require extraordinary evidence. So the cosmology community has decided that no such claim can yet be made.

Over the past several decades we’ve been able to refine probabilistic arguments associated with the determination of likelihood and uncertainty, developing an area of mathematics called Bayesian analysis which has turned the science of determining uncertainty into one of the most sophisticated areas of experimental analysis. Here we first fold in a-priori estimates of likelihood and then see how the evidence changes our estimate. This is science at its best: Evidence can change our minds, and it’s better to be wrong rather than to be fooled.

In the public arena, scientists’ inclusion of uncertainties has been used by some critics to discount otherwise important results. Consider the climate-change debate. The evidence for human induced climate change is neither controversial nor surprising. Fundamental physics arguments have anticipated the observed changes. When the data show that the last sixteen years have been the warmest in recorded human history, and when measured CO₂ levels exceed those determined over the past 500,000 years, and when the West Antarctic ice sheet is observed to be melting at an unprecedented rate, the fact that responsible scientists report many small uncertainties associated with each of these measurements shouldn’t discount the threat we face.

Louis Pasteur once said, “Fortune favors the prepared mind.” Incorporating uncertainties prepares us to make better-informed decisions about the future. This doesn’t obviate our ability to draw rational and quantitatively reliable conclusions on which to base our actions—especially when our health and security may depend on them.

EQUIPOISE

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There’s an old word in our language, “equipoise,” which has been around since at least the 16th century, when it meant something like “an equal distribution of weight.” With respect to science, it’s analogous to standing at the foot of a valley and not knowing the best way to climb to the top—poised, that is, between alternative theories and ideas about which, given current information, one is neutral. Use of the word peaked around 1840 and has declined roughly fivefold since then, according to Google Ngram, though it appears to be enjoying a resurgence in the last decade. But attention to equipoise ought to be greater.

The concept found a new application in the 1980s, when ethicists were searching for deep justifications to conduct randomized clinical trials in medicine. A trial was justified, they rightly argued, only when the doctors and researchers doing the trial considered (relying on their medical knowledge) the new drug and its alternative (a placebo, perhaps) as potentially equally good. If they felt otherwise, how could they justify the trial? Was it ethical, for the sake of research, to place patients at risk if the researchers suspected that one course of action might be materially better than another?

So equipoise is a state of equilibrium in which scientists cannot
be sure which of the alternative theories they're contemplating might be true.

In my view, equipoise is related to that famous Popperian sine qua non of science itself: falsifiability. Something isn't science if it isn't capable of disproof. We can't even imagine an experiment that would disprove the existence of God—so that's what makes a belief in God religion. When Einstein famously conjectured that matter and energy warp the fabric of space and time experiments to test the claim weren't possible but they were at least imaginable, so the theory was capable of disproof. Eventually he was proved right, based on astronomical observations of the orbit of Mercury, and also the bending of light from distant stars, observed during a 1919 solar eclipse—and most recently by the magnificent discovery by LIGO of gravitational waves from the collision of two black holes over a billion years ago. Yet even if he had been wrong, his conjecture would still have been scientific.

If falsifiability solves the “problem of demarcation” that Popper identified between science and non-science, equipoise addresses the problem of origin: Where ought scientists to start from? Thinking about where scientists do—and should—start from is often lacking. Too often, we simply begin from where we are. In some ways, therefore, equipoise is an antecedent condition to falsifiability: It is a state we can be in before we hazard a guess that we might test. It’s not quite a state of ignorance but rather a state of quasi-neutrality, when glimmers of ideas enter our mind.

Scientific equipoise tends to characterize fields both early and late in their course, for different reasons. Early in a field or a new area of research, it’s often true that little is known about anything, so any direction can seem promising and might actually be productive. An exciting neutrality prevails. Late in the exploration of a field, much is known, so it might be hard to head toward new things—or the new things, even if true, might be small or unimportant. An oppressive neutrality can rule.

Equipoise carries with it aspects of science which are sorely needed these days. It connotes judgment, for it asks what problems are worthy of consideration. It connotes humility, for we don’t know what lies ahead. It connotes openness, because it looks out at the unknown. It connotes discovery, because, whatever way forward we choose, we will learn something. And it connotes risk, because there are dangers in embarking on unknown journeys.

Equipoise is a state of hopeful ignorance, the quiet before the storm of discovery.

ANSATZ

NEIL GERSHENFELD
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“Ansatz” is a fancy way to say that scientists make stuff up.

The most common formulation of physics is based on what are called differential equations, which are formulas that relate the rate at which things change. Some of these are easy to solve, some are hard to solve, and some can’t be solved. It turns out that there’s a deep reason why there’s no universal way to find these solutions, because if that existed it would let you answer questions we know to be uncomputable (thanks to Alan Turing).

But differential equations do have a handy property: Their solutions are unique. If you find a solution, it’s the solution. You can guess a solution, try it out, and fiddle with it to see if you