

Science controversies past and present

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Reactions to the science of global warming have followed a similar course to those of other inconvenient truths from physics.

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Science—especially the science behind climate change—is under fire. The climate issue has sparked a vigorous, and at times surreal, public debate that seems to pit experts against one another on even the most basic facts, such as whether human greenhouse gas emissions dominate natural ones, whether added carbon dioxide alters the planetary emission of thermal radiation to space, and whether global temperatures are rising.¹ At its heart, global warming is a physics problem, albeit a messy one that cannot proceed far without bringing in meteorology, oceanography, and geology. (See the article by Raymond Pierrehumbert in *PHYSICS TODAY*, January 2011, page 33.) The climate debate has spread far beyond the confines of any of those scientific circles and into the media and public sphere, where politicization and vitriol are legion.

Although nearly all experts accept that the greenhouse gases emitted by humans have caused significant warming to the planet and will likely cause much more, only about half the US public agrees, even after years of heavy media coverage. How did we get into such a mess? What are the implications for science, for how it should be communicated, and for how debates should be interpreted? Some insights may be gained by noting that global warming is not the first “inconvenient truth” in physics. Consider this description of another, bygone debate:

The decision [whether to accept the new theory] was not exclusively, or even primarily, a matter for astronomers, and as the debate spread from astronomical circles it became tumultuous in the extreme. To most of those who were not concerned with the detailed study of celestial motions, Copernicus’s innovation seemed absurd and impious. Even when understood, the vaunted harmonies seemed no evidence at all. The resulting clamor was widespread, vocal, and bitter.²

Thus does science historian Thomas Kuhn describe the difficulties experienced by astronomers in convincing the public of the heliocentric theory of the solar system, which ultimately ushered in the scientific revolution. The “clamor” prevailed around the time of Galileo Galilei, more than a half century after Nicolaus Copernicus, on his deathbed, published the heliocentric model in 1543. Copernicus’s calculations surpassed all others in their ability to describe the observed courses of the planets, and they were based on a far simpler conception. Yet most people would not accept heliocentricity until two centuries after his death.

Why did it take so long? To modern minds, the Ptolemaic model of the solar system, with its nested cycles and epi-

cycles, seems rather silly. Surely, the need for a new tweak to the model each time more accurate observations came along should have been a tip-off that something fundamental was wrong. The heliocentric model’s elegance and simplicity, on the other hand, are now appreciated as the hallmarks of credibility for a scientific theory.

Paradigm shifts

It did take scientists a while, although not two centuries, to see the heliocentric model’s merit. Astronomers quietly adopted Copernicus’s calculations soon after they were published, but without at first accepting the heliocentric premise on which they were based. As young, open-minded astronomers replaced their elders, a paradigm shift toward the modern view began. By the time of Johannes Kepler’s recognition of simple elliptical orbits in 1609 (see the article by Owen Gingerich in *PHYSICS TODAY*, September 2011, page 50) and Galileo’s observations the following year, many top astronomers had converted to the Copernican view.

The revelations from Galileo’s telescope (lunar craters, migrating sunspots, planetary moons, and more), though spectacular, didn’t directly validate the heliocentric model. Instead, their most important effect was to challenge the preconceived notions that prevented the model’s acceptance: that the heavens were perfect, that all celestial objects orbited Earth, that Scripture fully described the universe (exemplified by Dante Alighieri’s conception of a geocentric divine arrangement, shown in figure 1).² Once those errors were revealed, the mind reopened to new possibilities. Modern educators have recently realized that a similar process is important in teaching physics in the classroom: Identifying and revealing incorrect intuitions—based on, say, friction-dominated systems—is sometimes necessary before students will truly assimilate an understanding of more general validity, such as Newton’s laws of motion. (See the article by Edward Redish and Richard Steinberg in *PHYSICS TODAY*, January 1999, page 24.)

More astute critics such as Tycho Brahe had a legitimate objection to the Copernican theory: If Earth is moving, one should see evidence of parallax in the shifting of the stars over the course of a terrestrial orbit, and Tycho could find none. But stars in Galileo’s telescope remained point-like even under strong magnification, which suggested that they were very distant indeed, and that the parallax would therefore be unobservably small; Galileo’s observations thereby removed Tycho’s objection. (Parallax was eventually observed in 1838.)

Despite the power of the new theory and its observa-

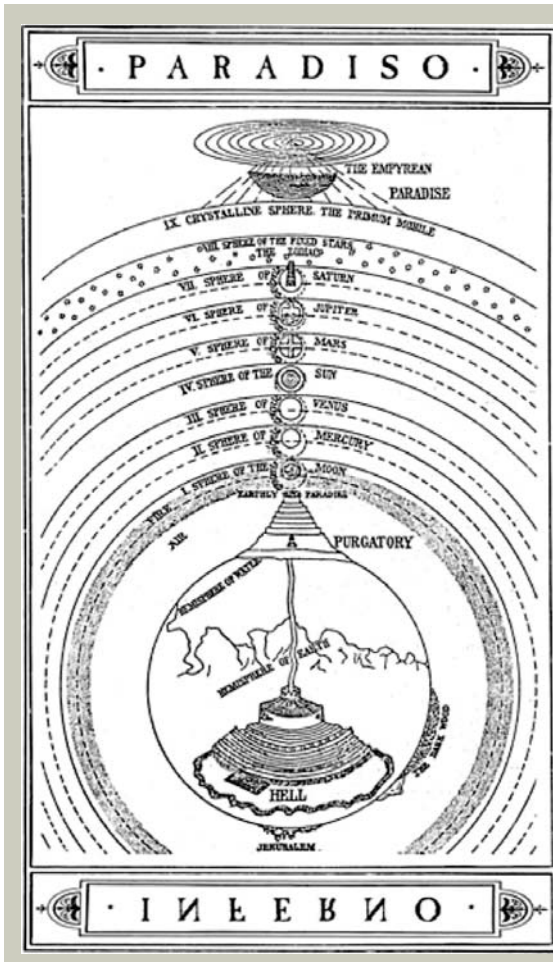


Figure 1. The Copernican paradigm shattered prevailing conceptions of how God had organized the world (left, adapted from C. Singer, ed., *Studies in the History and Method of Science*, Clarendon Press, Oxford, UK, 1917). Popular commentators such as Jean Bodin (top right) ridiculed the idea. John Donne (bottom right) expressed deep despair over the new theory in his 1611 poem *An Anatomy of the World*.

tional successes, many people, even in the scientific community, could not relinquish the idea that the universe was built around them. Their belief was so strong that some scientists simply refused to look through Galileo's telescope, and others invented ridiculous explanations for what it showed.² Compromise models became popular; Tycho himself proposed that the planets orbit the Sun but maintained that the Sun and its entourage all orbit Earth. Over time such crutches fell by the wayside; Copernicus's view was generally accepted among scientists by the late 17th century and among the public by the late 18th century.²

The progression of the global warming idea so far has been quite similar to that of Copernicanism. The idea that changes in atmospheric greenhouse gas concentrations can and do cause significant climate changes (a notion for which I will use the shorthand term "greenhouse warming") was proposed qualitatively in 1864 by renowned physicist John Tyndall, when he discovered carbon dioxide's opacity to IR radiation. In 1896 Nobel laureate Svante Arrhenius quantitatively predicted the warming to be caused in the future by coal burning; the prediction was tested and promoted by steam engineer Guy Callendar in the late 1930s. At first few could accept that humans were capable of influencing the climate of an entire planet, but over time, and with more calculations, scientists found the possibility increasingly difficult to dismiss.

As with Copernicanism, astute observers found legitimate objections. The 15-micron absorption of atmospheric CO₂ was already largely saturated, which some argued would prevent additional CO₂ from having any effect. The

ocean, with its large carbon-storing capacity, seemed poised to soak up most of the human emissions. By the 1970s, however, those objections had deflated in the face of contrary evidence,³ and a growing number of papers on climate were noting the likelihood of future warming.⁴

Many who are unwilling to accept the full brunt of greenhouse warming have embraced a more comforting compromise reminiscent of the Tychonic system: that CO₂ has some role in climate but its importance is being exaggerated. But accepting a nonzero warming effect puts one on a slippery slope: Once acknowledged, the effect must be quantified, and every legitimate method for doing so yields a significant magnitude. As the evidence sinks in, we can expect a continued, if slow, drift to full acceptance. It took both Copernicanism and greenhouse warming roughly a century to go from initial proposal to broad acceptance by the relevant scientific communities. It remains to be seen how long it will take greenhouse warming to achieve a clear public consensus; one hopes it will not take another century.

Backlash and politicization

Inconvenient scientific claims also show parallels in their political progression. In the decades before Galileo began his fervent promotion of Copernicanism, the Catholic Church took an admirably philosophical view of the idea. As late as 1615, Cardinal Robert Bellarmine acknowledged that "we should . . . rather admit that we did not understand [Scripture] than declare an opinion to be false which is proved to be true." But the very next year he officially declared Copernicanism to be false, stating that there was no evidence to

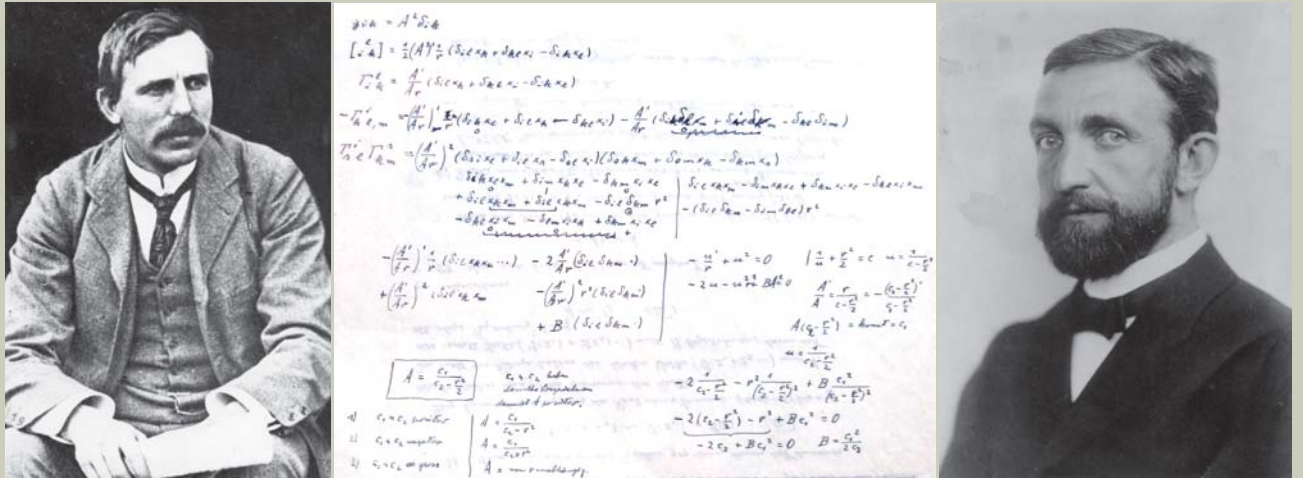


Figure 2. The theory of relativity's mathematical difficulty and its repudiation of bedrock concepts of space and time threatened many physicists of the day. Philipp Lenard (right), previously a strong supporter of Albert Einstein, became a harsh critic and fought the theory until his death. Others such as Ernest Rutherford (left) did not deny its validity but feared the direction in which it would take physics.¹⁶ (Center image adapted from the Albert Einstein Archives, #5-219.10, © The Hebrew University of Jerusalem.)

support it, despite Galileo's observations and Kepler's calculations.² Institutional imperatives had forced a full rejection of Copernicanism, which had become threatening precisely because of the mounting evidence.

Even Albert Einstein was not immune to political backlash. His theory of general relativity, excerpted on the notebook page in figure 2, undermined our most fundamental notions of absolute space and time, a revolution that Max Planck avowed "can only be compared with that brought about by the introduction of the Copernican world system."¹⁵ Though the theory predicted the anomalous perihelion shift of Mercury's orbit, it was still regarded as provisional in the years following its publication in 1916.

When observation, by Arthur Eddington and others, of a rare solar eclipse in 1919 confirmed the bending of light, it was widely hailed and turned Einstein into a celebrity. Elated, he was finally satisfied that his theory was verified. But the following year he wrote to his mathematician collaborator Marcel Grossmann:

This world is a strange madhouse. Currently, every coachman and every waiter is debating whether relativity theory is correct. Belief in this matter depends on political party affiliation.⁶

Instead of quelling the debate, the confirmation of the theory and acclaim for its author had sparked an organized opposition dedicated to discrediting both theory and author. Part of the backlash came from a minority of scientists who apparently either felt sidelined or could not understand the theory. The driving force was probably professional jealousy,⁶ but scientific opposition was greatly amplified by the anti-Semitism of the interwar period and was exploited by political and culture warriors. The same forces, together with status quo economic interests, have amplified the views of climate contrarians.⁷

The historical backlashes shed some light on a paradox of the current climate debate: As evidence continues to accumulate confirming longstanding warming predictions and showing how sensitive climate has been throughout Earth's history, why does climate skepticism seem to be growing rather than shrinking? All three provocative ideas—heliocentricity, relativity, and greenhouse warming—have

been, in Kuhn's words, "destructive of an entire fabric of thought," and have shattered notions that make us feel safe.² That kind of change can turn people away from reason and toward emotion, especially when the ideas are pressed on them with great force.⁸

The agitations of modern greenhouse proponents appear to have provoked an antiscience backlash similar to the one against Galileo. In the space of only two years, almost as fast as Bellarmine changed his position on Copernicanism, leading moderates have been squeezed out of the main conservative political parties in both the US and Australia and replaced by hard-line rejecters of climate science. In Australia, climate policy was the leading issue behind the backlash; in the US it was one of many contributing factors. Because the Catholic Church of Galileo's day had generally been a supporter of science and open inquiry, the condemnation of Copernicanism as it grew scientifically solid shocked many devout Catholics.² Likewise, modern conservative political parties have until recently been friends of science, including climate and environmental studies. In the 1970s Republicans and Democrats in Congress were equally concerned about climate change, and as recently as 2004 leading Republicans were—at least in public—enthusiastic in their support of science. Their recent rejections of climate science have probably shocked many supporters. In both cases the backlash seems to have come when leaders were pushed to act on the basis of new evidence. (Figure 3 further illustrates the connection between economic incentives and rejection of climate science.)

The ugly nature of the current climate debate, with its increasingly frequent characterization of scientists as opportunists, totalitarians, or downright criminals, is also, unfortunately, not new. Copernicus (posthumously) and his prominent followers through Isaac Newton were all accused of being heretics or atheists. Einstein was derided by his political opponents through the 1920s and 1930s as a Communist—despite his dim view of the Soviet Union—or simply as a fraud. When a group of American women tried to prevent him from entering the US because of his supposed Communism, he quipped, "Never before have I experienced from the fair sex such energetic rejection of all advances, or if I have, then certainly never from so many at once."⁹ At one point

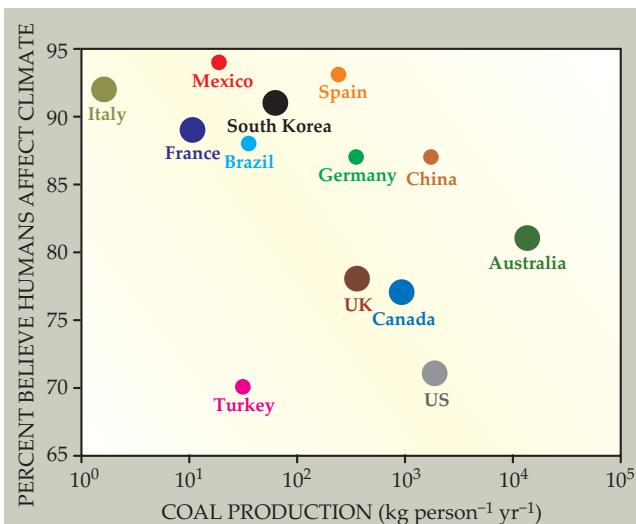


Figure 3. Greenhouse warming and its perceived policy implications challenge widely held libertarian ideals and provoke economic fears, as evidenced by the negative correlation between acceptance of anthropogenic climate change and coal production, especially among the wealthiest nations.¹⁷ Large dots show nations where more than 80% of survey respondents had heard “a lot” or “some” about global warming; small dots show nations where 70–80% had. The vertical axis is the percentage of respondents who agree that humans affect climate, not necessarily who accept the greenhouse theory.

Einstein stopped giving public lectures out of fear for his personal safety, also now a worry for some greenhouse warming proponents.

Bogus debates

It was easy for those not wishing to accept Copernicus’s insight to devise persuasive counterarguments against it. For example, in 1597 one prominent commentator declared that a moving Earth would “see cities and fortresses, towns and mountains thrown down,” and that “neither an arrow shot straight up, nor a stone dropped . . . would fall perpendicularly.”¹² Those arguments would not fly today because nearly everyone has experiential knowledge, from riding in cars and airplanes, of what are now called the Galilean principles of invariance. But laypeople in the 17th century did not. To explain those abstractions to them would have been much more difficult than to make the neat, simple, and wrong argument advanced by naysayers. As the 17th century progressed, arguments against heliocentricity tended to veer more toward scriptural rather than scientific ones, but both types persisted.

Greenhouse warming today faces an even greater array of bogus counterarguments based on the uninformed interpretation of data from ice cores, erroneous views about natural carbon sources, alleged but unobserved alternative drivers of climate change, naive expectations of the time scales over which models and observations should match, and various forms of statistical chicanery and logical fallacy. Many of the arguments sound reasonable to an inexpert but intelligent layperson. Critics use the alleged flaws to attempt to discredit the entire field.

Debates between mainstream scientists and silver-tongued opponents cannot be won by the side of truth no matter how obvious the fallacies may be to an expert. Incred-

ibly, as recently as the mid-19th century, a highly charismatic figure calling himself “Parallax” devoted two decades of his life to crisscrossing England arguing that Earth was flat. He debated legitimate astronomers—sometimes teams of them—in town-hall-type settings and wowed audiences.¹⁰ For similar reasons, Einstein himself gave up debating his critics early in the 1920s.⁶

Nearly a century after Callendar began to win converts to the idea, among experts actively studying and publishing peer-reviewed articles about the climate system the portion who accept greenhouse warming is now more than 95%;^{11,12} among the broader scientific community, a slightly smaller majority;¹¹ and among the public at large in the US and Australia, who mostly receive news on climate filtered through a media that highlights contrarian views and controversy, only about half,¹³ although the exact number depends on the survey details. A similar situation prevailed for Copernicanism in the mid 17th century: Nearly all important astronomers had become Copernicans by then, but not the public, whose perception was through poets and other popularizers (such as Jean Bodin and John Donne, shown in figure 1) who continued to be skeptical or derisive. It would require the rest of the 17th century and most of the 18th to convert the public to Copernicanism.²

Deduction, empiricism, and prediction

A weakness that impeded the acceptance of all three inconvenient ideas, especially outside expert circles, was the absence of a smoking gun or a benchtop experiment that could prove any of them unambiguously. Instead, heliocentricity and relativity succeeded by explaining the existing observations with fewer ad hoc assumptions. To judge them, one had first to consider the plausibility of the theory and then to appreciate how unlikely it would be for observations to have obeyed it by accident. That reasoning process is often unintuitive and requires detailed knowledge.

Like the Copernican model, Einstein’s theory of general relativity was a fundamental conceptual simplification arising from a few brilliant insights and an ability to question conventional wisdom. Einstein asked if there might be a way to represent the universe such that gravitational and inertial mass, which are distinct but coincidentally equal in Newtonian physics, were a single property. That constraint plus the insistence that the theory would apply in any arbitrary spacetime coordinate system were, with clever reasoning and some daunting math, sufficient to uniquely specify the complete theory.¹⁴

The current theory of global climate change is hardly elegant or scientifically revolutionary, and in that respect it seems like no bedfellow to the others. Its prominence comes from its implications for the sustainability of current Western consumption patterns, not from reshaping physics; its many contributors would not claim to be Einsteins. What it shares with the others, however, is its origin in the worked-out consequences of evident physical principles rather than direct observation. That sort of bottom-up deduction is valued by physics perhaps more than by any other science.

Indeed, the leaders of climate science in recent decades have largely been trained as physicists.³ Global warming is the first environmental forecast based on physical reasoning—the greenhouse effect and its intensification as IR atmospheric opacity increases—rather than on extrapolating observed patterns of past behavior. Anthropogenic warming was not unambiguously detected until nearly the end of the 20th century, well after most experts knew it was coming. Interestingly, forecast meteorologists, despite their familiarity

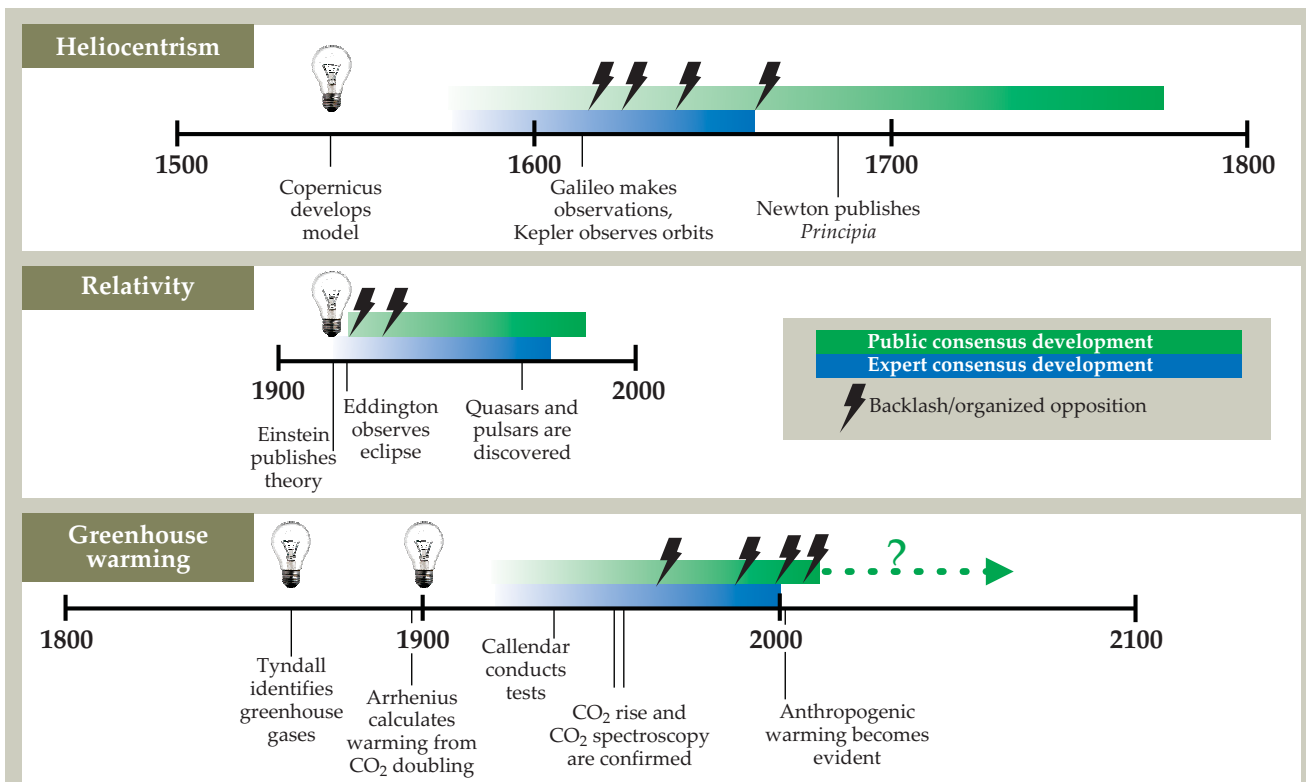


Figure 4. Timelines for heliocentrism, relativity, and greenhouse warming, aligned by their dates of introduction. Colored bars indicate the estimated times to consensus among experts and the public. Lightning symbols denote organized opposition from contrarian, religious, or political groups. The sequence of events is similar in all three cases except that relativity attained consensus more rapidly, especially among the public; it had emerged essentially fully formed, whereas the other two underwent refinements for many decades.

with weather and the atmosphere, are at least as skeptical of global warming as the general public; so, to some extent, are geologists.^{11,15} A similar situation confronted general relativity, whose critics were mainly experimentalists and astronomical observers. Traditional meteorologists and geologists both emphasize empiricism and classification; they relish the complexity of natural phenomena and typically consider ab initio theoretical approaches to be hopeless. Physicists, however, prefer the opposite approach of avoiding overly complex problems and seeking to strip the more tractable ones to their barest essence. Such approaches often become more powerful as technology advances.

A common refrain is the disparagement of new paradigms as mere theories with too little observational basis. Parallax, the flat-Earth proponent, beguiled audiences by deriding the “theory” of a globe Earth, in contrast to the flat disk supposedly proven by observation. Einstein’s colleague John Synge noted that relativists were easily dismissed as people “splitting hairs in an ivory tower” who are “not consulted in the building of a tower, a bridge, a ship, or an aeroplane.” Critics emphasized the meager size of the then-observable relativistic effects while brushing aside the theory’s deeper implications.¹⁶ Nowadays, greenhouse proponents are also dismissed by skeptics as out-of-touch academics infatuated with their models and ignorant of data—as if science could be done with only one or the other. Contrary to those myths, however, Einstein eagerly sought observational tests of his theory from the beginning, and climate models, imperfect though they are, are constantly tested for their ability to reproduce many kinds of observed climate variations.

Lessons for scientists today?

Relativity contrarians basked in conspiracy ideas, claimed to be able to disprove Einstein’s theory, and were convinced that the scientific establishment was suppressing their alternative views⁶—all claims echoed nowadays by climate contrarians. But it is not hard to spot the differences between those groups and the real vanguard of a scientific revolution. Copernicus, Einstein, Charles Darwin, and Alfred Wegener, the founder of plate tectonics, all proposed powerful new theories that challenged core assumptions held by humanity for generations. Their theories steadily gained traction first among up-and-coming experts, then among the general population. Relativity and climate contrarians instead offer a wide range of mutually exclusive and sketchy proposals, which generally predate the new theory and lack predictive power. But because the contrarian proposals reinforce traditional beliefs, they enjoy a prolonged period of public popularity even as their currency among successive generations of experts approaches zero.

It is jarring to ponder the scene of a colleague from the 17th century refusing to look into a telescope—a level of aversion to inconvenient facts, admittedly not common, that seems incredible. Yet modern counterparts can perhaps be found in those who vilify the Intergovernmental Panel on Climate Change without apparently ever having examined its reports, or who repeat claims—such as global warming having stopped in 1998—that can be trivially falsified by looking at the data. A lesser form of denial can be found in the eager adoption of Copernicus’s calculations by those rejecting his premises; a modern parallel is the use of global atmosphere

model simulations by weather forecasters who reject the climatic implications of the physical relationships on which the models are based. (The UK Met Office, whose model development effort is probably the largest in the world, now uses essentially identical atmosphere models for weather and climate prediction.)

Despite the clear historical precedents, summarized in the timeline in figure 4, scientists and environmentalists alike appear to have been unprepared for the antiscience backlash now under way. A first step toward better public communication of science, and the reason we need it, may lie in recognizing why the backlash happens: the frailty of human reason and supremacy of emotional concerns that we humans all share but do not always acknowledge. That step could be as important in the classroom as when engaging the public and policymakers more widely. Tempering confidence with a dose of humility never hurts either, as best articulated by Einstein himself: "All our science, measured against reality, is primitive and childlike—and yet it is the most precious thing we have." (For more on public communication of climate science, see the article by Richard Somerville and Susan Joy Hassol on page 48 of this issue.)

Sadly, some new textbooks in climate and atmospheric physics are being written with long prefaces explaining why students should believe what the textbook says, despite contrary information from their parents, radio talk show hosts, or the internet. Normally a textbook does not have to defend itself. Since modern science, and physics especially, is done primarily at the pleasure of the taxpaying public, such developments should concern all scientists.

At the same time, history tells us that in the end, science will probably come out fine. Whether the planet will is another matter.

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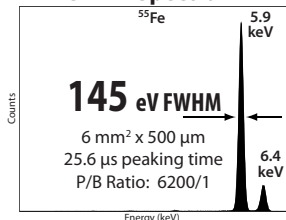
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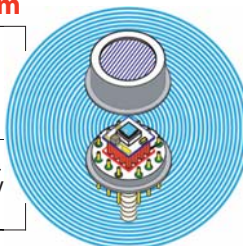
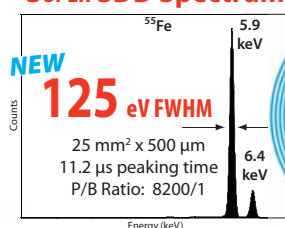


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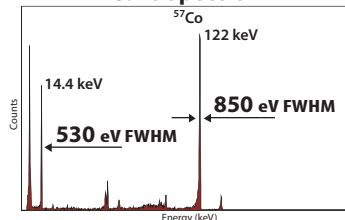
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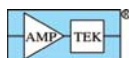
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