Whither now, *Homo sapiens?* What does NASA do for an encore in space pioneering?

Answer, plenty! A huge new agency now existed with a fat budget to match. Not since Galileo and the Medicis had such a window of political heft and hard cash opened on new science. Heady days fo astronomers, astrophysicists, and space engineers! Next stop for our space frontiersmen? Mars, of course, well within reach of Apollo's rocket technology. Problems, to be sure: How would the astronauts—for all their right stuff, human like the rest of us—endure two years or more of cosmic radiation in zero gravity? Would their bones soften, could their DNA unravel? Needed thought. Prudent first step: Build a space station to orbit the earth, and a cheap reusable spacecraft to shuttle astronauts there and back. Observe the effects of prolonged weightlessness and cosmic radiation on them as they do experiments in space science, floating for months in near-zero gravity. Then and onl then, on to Mars.

As for unmanned projects, exciting ideas abounded on the drawing boards; robot probes of all the planets, with cameras to send back blockbuster photographs for the world to marvel at, and advanced instruments to learn up close what was really there. The crown jewel of the unmanned program, the "Large Space Telescope," would orbit outside the blurry air we breathe, to give us our first clear look at the stars mankind would one day be exploring. When Apollo 11 planted a simulated Stars and Stripes on the moon, together with a plaque signed by the astronauts and President Nixon—*Here men from the planet Earth first set foot upon the moon July 1969, A. D. We came in peace for all mankind*—these projects were well along, and NASA was riding high.

No sooner had the last moonwalkers landed back home, than President Nixon axed the Large Spac Telescope: too expensive. The organized anguished howl of astronomers and astrophysicists could be shrugged off, but a letter-writing blizzard from a sizeable public devoted to television's *Star Trek* wa serious business. The telescope was okayed, otherwise NASA had bumped to earth with its moonwalkers. Race won, crash budget finished, start of the agency's annual sweat for appropriations. Down the years since, the robot probes of the solar system have been paying their way by wowing the world—and more importantly, Congress—with gorgeous close-ups of giant Jupiter, its Red Spot and its moons, Saturn and its ever-fascinating rings, and so on, while delivering significant new planetary science. Moreover, NASA's visionary Origins program—*Where have we come from? Are we alone?*–

has found earthlike planets circling the distant stars, and another program has landed two six-wheele crawlers on Mars that have explored and televised red rocky panoramas much like our Death Valley and Grand Canyon, reporting traces of water and even elusive hints of conditions possibly suitable fo life.

Yet manned spaceflight, the primary mission for which Congress created NASA, has languished. 2005 a seasoned space engineer, Michael Griffin, startled his first press conference as NASA's new administrator by announcing, "NASA lost its way in the 1970s, and took the wrong path. We have to get back to the right way." To the agency chiefs he spoke gruff words: "The American public will support only a NASA that goes somewhere and does something"; free translation, "We head for Mars pronto, troops, or we're dead." Griffin had coauthored a study by eight space scientists, "Extending Human Presence into the Solar System," and President Bush (the younger) had used its findings to issue a new Space Exploration Initiative, at which NASA's scientists quaked, for the study phased ou shuttle and space station to go for Mars via the moon, *while staying within the agency's current budget*. To fund the costly two-phase leap to Mars, other programs would have to be curtailed, stretched out, postponed, or dropped. In effect, the drama *Homo sapiens, Outward Bound* was closing out of town for drastic revision of Act Two.

Griffin's "Wrong Path": A Reminiscence

What was this wrong path? In short, the very first step: a space station and a cheap reusable spacecraft.

Way back in April 1981, as I well remember, an enormous TV audience of taxpayers like me awaited the launch of the first new American spacecraft since Apollo. On the Cape Canaveral launchpad, a bizarre monster wisped prelaunch vapor, about half as tall as Apollo's Saturn V rocket, clearly both a rocket and an airplane, the SHUTTLE; a thing sui generis, "the most complex machine ever built," so the agency publicists proudly put it. Called *Columbia*, it flamed and roared off into a two-day test flight; and the TV audience was almost as big when it returned, for it had to plunge at orbit speed from outer space into the incendiary friction of Earth's atmosphere. What protection did the strange hybrid have, its rocket elements discarded, only the plane doing the reentry? Walter Cronkite assured us that heat-resistant tiles lining its nose and wings would suffice, but when the pilot's chatter from *Columbia* abruptly ceased, Cronkite too stopped talking, no doubt holding his breath like the rest of us. As *Columbia*'s chatter resumed and our hearts beat again, an aircraft of a peculiar configuration came in sight; and to the televised rejoicing of everyone in Mission Control, and the cheers of the emergency crews waiting with firefighting gear, it glided to earth and released a drogue parachute for a flawless landing.

Two more shuttles, *Discovery* and *Challenger*, came on line. The missions, each about two weeks long, got to be routine. The launches and reentries dropped out of the news. Live TV pictures of shirtsleeved astronauts floating in the roomy shuttle, eating or experimenting or talking to Earth, wer brief novelties, and their pioneering spacewalks, suited up and tethered to the spacecraft, at first got wide coverage. However, their invariable success soon made for yawns, though each mission was exactly as perilous as the first one. NASA's manned spaceflight program had been out of whack from the start, when President Nixon approved only *half* the project: a shuttle, yes; a space station, no, not yet. Even for the "cheap reusable spacecraft," the appropriation was so meager that it had to be eked out with Air Force funding. The Air Force was mighty interested, of course, in the military aspects of space, but wanted value for its money.

The upshot was a custom-built space machine with a dual mission. Air Force purposes tended to b classified or blacked out in top secrecy. NASA's science goals required media visibility and public support. The shuttle metamorphosed into an engineering marvel at a far stretch of human ingenuity and American technology; perhaps indeed the most complex machine ever built, its design a web of innovation and compromise. Unlike other aircraft, for instance, the shuttle could not use reverse thru of engines on landing; super-powerful brakes had to bring it to a stop, hence a drogue parachute to assist.

In 1984 President Reagan drew renewed attention to the program by announcing a Teacher in Spa Project. NASA would train a schoolteacher as an astronaut, to stimulate interest of the young in spac by giving lessons from an orbiting shuttle. Eleven thousand teachers volunteered. Christa McAuliffe, an attractive mother of two from New Hampshire, was chosen, and her first mission provided fresh grist about the space mission for television and press. On the day of the launch I was in the synagogu at morning minyan, when a latecomer reported a rumor that the shuttle had exploded! I raced home i disbelief, turned on the TV, and with a sick heart watched the catastrophe played out over and over: *Challenger* rising in a perfect liftoff on a column of fire, soaring away into a clear blue sky, then a ba of yellow flame bursting in air, and a crooked trail of white smoke following the spacecraft debris down to the sea.

The country was in shock. Reagan appointed a Presidential Commission to probe the disaster. Former Secretary of State William Rogers was chairman, Neil Armstrong was his deputy, and among its members was Richard Feynman.

Feynman's Cold Water[*]

A theoretical physicist, a chalk-and-blackboard man, Feynman knew nothing of space engineering. H reluctantly responded to the call, cancelled his commitments for months ahead, and spent a long day at Caltech's Jet Propulsion Laboratory, sponging up shuttle technology from the engineers. Next day in Washington, at an informal get-together of the commission's members in Rogers' office, he took a shine to one General Kutyna, resplendent in Air Force uniform. The uniform didn't impress Feynman —after all, his father had dealt in uniforms—but when the meeting ended, he heard the general ask someone where the nearest Metro station was, and that impressed him. A big-shot general who had n car and driver at his beck and call was his kind of guy. Next day at the board's first encounter with NASA leaders, under bright TV lights, Feynman was sitting next to the general. Before the meeting began Kutyna muttered, "Copilot to pilot. Comb your hair." Feynman responded, "Pilot to copilot, ca I borrow your comb?" The two men somehow hit it off from the start.

Otherwise this first meeting had depressed and discouraged Feynman. He had gained a good technical grasp of the *Challenger* problem at the Jet Propulsion Lab, and was eager to attack it in depth; but he had heard only bland generalities, and the news that next week the commission would g to Cape Canaveral for a briefing, i.e., a mere dog and pony show. Rogers vetoed Feynman's impulse fly instead to the Johnson Space Center in Houston to talk to the engineers—"not an orderly procedure"—so Feynman asked at least to visit NASA's engineers right there in Washington. At another veto, the bumptious Nobel laureate raised a row, the chairman gave in, and next day Feynma crossed the street from his hotel to NASA headquarters, where the engineers were friendly and free wi disclosures.

The essential misjudgment of the launch, he soon discerned, might have been ghastly in its simplicity. A cold snap had dropped the mercury at Cape Canaveral to the 20s that fatal January

morning, and the shuttle was not supposed to go up in weather colder than 53 degrees. Bad enough, b what was the exact flaw or failure that might have caused the explosion? They told him that the hybri had five rocket components, all suspect: the three gigantic main engines, and two solid-fuel booster rockets. The engines were fueled from a towering tank that was discarded en route to orbit. The booster rockets quickly burned out at launch and parachuted into the sea, to be recovered and disassembled for repair; and their joints on reassembly were sealed with so-called O-rings of rubber.

Feynman was scrawling notes on all this in his hotel room when General Kutyna telephoned. William Rogers had asked him to tell Dr. Feynman *not* to go to NASA, after all. Feynman shrugged that off, inwardly amused. Kutyna went on, "Say, I was working on the O-rings in my carburetor this morning, and I got to thinking about the shuttle. It took off when the weather was 28, 29 degrees. You're a professor. What, sir, would be the effect of cold on O-rings?"

"Oh, well, make them stiff, of course."

Kutyna said no more. He didn't have to. The theoretical physicist caught the hint. A skilled practical joker—at Los Alamos he had beguiled tedium by picking security locks and cracking safes- Feynman resolved to try an end run around Washington's stifling procedures. He obtained at NASA a small strip of O-ring rubber from a model of the shuttle, and tested it in a glass of ice water. Sure enough, at 32 degrees it stiffened like wood. At the next public meeting of the commission, where for the first time NASA's launch personnel were testifying about the disaster before a packed press corps and a massed battery of TV cameras, he saw to it that a glass of ice water was on the table beside his microphone. Into this glass he dropped the rubber strip.

When a launch manager started briefing the board, Feynman reached for his microphone button to quiz him. General Kutyna leaned over, muttered, "Pilot to copilot, not just yet," and pointed out the O rings page in their briefing book. As soon as the manager reached that page, Feynman shot questions at him about the temperature on the launch morning; and lifting the wet rubber from the ice water, he demonstrated how inflexible it was at 32 degrees. "I believe this has some significance for our problem," Feynman remarked. Secretary Rogers struck in at once, "That is something we will certainly consider at length in our session on the weather," and told the flummoxed manager to proceed to the next topic. Of course the media caught on. Feynman's coup de theatre was the big story on the evening news and in the next day's headlines; and the chalk-and-blackboard man became better known to the public overnight, than a lifetime of brilliant physics plus the Nobel Prize had made him.

Three months later, all the board signed off on a summary report with a set of unanimous conclusions and recommendations—all, that is, except Richard Feynman. The board member assigned by Rogers to collate their varied views, a physicist who worked in Washington, had used not a single word of Feynman's observations! Pressed to explain, he could only come up with shifty evasions that convinced Feynman his strong views were being shunted aside. He threatened to remove his name from the report, and a compromise was reached; his comments, heavily edited, would be attached as an appendix. His memoir ends with this appendix and a postscript called "Afterthoughts" in which he levels about his ice-water feat. An astronaut friend had told General Kutyna, he discloses, that the lack of resilience in the O-rings at low temperatures was known at NASA but wasn't being talked about. Kutyna wanted to bring to light this clue to the disaster, but without jeopardizing the astronaut. "His solution," Feynman wryly writes, "was to get the professor excited about it, and his plan worked perfectly."

Rattled off like the whole memoir in his brash style, the appendix is a penetrating analysis of NASA's problems at the interface of science and politics, a sort of defining document of Act Two. At no time does Feynman disparage the eternal human urge to explore, nor the American pioneering

spirit at the heart of NASA's mandate. On the contrary, he tells of being moved near tears by a film o the agency's wondrous accomplishments in space science and technology. When he went to Washington he had long been fighting cancer. A year later he was dead. Summoned in his waning day to do a patriotic service, Richard Feynman suspended his last work in physics, poked around to find out what had happened to *Challenger,* and told the truth in a drench of cold water.

Columbia *Disintegrates*

The Manhattan Project was spawned to beat the Germans to the atomic bomb, and NASA was spawne to beat the Soviets to the moon. These two juggernauts of American resolve commandeered vast holdings of land, erected enormous structures, raised battalions of high-powered personnel, and after they won their races, kept rolling down the years until they collided head-on in the Appropriations Bi of 1993 under President Clinton. Two big-ticket science items were bitterly debated in Congress: the atomic physicists' Superconducting Super Collider and NASA's Space Station. Many years earlier President Reagan in his laid-back way had given the green light to both, but this was Clinton's first year. He had made a campaign pledge to tighten the national budget, and one of the science behemoth had to go down. The super collider got the axe. America's lead in high-energy physics was lost to Europe.* The space station squeaked through by one vote; clearly, seven years after *Challenger*'s fall Congress remained chilly about man in space; and funding continued so lean that when actual construction of the space station began in 1998, Japan, Canada, and Russia were chipping in as partners.

Meantime, the shuttle was redeeming itself with successful mission after mission; outstandingly, lifted into orbit the Large Space Telescope, christened the *Hubble Telescope* to honor Edwin Hubble, hero of our next chapter, who first accurately measured Feynman's Big Stage. When the images from the half-billion-dollar instrument proved fuzzy because the mirror was out of focus, a media circus ensued; but once the shuttle astronauts did a long complex repair job, the images sprang forth sharp and brilliant, and the Hubble astounded the world with its powerful new reach far, far back into the depths of the early universe. NASA caught its breath, as it were, for a while, and the International Space Station was coming along well, when *Columbia,* the first of the shuttles and for two decades a steady workhorse, got into trouble.

Columbia's launch in January 2003 went awry. Debris broke off the insulation of the discardable fuel tank; nothing very new, but this was a pretty big chunk, and it hit a wing of the shuttle. A friend of mine was in the crew—Ilan Ram-on, the first Israeli astronaut—so I was following with concern the broadcast snatches of very calm talk between the crew and Mission Control, as the fifteen-day mission was carried out as planned. On reentry the damaged heat tiles failed, and through a hole in th wing's leading edge, atmosphere superheated by reentry speed entered the wing like a blowtorch, melting everything in its path. *Columbia* disintegrated, and in the loss of seven more lives the wrong path dead-ended. Two shuttles out of five had fallen. The three surviving machines were grounded fo total overhaul—not retired, since America was committed by then to sixteen other countries to complete a "core" of the station, and only the shuttle had the cargo space and the thrust to lift the heavy stuff. Construction halted, and the small Russian Soyuz "lifeboat" serviced caretaker astronaut on the inert platform for three long years.

It was shortly before the overhauled *Discovery* went up on a test mission that Michael Griffin became administrator; and once again, large chunks of insulation broke off the fuel tank and struck th shuttle! *Discovery* survived to deliver its freight to the space station and got back to Earth safe, so

NASA public relations announced a successful test. Griffin, a no-nonsense guy, grounded all three shuttles for another year. When *Discovery* went up once more, I saw him on TV, unshaven and resolute, telling a press conference that if the crew were endangered this time he'd abort the entire shuttle program. The spacecraft performed without incident, and the program was on again. Today (March 2009) the International Space Station is not only flourishing but expanding. A recent shuttle load included living quarters for two more astronauts, six in all. Griffin's goal to complete the "American core" by 2010 appears on track, after which NASA's remarkable if flawed hybrid spacecraft will pass into history.

L'Envoi: "Saturn by 1970!"

In the forty years since his dazzling Apollo debut, *Homo sapiens*, cosmic explorer, has gone nowhere just circled Earth a few miles overhead, round and round and round. The study that Michael Griffin coauthored—and that President George W. Bush leaned on to keep NASA alive—opens with a sober discussion of funding requirements, and concludes with two linked hardheaded facts about the human reach beyond the moon:

1. MARS IS THE END OF THE LINE. The numbers are all but unanswerable. A manned round-trip missio to Mars has to take about three years. Jupiter, the next planet outward, is roughly *ten times* as far, so a mission to a Jupiter moon would involve some *thirty years*, more than an astronaut's working lifetime. Saturn is twenty times as far as Mars, and so on outward.

2. TRAVEL BEYOND MARS WILL REQUIRE NUCLEAR-PROPELLED SPACECRAFT, NOT FEASIBLE IN THE FORESEEABLE FUTURE. This seductive possibility—the million-to-one ratio of nuclear to chemical energy—has long been known to physicists. The chemical energy in five gallons of gasoline, say, will take an automobile a hundred miles or so along a freeway; the nuclear energy in those same five gallons would thrust a spacecraft *a hundred million miles, or all the way to Mars.* The Griffin study sums up, concerning this tantalizing fact of nature, that it may prove useful only at a far distant time, when international comity allows for cooperation not now thinkable.

Yet in 1958, the first year of the post-Sputnik frenzy, a proposal to build a nuclear-powered spaceship actually got some federal funding. Project Orion it was called, brainchild of the atomic gur Stanislaus Ulam, who coinvented the hydrogen bomb. Ulam testified before Congress that his big spaceship would cruise with ease around the solar system propelled by atomic minibombs, detonatin at intervals near a "pusher plate," which would absorb and soften the stupendous explosions so as not to jelly the astronauts. A model of Orion did fly—on chemical energy—and can be seen today at Washington's National Air and Space Museum. Several eminent physicists threw themselves into Orion heart and soul, their slogan, "*Saturn by 1970!*"* If the idea sounds loony to the reader, remember that after Sputnik the panic was on, and no notion seemed too wild to consider; also that in the airless black void between the planets there would be no noise, no flame, no fallout, just a very hard *push* every now and then to zip Orion along.**

Far out? Of course. When Hitler was rampaging toward Moscow, and World War II looked lost because the United States was staying out of it, Winston Churchill reassured his cabinet, "America is boiler!" Within the month Pearl Harbor lit off that boiler. Sixteen years later Sputnik lit it off again. Since then the boiler seems to have gone stone cold. Still, when all is said and done, Americans have walked on the moon, while other nations have given up trying or are in the first dogged stages of attempting it. The Hubble Telescope, rescued by an American public devoted to dreams of exploring the stars, has revolutionized astrophysics and shaken up philosophy and religion. Apollo and the

Hubble were the achievements of a bumbling, stumbling, brave Washington bureaucracy, the National Aeronautics and Space Administration.

Churchill said one thing more: "You can count on the Americans to do the right thing, after they have tried everything else."

Note: Freeman Dyson faulted this chapter, in vetting the manuscript, as mistaken on man in space and meager on the Russian space program. Dyson sees in beamed energy propulsion powerful microwaves driving lightweight vehicles along "laser highways," a sober future for travel to Mars and beyond. The concept is in fact under international study and experiment today. As to the Russians, in truth they were years ahead of NASA with a space station, *Mir,* and a really "cheap, reusable spacecraft," *Soyuz*. Their cosmonauts throve on *Mir* and still hold the record for continuous months lived in space; and only *Soyuz* will be keeping the International Space Station alive for years while NASA phases out the shuttle and tools up for the moon and Mars. Other authorities disagree with Dyson on man in space; for instance, in Steven Weinberg's long scathing study "The Wrong Stuff," he puts down manned space programs as a profligate waste of scarce science funding (*New York Review of Books,* April 8 2004). My chapter is a distillation of all I could learn in the writing, as it bore on my main theme.

How Big the Stage?

The Stagehands

Now there is in fact an energy other than nuclear, with which our star-trekking primate has already traveled far beyond Mars. It is the electric charge racing through the billion-threaded nerves of his brain.

A chimpanzee will pull a banana into his cage with a stick, and if the stick isn't long enough, he can fit two sticks together to get it.* This interesting fact bears on Feynman's Big Stage, for *Homo sapiens* in much the same way—so the animal behaviorists might well insist—has fitted pieces of glass into a tube, pointed the tube at the sky, and with it pulled in the measure of the universe.** Certainly the naked-eye cosmos of the ancients—and of our uncorrected common sense—dissolved once Galileo pricked it with his tube improved from a Dutch invention; and once Newton devised his "catadioptrical" mirror, as his amazed peers termed it, giving undistorted clarity to the view through the tube, no theoretical boundary remained to the brain's reach into space.

These tools of Galileo and Newton—the senior stagehands, let's call them—were the merest by-products of their great work. The junior stagehands, George Ellery Hale and Henrietta Leavitt, gave their whole lives to the tube. In 1642, the year Galileo died, Newton was born, and Hale and Leavitt were both born in 1868; so two centuries separated the immortal seniors and the more or less unsung juniors. The history of astronomy is studded with resounding names, but by building principally on th work of these four—such is my perception, anyway—Edwin Hubble saw before anyone else the true size of Feynman's stage; not at all the naked-eye universe of our night skies, a fantastical vision, rather, of billions of galaxies each containing billions of stars, fleeing ever faster from each other in all directions. A distinguished physicist once gave me a book of his inscribed, *"To Herman Wouk, on of the few who does not write if he does not understand."* Not true here, alas. About astrophysics, I ar the man on the street. As a Columbia freshman I registered for an astronomy course, but upon leafing the textbook crawling with calculus, I dropped out fast. Astronomers, I guess, hear God talk all the time. In that language, I never will. Galileo and Newton need no further words of mine. Herewith, brief sketches of the juniors, starting with the spectacularly energetic George Ellery Hale.

Hale's father headed a major Chicago firm, Hale Elevators. His son chose stargazing over the family business, rose to distinction as a solar astronomer, declined the presidency of MIT to found an direct the Mount Wilson Observatory, coined the term *astrophysics,* and started and edited the *Astrophysical Journal*, still going strong today. With all that, building great telescopes was Hale's thing.* As Galileo worked the Medicis, so Hale worked the robber barons of the Gilded Age to build four giant tubes, each at first light the biggest on earth. Hale's first patron was Charles Yerkes, a flamboyant operator who built Chicago's streetcar system, with peculations that put him briefly behind bars. Such characters are resilient. Yerkes refurbished his image by funding Hale to erect a 40 inch refractor for the University of Chicago, "the biggest telescope in the world"—biggest by four inches.

A word about telescope dimensions. A lens *refracts* starlight, a mirror *reflects* it. The size of the primary lens or mirror dictates the size of the telescope, sometimes of the observatory. Beyond a 40-inch diameter, the weight and color distortions of a lens make a refractor telescope impractical. In theory a mirror is practical to any size, but hard to get right. Nowadays mirrors *thirty yards* across ar more are in the works, in segments controlled by computers. Edwin Hubble made his historic breakthroughs with the 60-inch and 100-inch reflectors on Mount Wilson, paid for mainly by Carneg and a minor mogul named Hooker. The George Ellery Hale Telescope on Mount Palomar, funded wholly by Rockefeller, has a 200-inch mirror, one of the largest ever made of a single slab of solid glass. That telescope is Hale's monument, and his due. He did not live to point it toward the stars.*

Henrietta Leavitt's Donkey Work

Dick Feynman's point about the making of the atomic bomb—that it was a rabbit shoot, not a lion hunt—applies foursquare to the lifework of the junior stagehands. George Hale bagged many and varied cosmic rabbits. Henrietta Leavitt brought down only one astral quarry, but it was a lion.

The human eye is an awesome contrivance—Charles Darwin himself said that thinking about it "made his blood run cold"—but it is not up to staring for hours at one star.* Astronomy today is in good part picture taking, optical, infrared, and x-ray, and the great discoveries are found in photographic plates and spectrograms. This turn to photography late in the nineteenth century pried open the doors of Harvard Observatory to Henrietta Leavitt, a Radcliffe-educated, stone-deaf spinste The observatory in those days was strictly men's turf, but the director, a Dr. Edward Pickering, starte using ladies to do the donkey work of inspecting the men's glass plates for dots, stains, streaks, and spectra, and Leavitt joined the drudging sisterhood as a volunteer.

After some years, noting her skill, Pickering promoted her to steady employment at thirty cents ar hour. She remained in that job for the rest of her life. In time he assigned to her the plates from Harvard's observatory in Peru, where the staff scanned the Southern Hemisphere skies, and in these she spotted the spoor of her lion. The meager references I've dug up about Henrietta Leavitt tend to encapsulate her find as "the period-luminosity relationship in Cepheid variables," which may not sound like much; but Michelangelo said proudly of his own work, "I have patience to get to the desired end," and Leavitt's genius was something like that, a capacity for years of anonymous eye-straining labor and analysis, to arrive at one pivotal scientific discovery.

Cepheid variables are stars that blink. No human eye can see the blink, for it is a slow blink, and not an on-and-off-blink either, just a dimming and brightening over days or weeks. The first such blinking star was discovered long ago near the North Star, in the small constellation Cepheus, hence the name. Cepheids abound in two hazy patches in the southern skies called the Magellanic Clouds, which are nearby "satellite galaxies" of the Milky Way.* Out of those southern plates, Henrietta Leavitt wrested a rigorous new truth of Nature: the slower the blink, the brighter the Cepheid. In astronomical numbers, all the Cepheids in the Magellanic Clouds were about the same distance away so brightness varied *directly* with the duration of the blink. Therefore, if the blink was very slow, yet the star was very faint, it had to be a huge, huge distance away. She determined this to be true on a predictable scale, hence, a "period-luminosity relationship."

She then calibrated her Cepheids relative to each other, so that once some gentleman at a telescop ascertained the absolute distance of one such blinking star, her entire scale would spring to life as a major new cosmic yardstick. A Dane, Ejnar Hertzsprung, was the first to do this, and word of Leavitt discovery rapidly spread in astronomic circles. A Swedish savant was planning to name her for a