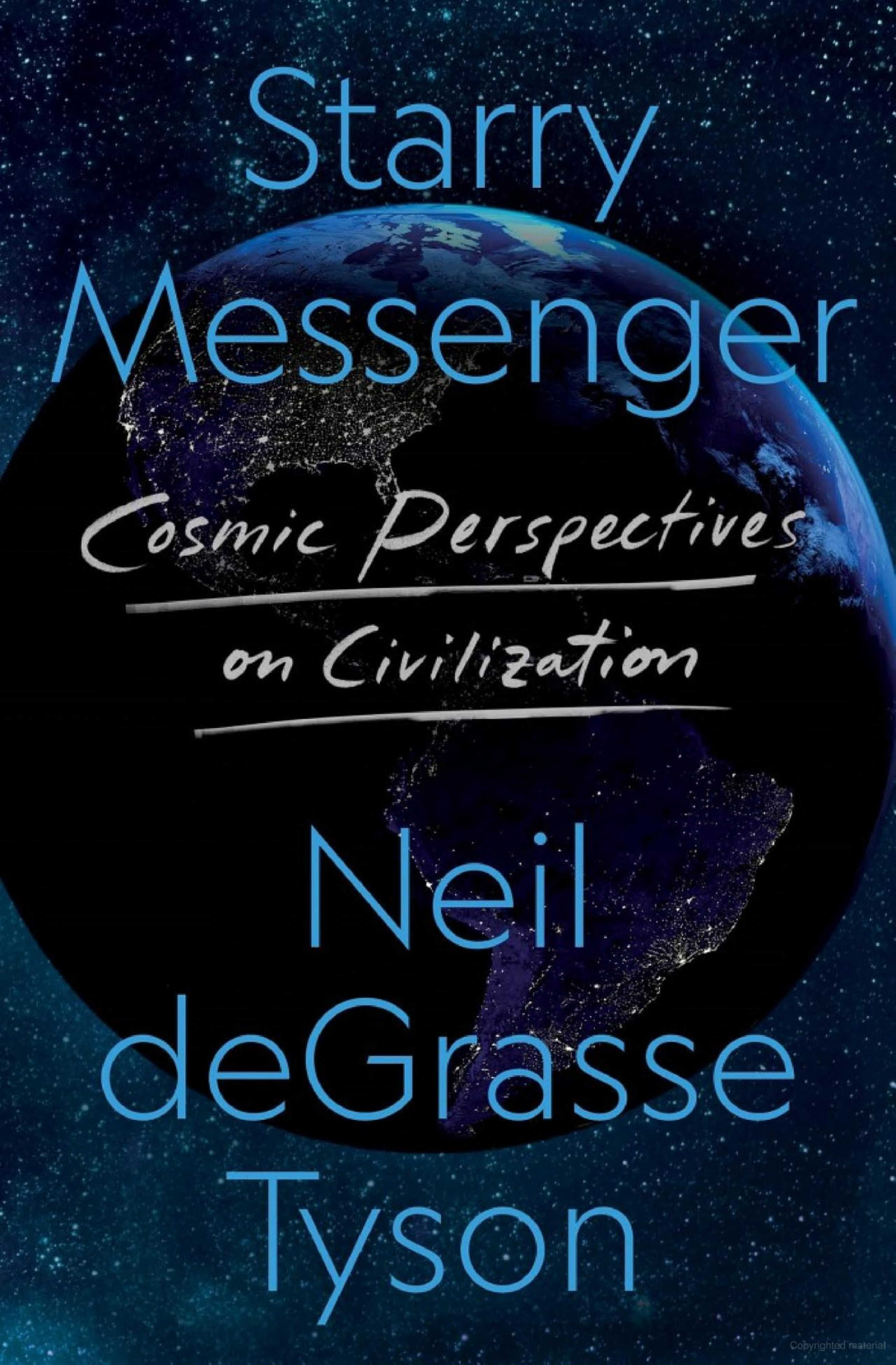

Starry Messenger

Cosmic Perspectives on Civilization

Neil deGrasse Tyson

Dedicated to the memory of Cyril DeGrasse Tyson[1]
and all others who want to see the world
as it could be, rather than as it is.

You develop an instant global consciousness, a people orientation, an intense dissatisfaction with the state of the world, and a compulsion to do something about it.

From out there on the Moon, international politics look so petty. You want to grab a politician by the scruff of the neck and drag him a quarter of a million miles out and say, "Look at that, you son of a bitch."

—Edgar D. Mitchell, *Apollo 14* astronaut

PREFACE

Starry Messenger is a wake-up call to civilization. People no longer know who or what to trust. We sow hatred of others fueled by what we think is true, or what we want to be true, without regard to what is true. Cultural and political factions battle for the souls of communities and of nations. We've lost all sight of what distinguishes facts from opinions. We're quick with acts of aggression and slow with acts of kindness.

When Galileo Galilei published *Sidereus Nuncius* in 1610, he brought to Earth cosmic truths that had been waiting since antiquity to descend upon human thought. Galileo's freshly perfected telescope revealed a universe unlike anything people presumed to be true. Unlike anything people wanted to be true. Unlike anything people dared say was true. *Sidereus Nuncius* contained his observations of the Sun, Moon, and stars, as well as the planets and the Milky Way. Two fast takeaways from his book: (1) human eyes alone are insufficient to reveal fundamental truths about the operations of nature, (2) Earth is not the center of all motion. It orbits the Sun as just one among the other known planets.

Sidereus Nuncius translates from the Latin to *Starry Messenger*.

These first-ever cosmic perspectives in our world were ego checks on our self-importance—messages from the stars forcing people to rethink our relationships to one another, to Earth, and to the cosmos. We otherwise risk believing the world revolves around us and our opinions. As an antidote, *Starry Messenger* offers ways to allocate our emotional and intellectual energies that reconcile with the biology, chemistry, and physics of the known universe. *Starry Messenger* recasts some of the most discussed and debated topics of our times—war, politics, religion, truth, beauty, gender, race, each an artificial battlefield on the landscape of life—and returns them to the reader in ways that foster accountability and wisdom in the service of civilization. I also intermittently explore how we might appear to space aliens who arrive on Earth with no preconceived notions of who or what we are—or how we should be. They serve as impartial observers of our mysterious ways, as they highlight inconsistencies, hypocrisies, and occasional idiocies in our lives.

Think of *Starry Messenger* as a trove of insights, informed by the universe and brought to you by the methods and tools of science.

OVERTURE

SCIENCE & SOCIETY

When people disagree in our complex world of politics, religion, and culture, the causes are simple, even if the resolutions are not. We all wield different portfolios of knowledge. We possess different values, different priorities, and different understandings of all that unfolds around us. We see the world differently from one another, and by doing so, we construct tribes based on who looks like us, who prays to the same gods as we do, and who shares our moral code. Given the longtime Paleolithic isolation within our species, perhaps we should not be surprised by what evolution has wrought. Groupthink, even when it defies rational analysis, may have conferred survival advantages to our ancestors.[1]

If we instead back away from all that divides us, you might find common, unifying perspectives on the world. If so, watch where you step. That new vista is neither north nor south nor east nor west of where you stand. In fact, the place exists nowhere on the compass rose. One must ascend from Earth's surface to get there—to see Earth, and everybody on it, in a way that leaves you immune to provincial interpretations of the world. We speak of this transformation as the "overview effect," commonly experienced by astronauts who have orbited Earth. Add to this the discoveries of modern astrophysics as well as the math, science, and technology that birthed space exploration, and yes, a cosmic perspective is literally above it all.

Nearly every thought, every opinion, and every outlook I formulate on world affairs has been touched—informed and enlightened—by knowledge of our place on Earth and of our place in the universe. Far from being a cold, feelingless enterprise, there is, perhaps, nothing more human than the methods, tools, and discoveries of science. They shape modern civilization. What is civilization, if not what humans have built for themselves as a means to transcend primal urges and as a landscape on which to live, work, and play.

What then of our collective and persistent disagreements? All I can promise is that whatever opinions you currently hold, an infusion of science and rational thinking can render them deeper and more informed than ever before. This path can also expose any unfounded perspectives or unjustified emotions you may carry.

One can't realistically expect people to argue in the same way scientists do among themselves. That's because scientists are not in search of each other's opinions. We're in search of each other's data. Even when arguing opinions, you may be surprised how potent a rational perspective can be. When illuminated by it, you fast discover that Earth supports not many tribes, but only one—the human tribe. That's when many disagreements soften, while others simply evaporate, leaving you with nothing to argue about in the first place.

Science distinguishes itself from all other branches of human pursuit by its power to probe and understand the behavior of nature on a level that allows us to predict with accuracy, if not control, the outcomes of events in the natural world. Scientific discovery often carries the power to broaden and deepen perspectives on all things. Science especially enhances our health, wealth, and security, which are greater today for more people on Earth than at any other time in human history.

The scientific method, which underpins these achievements, is often conveyed with formal terms that reference induction, deduction, hypothesis, and experiment. But it can be summarized in one sentence, which is all about objectivity:

Do whatever it takes to avoid fooling yourself into believing that something is true when it is false, or that something is false when it is true.

This approach to knowing enjoys taproots in the eleventh century, as expressed by the Arabic scholar Ibn al-Haytham (AD 965–1040), also known as Alhazen. In particular, he cautioned the scientist against bias: "He should also suspect himself as he performs his critical examination of it, so that he may avoid falling into either prejudice or leniency."[2] Centuries later, during the European Renaissance, Leonardo da Vinci would be in full agreement: "The greatest deception men suffer is from their own opinion."[3] By the seventeenth century, shortly after the near-simultaneous inventions of both the microscope and the telescope, the scientific method would fully bloom, propelled by the work of astronomer Galileo and philosopher Sir Francis Bacon (Lord Verulam). In short, conduct experiments to test your hypothesis and allocate your confidence in proportion to the strength of your evidence.

Since then, we would further learn not to claim knowledge of a newly discovered truth until a majority of researchers obtain results consistent with one another. This code of conduct carries remarkable consequences. There's no law against publishing wrong or biased results. But the cost to you for doing so is high. If your research is checked by colleagues, and nobody can duplicate your findings, the integrity of your future research will be held suspect. If you commit outright fraud—if you knowingly fake data—and subsequent researchers on the subject uncover this, the revelation will end your career.

This internal, self-regulating system within science may be unique among professions, and it does not require the public or the press or politicians to make it work. Watching the machinery operate may nonetheless fascinate you. Just observe the flow of research papers that grace the pages of peer-reviewed scientific journals. This breeding ground of discovery is also, on occasion, a battlefield of scientific controversy. But if you handpick pre-consensus scientific research to serve cultural, economic, religious, or political objectives, you undermine the foundations of an informed democracy.

Not only that, conformity in science is anathema to progress. The persistent accusations that we take comfort in agreeing with one another come from those who have never attended scientific conferences. Think of such gatherings as "open season" on anybody's ideas being presented, no matter their seniority. That's good for the field. The successful ideas survive scrutiny. The bad ideas get discarded. Conformity is also laughable to scientists attempting to advance their careers. The best way to get famous in your own lifetime is to pose an idea that counters prevailing research and that earns a consistency of observations and experiment. Healthy disagreement is a natural state on the bleeding edge of discovery.

★ ★ ★

In 1660, a mere eighteen years after Galileo's death, the Royal Society of London was founded, and is still going strong as the world's oldest independent scientific academy. Newly advanced scientific ideas have been contested there ever since, inspired by its marvelously blunt motto, "Take nobody's word for it." In 1743, Benjamin Franklin founded the American Philosophical Society to promote "useful knowledge." They continue today in precisely that capacity, with members representing all fields of academic pursuit in both the sciences and humanities. And in 1863, a year when he clearly had more pressing matters at hand, Abraham Lincoln—the first Republican US president—signed into existence the National Academy of Sciences (NAS), based on an act of Congress. This august body would provide independent advice to the nation, founded in living memory, on matters relating to science and technology.

Into the twentieth century, a proliferation of agencies with scientific missions serves a similar purpose. In the US, these include the National Academy of Engineering (NAE); the National Academy of Medicine (NAM); the National Science Foundation (NSF); and the National Institutes of Health (NIH). It also includes the National Aeronautics and Space Administration (NASA), which explores space and aeronautics; the National Institute of Standards and Technology (NIST), which explores the foundations of scientific measurement, on which all other measurements are based; the Department of Energy (DOE), which explores energy in all usable and useful forms; and the National Oceanic and Atmospheric Administration (NOAA), which explores Earth's weather and climate, and how they may impact commerce.

These centers of research, as well as other trusted sources of published science, can empower politicians in ways that lead to enlightened and informed governance. This won't happen until the people who vote, and the people they vote for, come to understand how and why science works. Scientific achievement among a nation's institutions of research constitutes the seedbed of that nation's future and is nourished by the breadth and depth of support the agencies may receive from the administrative bodies that govern them.

After thinking deeply about how a scientist views the world, about what Earth looks like from space, and about the magnitude of cosmic age and of infinite space, all terrestrial thoughts change. Your brain recalibrates life's priorities and reassesses the actions one might take in response. No outlook on culture, society, or civilization remains untouched. In that state of mind, the world looks different. You are transported.

You experience life through the lens of a cosmic perspective.

ONE

TRUTH & BEAUTY

Aesthetics in life and in the cosmos

Since antiquity, the subjects of truth and beauty have occupied the thoughts of our deepest thinkers—especially the minds of philosophers and theologians and the occasional poet such as John Keats, who observes within his 1819 poem "Ode on a Grecian Urn":[1]

Beauty is truth, truth beauty,—that is all

What might these subjects look like to visiting aliens who have crossed the Galaxy to visit us? They will have none of our biases. None of our preferences. None of our preconceived notions. They would offer a fresh look at what we value as humans. They might even notice that the very concept of truth on Earth is fraught with conflicting ideologies, in desperate need of scientific objectivity.

Endowed by methods and tools of inquiry refined over the centuries, scientists may be the exclusive discoverers of what is objectively true in the universe. Objective truths apply to all people, places, and things, as well as all animals, vegetables, and minerals. Some of these truths apply across all of space and time. They are true even when you don't believe in them.

Objective truths don't come from any seated authority, nor from any single research paper. The press, in an attempt to break a story, may mislead the public's awareness of how science works by headlining a just-published scientific paper as the truth, perhaps also touting the academic pedigrees of the authors. When drawn from the frontier of thought, the truth still churns. Research can wander until experiments converge in one direction or another—or in no direction, a warning flag of no phenomenon at all. These crucial checks and balances commonly take years, which hardly ever counts as "breaking news."

Objective truths, established by repeated experiments that give consistent results, are not later found to be false. No need to revisit the question of whether Earth is round; whether the Sun is hot; whether humans and chimps share more than 98 percent identical DNA; or whether the air we breathe is 78 percent nitrogen. The era of "modern physics," born with the quantum revolution of the early twentieth century and the relativity revolution of around the same time, did not discard Newton's laws of motion and gravity. Instead, it described deeper realities of nature, made visible by ever-greater methods and tools of inquiry. Like a matryoshka nesting doll, modern physics enclosed classical physics within these larger truths. The only times science cannot assure objective truths is on the pre-consensus frontier of research. The only era in which science could not assure objective truths was before the seventeenth century, back when our senses—inadequate and biased—were the only tools at our disposal to inform us of the natural world. Objective truths exist independent of that five-sense perception of reality. With proper tools, they can be verified by anybody, at any time, and at any place.

Objective truths of science are not founded in belief systems. They are not established by the authority of leaders or the power of persuasion. Nor are they learned from repetition or gleaned from magical thinking. To deny objective truths is to be scientifically illiterate, not to be ideologically principled.

After all that, you'd think only one definition for truth should exist in this world, but no. At least two other kinds prevail that drive some of the most beautiful and the most violent expressions of human conduct. Personal truths have the power to command your mind, body, and soul, but are not evidence-based. Personal truths are what you're sure is true, even if you can't—especially if you can't—prove it. Some of these ideas derive from what you want to be true. Others take shape from charismatic leaders or sacred doctrines, either ancient or contemporary. For some, especially in monotheistic traditions, God and Truth are synonymous. The Christian Bible says so:[2]

Jesus saith unto him, I am the way, the truth, and the life: no man cometh unto the Father, but by me.

Personal truths are what you may hold dear but have no real way of convincing others who disagree, except by heated argument, coercion, or force. These are the foundations of most people's opinions and are normally harmless when kept to yourself or argued over a beer. Is Jesus your savior? Did Muhammad serve as God's last prophet on Earth? Should the government support poor people? Are current immigration laws too tight or too loose? Is Beyoncé your Queen? In the *Star Trek* universe, which captain are you? Kirk or Picard—or Janeway?

Differences in opinion enrich the diversity of a nation, and ought to be cherished and respected in any free society, provided everyone remains free to disagree with one another and, most importantly, everyone remains open to rational arguments that could change your mind. Sadly, the conduct of many in social media has devolved to the opposite of this. Their recipe: find an opinion they disagree with and unleash waves of anger and outrage because your views do not agree with theirs. Social, political, or legislative attempts to require that everybody agree with your personal truths are ultimately dictatorships.

Among wine aficionados, there's the Latin expression, "In vino veritas," which translates to "In wine there is truth." Audacious for a beverage that contains 12 to 14 percent ethanol, a molecule that disrupts brain function and (irrelevantly) happens to be common in interstellar space. The epigram nonetheless implies that a group of people drinking wine will find themselves, unprompted, being calmly truthful with one another. Maybe that happens at some level with other alcoholic beverages. Even so, vanishingly few of us have ever seen a bar fight break out between two people drinking wine. Gin, maybe. Whisky, definitely. Chardonnay, no. Imagine the absurdity of such a line in a movie script: "I'm going to kick your ass, but only after I'm done sipping my Merlot!" The same incredulous claim can probably be said of marijuana. Smoking dens don't tend to be the places where fights break out. Supportive evidence, if cinematically anecdotal, that honest truth can breed understanding and reconciliation. Maybe that's because honesty is better than dishonesty, and truths are more beautiful than untruths.

Far beyond wine truths, and close cousins of personal truths, are political truths. These thoughts and ideas already resonate with your feelings but become unassailable truths from incessant repetition by forces of media that would have you believe them—a fundamental feature of propaganda. Such belief systems almost always insinuate or explicitly declare that who you are, or what you do, or how you do it, is superior to those you want to subjugate or conquer. It's no secret that people will give their lives, or take the lives of others, in support of what they believe. Often the less actual evidence that exists in support of an ideology, the more likely a person is willing to die for the cause. Aryan Germans of the 1930s weren't born thinking they were the master race to all other people in the world. They had to be indoctrinated. And they were. By an efficient, lubricated political machine. By 1939 and the start of World War II, millions were ready to die for it—and did.

* * *

The aesthetics of what is beautiful and desired in culture typically shifts from season to season, year to year, and from generation to generation, especially regarding fashion, art, architecture, and the human body. Based on the size of the cosmetics industry and the larger beauty industrial complex, visiting space aliens would surely think that we think we are ugly beyond repair, in persistent need of "improvements." We've designed household tools to straighten curly hair and to curl straight hair. We invented methods to replace missing hair and to remove unwanted hair. We use chemical dyes to darken light hair and to lighten dark hair. We don't tolerate acne or skin blemishes of any kind. We wear shoes that make us taller and perfumes that make us smell better. We use makeup to accentuate the good and suppress the bad elements of our appearance. In the end, there's not much real about our appearance. The beauty we've created is not even skin-deep. It washes off in the shower.

That which is objectively true or honestly authentic—especially on Earth or in the heavens—tends to possess a beauty of its own that transcends time, place, and culture. Sunsets remain mesmerizing, even though you get one every day. Beautiful as they are, we also know all about the thermonuclear energy sources in the Sun's core. We know about the tortuous journey of its photons as they climb out of the Sun. We know of their swift journey across space, until they refract through Earth's atmosphere, en route to my eye's retina. The brain then processes and "sees" the image of a sunset. These added facts—these scientific truths—have the power to deepen whatever meaning we may otherwise ascribe to nature's beauty.

Hardly any of us have ever grown tired of waterfalls or the full Moon ascending over a mountainous or urban horizon. We persistently fall speechless at the singular spectacle that is a total solar eclipse. Who can turn away from the crescent Moon and Venus, together, suspended in the twilight skies? Islam couldn't. That juxtaposition of a "star" with the crescent Moon remains a sacred symbol of the faith. Vincent van Gogh couldn't turn away either. On June 21, 1889,[3] he captured it from the pre-dawn skies in Saint-Rémy, France, creating what is perhaps his best-known painting, *The Starry Night*. And we never seem to get enough landscape panoramas from planetary rovers or cosmic imagery delivered courtesy of the Hubble Space Telescope and other portals to the cosmos. The truths of nature are rampant with beauty and wonder, out to the largest of measures of space and time.

It's therefore no surprise that the God or gods we worship tend to occupy high places, if not the sky itself. Or we perceive high places as closer to God—from mountaintops to puffy clouds to the heavens. Noah's ark settled atop Mount Ararat, not on the edge of a lake or river. Moses didn't receive the Ten Commandments in a valley or on the plains. They came to him atop Mount Sinai. Mount Zion and the Mount of Olives are holy places in the Middle East, as is the Mount of Beatitudes, the likely location of Jesus's famous Sermon on the Mount.[4] Mount Olympus was a high place above the clouds, crowded with Greek gods. Not only that, altars tend to be built in high, not low, places, with Aztec human sacrifices, for example, typically held atop Mesoamerican pyramids.[5]

How often have we seen posters, or even fine art, depicting cherubs, angels, saints, or a bearded God himself floating on a cumulonimbus cloud—the greatest of them all. Cloud taxonomy fascinated the Scottish meteorologist Ralph Abercromby, and in 1896 he documented as many as he could around the world, creating a numerical sequence for them. You guessed it. Cumulonimbus clouds landed at number 9, unwittingly seeding the everlasting concept of being on "cloud nine" when in a blissful state.[6] Combine cloud nine with beams of sunlight reaching every corner of an image, and you can't help but think of divine beauty.

Animist religions, common to indigenous peoples around the world from Alaska to Australia, instead tend to assert that nature itself—the brook, the trees, the wind, the rain, and the mountains—is imbued with a kind of spirit energy. If ancient peoples had had access to the cosmic imagery of today, their deities might have enjoyed even more places of beauty to hang out in while looking over Earth. One nebula (PSR B1509–58), imaged by NASA's orbiting Nuclear Spectroscopic Telescope Array (NuSTAR) in x-ray light, resembles a huge glowing hand in space with a clearly visible wrist, palm, outstretched thumb, and fingers. Even though the nebula is the glowing remains of a dead, exploded star, that didn't stop people from dubbing it "The Hand of God."

Alongside their catalog IDs,[7] we typically name astrophysical nebulae for what they resemble, using all kinds of fun earthly references, including the Cat's Eye Nebula (NGC 6543), the Crab Nebula (NGC 1952), the Dumbbell Nebula (NGC 6853), the Eagle Nebula (NGC 6611), the Helix Nebula (NGC 7293), the Horsehead Nebula (IC 434), the Lagoon Nebula (NGC 6523), the Lemon Slice Nebula (IC 3568), the North American Nebula (NGC 7000), the Owl Nebula (NGC 3587), the Ring Nebula (NGC 6720), and the Tarantula Nebula (NGC 2070). Yes, they all actually look like or strongly evoke what we've called them. One more: the Pacman Nebula (NGC 281), named for the hungry 1980s video game character.

Splendor doesn't end there. In our own Solar System, we've got comets and planets and asteroids and moons, each revealing a stunning uniqueness of shape and form. For many of these objects, we've amassed intimate, objectively true knowledge of what they're made of, where they've come from, and where they're going. All while they rotate and move along their appointed paths through the vacuum of space, like pirouetting dancers in a cosmic ballet, choreographed by the forces of gravity.

★ ★ ★

In the White House of the 1990s, Bill Clinton kept on his Oval Office coffee table, between the two facing couches, a sample Moon rock brought back to Earth from a quarter-million miles away by Apollo astronauts. He told me that any time an argument was about to break out between geopolitical adversaries or recalcitrant members of Congress, he would point to the rock and remind people it came from the Moon.[8] This gesture often recalibrated the conversation, serving as a reminder that cosmic perspectives can force you to take pause and reflect on the meaning of life, and on the value of peace that sustains it.

A form of beauty unto itself.

But nature does not limit its beauty to things. Objectively true ideas can carry a beauty all their own. Allow me to choose some favorite examples:

One of the simplest equations in all of science is also the most profound: Einstein's equivalence of energy (E) and mass (m): $E = mc^2$. The small c stands for the speed of light—a constant that shows up in countless places as we unravel the cosmic codes that run the universe. Among a zillion other places that it shows up, this little equation underpins how all stars in the universe have generated energy since the beginning of time.

Equally simple, and no less profound, is Isaac Newton's second law of motion, which prescribes precisely how fast an object will accelerate (a) when you apply a force (F) to it: $F = ma$. The m stands for the mass of the object being pushed. This little equation, and Einstein's later extension of it from his Theory of Relativity, underpins all motion there ever was or will be for all objects in the universe.

Physics can be beautiful.

You've probably heard of pi—a number between 3 and 4 that harbors infinite decimal places, although often truncated to 3.14. Here's pi with enough digits to see all ten numerals 0 through 9:

3.14159265358979323846264338327950 ...

You get pi simply by dividing the circumference of a circle by its diameter. That same ratio prevails no matter the size of the circle. The very existence of pi is a profound truth of Euclidean geometry, celebrated each year by all card-carrying geeks of the world on March 14—a date that can be written as 3.14.

Math can be beautiful.

Oxygen promotes combustion. Hydrogen is an explosive gas. Combine the two and get water (H_2O), a liquid that douses fires. Chlorine is a poisonous, caustic gas. Sodium is a metal, soft enough to cut with a butter knife and light enough to float on water. But don't try that at home because it reacts explosively in water. Combine the two and get sodium chloride (NaCl), more commonly known as table salt.

Chemistry can be beautiful.

Earth harbors at least 8.7 million species[9] of living organisms, most of which are insects. This staggering diversity of life sprang forth from single-celled organisms four billion years ago. In this very moment a harmonic intersection of Earth's land, sea, and air supports every one of them. We are all in this together. One genetic family on spaceship Earth.

Biology can be beautiful.

What then of all that is true but ugly in the world? Earth is commonly thought to be a haven for life—nurtured by the maternal instincts of Mother Nature. That's true to an extent. Earth has been teeming with life ever since it could support life. Yet Earth is also a giant killing machine. More than 99 percent of all species that ever lived are now extinct[10] from forces such as regional and global climate change as well as environmental assaults such as volcanoes, hurricanes, tornadoes, earthquakes, tsunamis, disease, and infestations. The universe is also a killing machine, responsible for asteroid and comet impacts, the most famous of which struck Earth sixty-six million years ago, rendering all the famous oversized dinosaurs extinct, as well as 70 percent of all other land and marine species of life on Earth. No land animal larger than a duffel bag survived.

What's true but hard to admit is our morbid fascination with massive geologic catastrophes as well as destructive weather systems. They're all things of beauty—perhaps even an entire category unto itself: something to behold and admire, but only from a safe distance, although some people ignore the safe distance rule. How else do you breed "storm chasers" and death-wish meteorologists who report live from the docks while catastrophic storms batter the shoreline, drenching themselves and whoever was volunteered to hold the video camera that day.

A volcano is stunning at any angle. The red-hot fluid oozing from its caldera and down its slopes via tributaries and rivers is composed of liquefied rocks. At room temperature, these are things we sit on, build homes upon, and use as metaphor for all that is stable in the world. The volcano built itself with liquefied rocks, in that spot, on its own schedule, serving as a portal to Earth's literal underworld.

And is there anything more beautiful than a 300-mile- wide hurricane, viewed from on high or from space, slowly rotating like the gaseous pinwheel of storm clouds it is? How about a vigorous thunderstorm, with frequent, loud, and scary cloud-to-cloud and ground-to-cloud[11] lightning strikes?

And even though an asteroid took out Earth's big-toothed, badass dinosaurs, their absence pried open an ecological niche that allowed our tiny mammalian ancestors to evolve into something more ambitious than hors d'oeuvres for *T. rex*. That's undeniably a beautiful thing—at least for the branch on the tree of life that became primates, to which we belong.

★ ★ ★

Cosmic impacts can be destructive and deadly no matter where they occur. When sky-watchers Caroline and Eugene Shoemaker, along with David Levy, discovered comet Shoemaker-Levy 9 (one of many comets that bear their names), astro-geeks of the world all fought for a look through their telescope eyepieces. Why? After discovery, the comet's orbit was quickly determined to be on a collision course with the planet Jupiter. The world's astrophysicists mobilized our largest and most powerful telescopes, Hubble included. Previously scheduled observing slots were willingly forfeited. We even deputized *Galileo*, a Jupiter-destined space probe, not yet arrived, to join the observations. In a previous visit, Jupiter's strong tidal forces had ripped the comet apart, creating a parade of smaller chunks that maintained orbit. On July 16, 1994, we witnessed the first of nearly two dozen impacts—fragments A through W—on Jupiter. The biggest of these, fragment G, collided with the energy of six teratons (six million megatons) of TNT, equivalent to six hundred times the world's arsenal of nuclear weapons. These impacts left visible scars in Jupiter's atmosphere larger than Earth itself.

And it was beautiful.

A cosmic perspective cloaks the up-close damage and mayhem caused by these catastrophes. Their beauty subsumes all that is destructive. All that is lethal. Nothing died on Jupiter that day. Had those comet fragments collided with Earth, it would have been an extinction-level event.

Perhaps the line drawn between beautiful and ugly depends on whether it will harm us. Some objectively ugly things in nature might include a close-up of a tarantula's underbelly—lovable, perhaps, only to arachnologists. A tarantula can harm you with its bite, and maybe we know this intuitively. How about a Komodo dragon slowly stalking you? Or a swarm of bloodsucking ticks, or leeches? How about malaria? Or the bacterium that causes the bubonic plague? Or the virus that causes smallpox, or AIDS? How about all the spontaneous cell mutations that cause birth defects and cancers and other diseases that shorten our lives in the genetic lottery? They're all part of the same nature that contains countless objects and scenes we admire. But none of these parasites or diseases or creepy creatures show up in posters with Bible quotes. Smallpox, malaria, and the bubonic plague together have killed upwards of 1.5 billion people throughout time, worldwide. That toll far exceeds all deaths from all armed conflicts in the history of our species. Nature has killed more of us than we have of ourselves. These thoughts hardly ever (likely never) arise whenever we declare nature's beauty.

Maybe they should. If they did, we'd be more honest with ourselves about our place in the universe. Evidence shows that nature doesn't actually care about our health or longevity. We're equipped by natural instincts to sift between some of what might harm us and some of what may bring us comfort. Yet there is no hint from space that anyone or anything in the universe will arrive to save us from Earth, or from ourselves.

It is we alone who care about us.

Medical researchers develop vaccines to protect us from lethal viruses, and medicines to ward off bacteria and parasites. Architects and builders create homes and shelters to protect us from catastrophic weather. In the future, astrodynamicists will develop space systems that deflect the trajectories of killer asteroids headed our way. Contrary to implicit tenets of the green movement, not all that is natural is beautiful, and not all that is beautiful is natural.

Maybe that's why the world needs poets. Not to interpret what is plain and obvious, but to help us take pause and reflect on the beauty of people, places, and ideas—things we might otherwise take for granted. Simple beauty that emanates from simple truths. After reading Joyce Kilmer's most famous poem,[12] will you ever again walk past a tree without reflecting on its silent majesty?

I think that I shall never see
A poem lovely as a tree.

A tree whose hungry mouth is prest
Against the earth's sweet flowing breast;

A tree that looks at God all day,
And lifts her leafy arms to pray;

A tree that may in Summer wear
A nest of robins in her hair;

Upon whose bosom snow has lain;
Who intimately lives with rain.

Poems are made by fools like me,
But only God can make a tree.

Kilmer, a New Jersey native, was slain by a sniper's bullet on the Western Front in 1918, during World War I. One who died by the hands of another human and not by the hands of Mother Nature.

Where does this leave us? Perhaps nowhere. Perhaps everywhere. Personally, as a human, as a scientist, and as a resident of Earth, the most beautiful thing about the universe may be that it's knowable at all. No message written on tablets in the sky pre-required this to be so. It just is. For me, this summit of objective truth makes the universe itself the most beautiful thing in the universe.

TWO

EXPLORATION & DISCOVERY

The value of both when shaping civilization

Skeptics often think of space exploration as an expensive luxury, preferring instead to first solve our problems here on Earth. The list of societal challenges hasn't changed much over the decades and includes progressive goals to solve hunger and poverty, improve public education, reduce social and political unrest, and end war. These make potent headlines in any news cycle, but especially when contrasted with the tens of billions of dollars the US government spends annually in space. The topic is hotly debated in India,[1] a country that recently redoubled its efforts to explore space, all while eight hundred million of its citizens live in poverty. Half of those in poverty live in squalor[2]—more than the entire population of the US. Odd that these same skeptics hardly ever wonder whether we should do both: explore space and fix society's problems. The world's list of challenging problems long predates anybody ever spending a dime on space.

To gain insight, let's rewind thirty thousand years and eavesdrop on our ancestral cave dwellers. Those among them with the urge to explore decide to consult the elders, saying, "We want to see what's beyond the cave door." The elders are wise. They caucus among themselves, weighing what they think are the risks and rewards, and reply, "No. We must first solve the problems of the cave before anyone ventures beyond."

A laughably absurd exchange indeed, but to a space explorer, that's what people sound like when they require Earth's problems get solved before anybody goes anywhere else in the universe. One final note on our troglodytes: They breathed fresh air. They drank clean water. They ate organic plants and free-range animals—yet their staggeringly high infant mortality left them with an average life expectancy of barely thirty years. Science matters.

A cosmic perspective reminds you that Earth is a mote, isolated in a vast, rich universe. Is the cave any different from Earth itself? Yet, we knew more about the Moon before we visited for the first time than any fifteenth or sixteenth-century explorer knew about their destinations. We knew more about the surface of Mars and where to land our rovers than the twelfth and thirteenth-century Polynesian wayfinders knew about the Pacific islands that awaited them, far beyond their oceanic horizons. We spent centuries exploring and mapping Earth's surface, culminating with the discovery of Antarctica in 1820. Yet we've explored space for only a precious few decades.

If you travel beyond the cave door, you may just discover things that help solve your cave problems. To even suspect this is true requires enlightened foresight. You could find a diversity of plants that serve as medicine. You could discover an assortment of materials—wood, stone, bone—useful to fashion into tools. You could reveal additional sources of water, food, and shelter. More importantly, perspective lurks beyond the cave door. These places are not only destinations but new ways of seeing things. You don't need a scientist to tell you that. The noted writer T. S. Eliot once mused,[3]

> *We shall not cease from exploration*
> *And the end of all our exploring*

Will be to arrive where we started
And know the place for the first time.

That's as close an analogue to the cosmic perspective as has ever been penned by a poet.

Part of the problem is that we're all wired with linear minds, leaving us prone to think small. It's not our fault. We think in additives and multiples, with no evolutionary pressure to think in exponentials. An exponential is a number raised to the power of another number. When you do that, quantities and rates described by them rise (or shrink) faster than our normal capacity to comprehend. Consider this simple example: You can choose to receive $5 million now or instead receive a penny a day doubled for a month. Most people would take the $5 million and run, avoiding the pennies altogether. Let's first think it through. That's a penny today. Then two pennies tomorrow. Four pennies the next day. Eight pennies the day after that, and so on. How rich are you at the end? If you do the math, on the thirty-first day you will be handed $10,737,418.24. And the sum of pennies from your previous thirty days brings your total to $21,474,836.47. That's the power of an exponential.

In one more example, you learn that a species of unwanted algae is spreading on the surface of your favorite pond. The growth is persistent and doubles in area every day. After a month, the lake is half-covered in algae. At this rate, how much longer until algae covers the entire lake? Our primitive, linear brain calculates "one month." But the actual answer is "one day." Doesn't even matter how long it took for the pond to become half-covered. If the rate of coverage doubles every day, you can be sure that when it's half-covered, you've got just one day left.

The devastating collapse of our economic system in 2008 was precipitated by predatory low-interest, floating-rate loans that granted mortgages to unqualified people. Who knows whether this economic episode could have been softened, or avoided altogether, if the people whose loans were approved were also fluent in exponential calculations. They would have realized in an instant that any uptick in compounded interest rates would leave them bankrupt, empowering them to decline the loan in the first place.

Consider how often we do simple linear calculations in our head: We've been driving for an hour and we're halfway there, so there's one more hour before we're home. That's straightforward linear thinking. But, in the spirit of "Are we there yet?" here's a sentence that has never been uttered in the history of transportation:

We've been driving for a thousandth of a second and we're one three-millionth of the way there, so just 2,999.999 more seconds before we're home.

Yet mathematical factors of millions and billions and trillions are cosmically commonplace. The sphere of the Earth, which is so large that some people (still) think it's flat, is dwarfed by the Sun. If the Sun were hollow, you could pour a million Earths into its volume and still have room left over. Let's not stop there. In five billion years, when the Sun dies, it will pass through a phase called Red Giant, in which it swells enormously, engulfing the orbits of Mercury, Venus, and likely Earth as well. At that size, the Sun has ballooned to ten million times larger than it is now. The Solar System, out to the Kuiper Belt of comets beyond Neptune, is a million times larger still. The soul of the cosmic perspective—its spirit energy—derives from embracing these astronomical scales of measure. An inability to do so can thwart attempts to fathom the depths of time through which we live, and space through which we move.

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You also need measurement moxie to embrace modern biology and geology. We think of Darwinian evolution as imperceptibly slow. That's because we live, at most, 100 years, and our brain wiring resists the fact that speciation can take thousands and even millions of times longer than our lifetime to unfold. That's how you go from our ancestral mammalian rodents running underfoot of *T. rex* to human beings in 66 million years—a stretch of time just 1.5 percent of the 3.8 billion years that Earth has hosted life. Still feels like long ago? Know what also takes a long time? The geologic carving of landforms such as Arizona's Grand Canyon, and continental drift, where Earth's largest landmasses move across the surface at about the same rate your fingernails grow. How about my favorite? If the gridiron of a football field were a timeline of the universe, with the Big Bang at one end and this moment at the other, then all of human recorded history would span the thickness of a blade of grass in the end zone.

Terrestrial exploration and discovery have long been associated with land grabs by military or colonizing powers, epitomized by Julius Caesar's infamous Latin quip (c. 45 BC):

Veni, vidi, vici (I came, I saw, I conquered).

The activity also involved flag planting on uncharted, never-before-visited places, such as the South Pole or the summit of Mount Everest. Flag planting also occurred where local residents were already there to greet you, which brings to mind what Christopher Columbus wrote to King Ferdinand and Queen Isabella in 1493 after his first voyage to the Caribbean:[4]

I discovered many islands inhabited by numerous people. I took possession of all of them for our most fortunate King by making public proclamation and unfurling his [flag].

Even the *Apollo 11* mission to the Moon planted a flag—the American flag. Although the plaque that accompanied it was unlike any other in the history of hegemony:

HERE MEN FROM THE PLANET EARTH FIRST SET FOOT UPON THE MOON JULY 1969, A.D. WE CAME IN PEACE FOR ALL MANKIND

With Earth charted and the Moon visited, our collective concept of exploration and discovery must now extend further in the Solar System and beyond. The exercise also includes the discovery of ideas and inventions and new ways of doing things.[5] With systems in place to disseminate thought, such as scientific conferences, peer-reviewed journals, and patent filings, every next generation can use discoveries of the previous generation as fresh starting points. No reinventing the wheel. No wasted efforts. This blunt and obvious fact carries profound consequences. It means knowledge grows exponentially, not linearly, rendering our brains hopeless in our attempts to predict the future based on the past. It also leaves you thinking that all the amazing discoveries and inventions—the ones in your lifetime—mean you live in special times. Yet that's a fundamental feature of exponential growth: everyone thinks they live in special times, no matter where they are on the curve. How often have we all heard the phrase, "the miracles of modern medicine"? Now look back fifty years at the doctor's bag with scary tools and questionable cures and you take smug delight in being alive today instead of at any other time. People back then also praised their own state of advances relative to fifty years earlier. At no time on the exponential growth curve did anybody say, "Gee, we sure live in backward times," no matter how backward it may look to subsequent generations.

Borrowing the math from our pennies and algae, what's the "doubling time" of exploration and discovery? In 1995, while a postdoc at Princeton University, I decided it might be fun to measure a wall of research journals on the shelves of the Peyton Hall astrophysics library. A single publication, *The Astrophysical Journal*, is preeminent in my field and occupied most of the shelves. Perfect setup for my doubling experiment. The inaugural journal dates from 1895. All I did was find the middle of the wall and record the year of the journals at that location. It was 1980. That meant there was as much published astrophysics research in the fifteen years from 1980 to 1995 as had been previously published since 1895. That's a fifteen-year doubling time, but would it persist back to the beginning? I then found the midway point between 1895 and 1980. It was 1965. The next midpoint was 1950, followed by 1935, and then 1920. I may be off by a year or two because over time the *Journal* increased its page size. I was measuring shelf space when, to be precise, I should have been summing printed page areas, but the lesson of this exercise is nonetheless clear.

You might think the emergent publish-or-perish culture of academia has increased pressure to generate frivolous papers, artificially boosting the researcher's productivity. No. It's driven by the sheer increase in the number of researchers and the productivity that comes from large collaborations.[6] I would come to learn that a fifteen-year doubling time is consistent with the pace of other active fields of scientific research.

How about inventions? The US Patent and Trademark Office registered 3.5 million patents from 2010 to 2020, more than was registered in the nearly forty-year stretch from 1963 to 2000.[7] So they're on a roll too.

All this had me wondering: What might be the doubling time of modern society? And how would you measure it? I don't know and I don't know, but I'm happy to try. Let's look at thirty-year runs of the industrialized world since 1870, with emphasis on the United States, and compare life at the beginning to life at the end of each interval. How have exploration and discovery, the drivers of science, shaped our lives?

From 1870 to 1900, there are great advances in transportation. Steamships cross the oceans in record times. In 1869 the last "golden spike" is hammered, completing the 2,000-mile transcontinental railroad across the US. This enables decades of mobility and expansion for the population. In 1893 the legendary Orient Express, among many rail routes on the continent, begins its 1,400-mile circuit between Paris and Istanbul. Rail travel rendered transportation by stagecoach obsolete along many routes. Also, in the 1880s, German engineer Karl Benz improves on the internal combustion engine and births the first practical automobile. English inventor John Kemp Starley perfects the velocipede[8]—credit him for the now-familiar "safety bicycle," which uses two wheels of equal size and a chain connecting the rear wheel to the pedals. And over that time, powered balloons that enable transportation through the air are all the rage.

Daily life in 1900 would be unrecognizable to anyone transported from the year 1870.

Time to look at published predictions in 1900 for the year 2000. That's what people do when a new century begins. With the clever subtitle "The History of the Future," the website paleofuture.com specializes in just that. Rampant among predictions, such as what appeared in the publications *Punch*, the *Atlantic Monthly*, and *Collier's*, are simple linear extrapolations of what was happening in 1900. They see the promise of electric lighting but imagine it only for special occasions. They love airship travel and imagine that everyone in the future moves around via their own private balloon, including Santa—because who needs magic reindeer when you have blimps. Again, humans are linear thinkers, so you can't blame any of them for these quaint imaginings of their future.

The *Brooklyn Daily Eagle*'s last Sunday newspaper of the nineteenth century included a sixteen-page supplement of articles and illustrations titled, "Things Will Be So Different a Hundred Years Hence." The contributors—business and military leaders, pastors, politicians, and other experts in their fields—opined on what housework, poverty, religion, sanitation, and war would be like in the year 2000. They enthused about the potential of electricity and the automobile. There is even a map of the world-to-be, showing an American Federation comprising most of the Western Hemisphere from the lands above the Arctic Circle down to the archipelago of Tierra del Fuego, plus sub-Saharan Africa, the southern half of Australia, and New Zealand.

Most of the writers portray a future rich with fanciful extensions of the day's technologies, although one futurist could not see the future at all. George H. Daniels, who worked for the New York Central and Hudson River Railroad, peered into his own crystal ball and predicted, *It is scarcely possible that the twentieth century will witness improvements in transportation that will be as great as were those of the nineteenth century.*

Written just three years before the invention of flight, that's gotta be the most boneheaded prediction ever made. Rather than simply under-predict the future, like everybody else, he actively denies a future of innovations—in his own field. Elsewhere in his article, Daniels envisions affordable global tourism and the diffusion of white bread to China and Japan. Yet he simply can't imagine what might replace steam as the power source for ground transportation, let alone a heavier-than-air vehicle flying through the air. Even though he stood on the doorstep of the twentieth century, this manager of the world's biggest commuter rail system could not see beyond the automobile, the locomotive, and the steamship. Yet another victim of linear thinking unwittingly embedded in exponential growth.

Between 1900 and 1930, the existence of atoms is confirmed. Powered "aero"planes are invented, and the range of flight extends from the 120-foot (36-meter) distance flown in 1903 by the Wright brothers in their original Wright Flyer, to a 5,218-mile closed-circuit trip[9] in 1930, logged by the Italian aviators Major Umberto Maddalena and Lieutenant Fausto Cecconi. Back on the ground, we learn to exploit radio waves as a fundamental source of information and entertainment. Urban transportation shifts almost entirely from a horse-driven economy, the backbone of civilization for thousands of years, to an automobile economy, in which you can't give away a horse. This period also sees a world war, in which planes are used in combat for the first time. Orville Wright, writing from Dayton, Ohio, laments this fact in a letter dated December 19, 1918, to Alan R. Hawley, President of the Aero Club of America, New York City:[10]

Many thanks for your telegram remembering the fifteenth anniversary of our first flight at Kitty Hawk. Although Wilbur, as well as myself, would have preferred to see the aeroplane developed more along peaceful lines, yet I believe that its use in this great war will give encouragement for its use in other ways.

Meanwhile, cities are electrified. To read at night, no longer do you burn wax, whale oil, or any other source of flame. And over this time cinema, silent and in black and white, becomes a leading source of entertainment.

Daily life in 1930 would be unrecognizable to anyone transported from the year 1900.

From 1930 to 1960, we go from airplanes flying at speeds of a few hundred miles per hour, to breaking the sound barrier in 1947, to the dawn of the space age, inspired in part by ballistic rockets developed as wartime weapons. In 1957 the Soviet Union launches Sputnik, Earth's first artificial satellite, which travels at 17,500 mph in low-Earth orbit. In 1958, the world's first commercial jet airplane—the Boeing 707, flown by Pan American Airways—enjoys a wingspan wider than the distance flown by the Wright brothers' first flight in 1903. This period also sees another world war and the invention of the laser. Nuclear weapons, from their invention in 1945 to 1960 (a mere fifteen years), increase in destructive power by nearly a factor of 4,000, accompanied by rocket and suborbital missile technologies to deliver their destructive power anywhere on Earth's surface within forty-five minutes. We see the rise of television as a potent source of instant information and entertainment, as well as the further rise of cinema, now in color and with sound.

Daily life in 1960 would be unrecognizable to anyone transported from the year 1930.

From 1960 to 1990, a Cold War nuclear arms race between the United States and the Soviet Union threatens the survival of civilization. Though begun in the 1950s, the US stockpile of nuclear warheads peaks in the 1960s, with the Soviets' stockpile peaking in the 1980s.[11] The Berlin Wall, erected in 1962, becomes the greatest symbol of Winston Churchill's "Iron Curtain," separating Eastern from Western Europe. Yet it's dismantled by 1989, as peace breaks out in

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