ON THE LIMITS OF THE INSTRUMENT

# Forty-Six

*Three worlds, one narrow window, and the small embarrassed noise that built everything we know.*

For thirty-four years, every biology textbook on Earth carried the wrong number of chromosomes in a human being. Nobody was lying. This is an essay about how that happens, why it will happen again, and why that is the most hopeful fact available to us.

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*Intelligence with intent.*

> *They had the right answer. They threw it away. Because the right answer meant they were bad at their jobs.*

For thirty-four years, every biology textbook on Earth said that human beings have forty-eight chromosomes.

We have forty-six.

Nobody was lying.

The number came from a careful man named Theophilus Painter, who published it in 1921 and again, definitively, in 1923. He was a good scientist working with bad glass. His own preparations sometimes showed forty-six. He hedged, went back and forth, and eventually settled on forty-eight, which is roughly what you would expect from a coin flip made by a careful person under difficult conditions. And then the number went into the textbooks, and the textbooks went into the universities, and forty-eight became a fact about your body that was not a fact about your body.

Here is the part that should keep you up at night.

Sometime in the early 1950s, in Sweden, three researchers named Eva Hansen-Melander, Yngve Melander, and Stig Kullander were counting chromosomes in human liver cells. They kept getting forty-six. They got it repeatedly. And they stopped, and they did not publish, because a paper had just come out that seemed to settle the question in favour of forty-eight, and the only sane conclusion available to three competent people who kept counting the wrong number was that something was wrong with their technique.

They had the right answer. They threw it away. Because the right answer meant they were bad at their jobs.

The correction came on the twenty-second of December, 1955, at about two in the morning, when a man named Joe Hin Tjio, working in Albert Levan's lab in Lund, photographed a cell that showed forty-six chromosomes so clearly there was no argument left to have. He then counted more than two hundred and fifty cells. He published in 1956. Thirty-four years of textbooks went into the bin, and the number of

**34**

Years the wrong chromosome count stood in every textbook on Earth.

**~300**

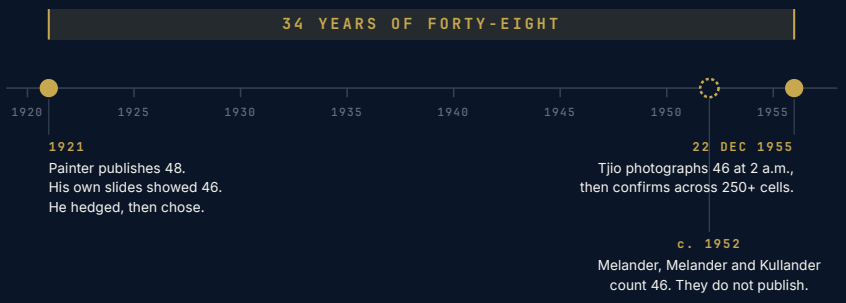
Papers published on N-rays between 1903 and 1906. N-rays do not exist.

**0.0066%**

Share of Earth's history occupied by anatomically modern humans.

FIGURE 1

**A correct answer, observed and discarded**




The hollow marker is a measurement that was made, and thrown away, because it disagreed with the record.

ORIGINAL FIGURE / IPURPOSE / VERIFIED AGAINST HEREDITAS 1956

I want to be careful here, because the easy move is to laugh at these people, and the easy move is wrong. Nobody in that story was stupid. Nobody was lazy. The Swedes threw away the correct count *because they were being rigorous*. Deference to the published record is not a bug in science. It is the entire mechanism by which any of us know anything at all. You cannot personally verify the boiling point of water at altitude, the safety of the bridge you drove over this morning, or the number of bones in your own foot. You take it on the authority of monkeys you have never met.

That deference is the most powerful technology our species ever built. It is also exactly how a wrong number lives for thirty-four years inside every skull on the planet.

There are three worlds, and we mostly talk as if there were one.

The first is what is actually there. Atoms. Rock. Hydrogen fusing eight light-minutes away. A river that does not know it is a river and will keep running whether or not anyone names it. This world does not require our attendance. It ran for four and a half billion years before the first thing on Earth had an opinion about it, and it will run afterward.

The second is the part of that world our equipment can pick up. Every animal has a window. Ours is a particular shape, and we did not choose it, and it is narrow.

The third is the story the monkeys agreed on. And this is the one we live in almost all of the time.

Consider Tuesday.

There is no Tuesday. There has never been a Tuesday. Nothing in the sky has a period of seven days. The year is a real thing, an orbit you can measure. The day is a real thing, a rotation you can watch. The month is a smudged version of a real thing, the moon, which is why it does not divide evenly into anything. But the week is pure invention. Seven is not a physical constant. Seven is a number some people liked, which propagated, and now four billion people organise their labour, their grief, their weddings, and their sense of dread around a rhythm with no referent in the universe whatsoever.

Money is the same trick. A border is a line that exists in the sense that men with rifles will enforce it, and does not exist in the sense that no atom on either side of it is different. A corporation is a shared agreement to treat a stack of paper as a person. Your name is a sound that other monkeys make with their faces, and when they make it, you turn around.

None of that is an insult. It is the opposite. Every one of those inventions is load-bearing. The reason our species runs the planet is not that we are strong or fast or particularly smart one-on-one. It is that we can extend trust past the range of physical proximity. A wolf trusts the pack it can smell. We can act, at scale, on the idea of a stranger we will never meet, based on a document neither of us has read, denominated in a currency neither of us can eat.

That extension is the whole magic. It is also where nearly every pathology comes from, because ideas that were built for the extended radius keep getting handled like commitments made in the local one. And it is why forty-eight lived for thirty-four years. Nobody re-counted. Nobody had to. The number was inside the trust radius, and things inside the trust radius do not get checked. That is what the radius is *for*.

Start with the window, because the window is the easiest thing to be wrong about and the hardest to notice you are wrong about.

Right now, in whatever room you are in, there are radio waves passing through your body carrying entire conversations. There is infrared coming off your own skin. If you are near a window there is ultraviolet arriving from a star. You are transparent to almost all of it and blind to the rest, and the sensation of that is *nothing*. There is no static. There is no faint hum at the edges of perception where the rest of the spectrum should be. The universe does not present you with a locked door. It presents you with a wall, and the wall feels like the end of the world.

You will see it written that human beings can see about 0.0035% of the electromagnetic spectrum. I am not going to use that number, and I want to tell you why, because it matters more than the number does.

> WHY THAT STATISTIC GETS CUT
>
> The figure is arbitrary. The spectrum has no ends. There is no longest radio wave and no shortest gamma ray. So any percentage depends entirely on where you decided to stop measuring. Run the same arithmetic on a logarithmic scale, which is the honest way to describe something spanning that many orders of magnitude, and you get about 2.3% instead. Same physics. Same eyes. A number six hundred times larger, produced by nothing but a choice about the graph paper.

An essay about humility that reaches for a misleading statistic to prove its point deserves to be thrown out. So here is the true version, which is better anyway: human vision covers roughly one octave. Not




ORIGINAL FIGURE / IPURPOSE / WAVELENGTH ON A LOGARITHMIC SCALE

Inside that octave, we do quite well. Outside it, other animals are having entire conversations.

Birds are the ones that get me. Many of them are tetrachromats, carrying a fourth cone type sensitive down into the ultraviolet, around three hundred and twenty nanometres, where our vision has already given up. This is not a small enhancement. In 2005, a researcher named Muir Eaton took a spectrophotometer to a hundred and thirty-nine songbird species that ornithology had classified as monochromatic, meaning males and females look identical. About ninety percent of them turned out to be dichromatic. The males and females look nothing alike. They have looked nothing alike this entire time.

> *Every field guide ever printed is wrong about what those birds look like. Not wrong about the taxonomy. Wrong about the picture.*

There are patterns on the heads of birds in your yard, right now, that have been there for millions of years, that the birds are absolutely using to make decisions about each other, and that no human being has ever seen with their own eyes.

It goes further than colour. There is good evidence that migratory birds detect the Earth's magnetic field, and the leading candidate mechanism puts the receptor in a protein in the retina, which would mean that a robin does not *feel* magnetic north the way you feel a draft. A robin may *see* it. An overlay on vision. A direction that is simply visible, the way blue is visible to you, which means we may share the planet with animals for whom "which way is north" is not a question but a colour.

I will flag that the mechanism is still contested. The phenomenon is not.

Elephants talk below twenty hertz, under the floor of human hearing, in calls that travel for kilometres through air and through the ground, so that a herd can be in conversation across a landscape while a person standing in the middle of it hears nothing at all. Baleen whales do a version of this across ocean basins. Bats and dolphins work above the ceiling instead. Sharks and rays hunt by reading the electrical fields of muscle contractions through jelly-filled canals in the snout. The platypus closes its eyes, its ears, and its nostrils underwater and hunts entirely by electricity, which means it has a sense we do not have a *word* for, only a Latin description.

And then there is the woman in the literature known as cDa29.

The genetics work out such that a certain number of women can carry a fourth cone type, because the relevant genes sit on the X chromosome. The theoretical estimate has been kicked around for decades, sometimes as high as one in eight women. Almost none of them turn out to see anything unusual. In 2010, Gabriele Jordan and John Mollon tested twenty-four women who carried the fourth cone. Twenty-three performed like everyone else.

One did not. cDa29 identified the odd stimulus every single time, in a way a three-cone system cannot do.

She is alive. She has, in all likelihood, no idea which of the things she sees you do not. There is no way for her to tell you, because the only instrument either of you has for describing colour is a set of words built by trichromats, for trichromats, to divide up a smaller space than the one she is living in.

FIGURE 3

### Channels carrying information you cannot receive

| | VISIBLE | ULTRA-VIOLET | INFRA-SOUND | ULTRA-SOUND | ELECTRIC FIELD | MAGNETIC FIELD | POLARISED LIGHT |
|---|---|---|---|---|---|---|---|
| **You** | ● | ○ | ○ | ○ | ○ | ○ | ○ |
| Honeybee | ● | ● | ○ | ○ | ○ | ○ | ● |
| Songbird | ● | ● | ○ | ○ | ○ | ○ | ○ |
| European robin | ● | ● | ○ | ○ | ○ | ● | ○ |
| Elephant | ● | ○ | ● | ○ | ○ | ○ | ○ |
| Bat | ● | ○ | ○ | ● | ○ | ○ | ○ |
| Shark | ● | ○ | ○ | ○ | ● | ○ | ○ |
| Platypus | ● | ○ | ○ | ○ | ● | ○ | ○ |
| Mantis shrimp | ● | ● | ○ | ○ | ○ | ○ | ● |

Filled marks a channel the animal detects. Magnetoreception is well evidenced as a phenomenon; the receptor mechanism is still contested. Every one of these signals is in the room with you right now.

ORIGINAL FIGURE / IPURPOSE / FILLED MARKS A DETECTED CHANNEL

We are not standing at the top of the perception ladder taking notes on the animals below us. We are one instrument, with one bandwidth, reporting on a small slice of a very loud room.

Now the third world, which is where things get funny.

In 1903, a physicist named René Blondlot, a member of the French Academy of Sciences, announced the discovery of a new form of radiation. He called them N-rays, after Nancy, where he worked. This was a reasonable moment to be discovering rays. X-rays had turned up eight years earlier and rewritten physics, and the smart money said there was more where that came from.

Detecting N-rays required an observer to notice subtle changes in the brightness of a faintly illuminated surface in a darkened room.

Between 1903 and 1906, about a hundred and twenty trained scientists published nearly three hundred papers on the properties of N-rays. Blondlot wrote twenty-six of them and a book. Researchers characterised how N-rays were produced, what materials they passed through, what stored them, what emitted them. It was a functioning field of physics with a literature.

The end came when an American named Robert Wood visited the lab on behalf of *Nature* in 1904. In the dark, while Blondlot's assistant was describing the N-ray spectrum he was observing, Wood quietly removed the prism from the apparatus. The prism was the piece that made the whole thing work. The assistant kept describing the spectrum.

I think about that room a lot. Nobody in it was a fraud. That is the thing. Blondlot spent his career on a real question and his instrument was his own eye at the edge of its sensitivity, which is a place where a human being will find whatever he expects to find, every time, reliably, forever.

Same century, different planet. In 1877, Giovanni Schiaparelli looked at Mars and reported about a hundred linear features. He called them *canali*, which in Italian means channels. A neutral word. Water cuts channels. Nobody has to dig them.

It came into English as "canals."

One word. Percival Lowell, a wealthy man who built his own observatory in 1894, spent the next twenty years mapping the irrigation network of a dying Martian civilisation, publishing three books about a planet whose inhabitants were heroically moving polar meltwater to their equator. He drew maps. Detailed ones. Mariner 4 flew past in July of 1965 and photographed a surface with no canals on it and never had been. What Lowell had been drawing was the human visual system doing what it does best, which is connecting scattered low-contrast dots into a line, because a line is a thing our equipment is built to find and dots are not.

> *A translator's word choice created a civilisation. It took eighty-eight years and a spacecraft to un-create it.*

Here is where the essay turns on itself, and I would like you to watch me get hit.

You have probably heard about the mantis shrimp. It has twelve to sixteen photoreceptor types. You have three. The internet has spent fifteen years explaining that the mantis shrimp therefore sees colours so far beyond human experience that we cannot conceive of them, and it usually shows up in exactly the kind of essay you are reading right now, as a humbling fact about the narrowness of human perception.

In 2014, a team led by Hanne Thoen trained mantis shrimp to pick coloured targets for food and measured what they could actually discriminate. The animals needed gaps of twelve to twenty-five nanometres to tell two colours apart. Humans manage one to five. The mantis shrimp is roughly ten times *worse* at colour discrimination than you are. It appears not to compare its receptors against each other the way we do at all. It seems to run a fast, coarse recognition pass, trading precision for speed, which for a predator that strikes in three thousandths of a second is a sensible trade.

The single most repeated fact about the limits of human perception is itself a failure of human perception. It is a wrong number that lived in the trust radius, propagating for years, in essays written by people trying to be humble.

I include myself. I believed it. I was going to use it.

And it gets worse, because there is a story one layer up, and that one caught me too.

Everyone who reads popular science knows about Lord Kelvin and the age of the Earth. He calculated, from the rate at which a molten sphere would cool, that the planet was far younger than the geologists needed, eventually narrowing to about twenty-four million years. The geologists were right and Kelvin was wrong, and the reason he was wrong, as everybody knows, is that radioactivity had not been discovered yet, so he did not know the Earth had its own furnace.

That story is false.

Put realistic radioactive heating into Kelvin's model and the answer does not improve. His actual error was assuming the Earth was rigid and cooled only by conduction. It is not and it does not. The interior convects, which changes everything, and this was pointed out in 1895 by a man named John Perry, who had been Kelvin's own assistant,

Perry was ignored. Ernest Rutherford, who was a superb physicist and an even better storyteller, liked the version where the discovery of radioactivity rides in and saves the day, and told it that way, and that version won.

> *The correction has been sitting in the record since 1895. It lost to a better anecdote. The story that spreads is not the story that is true. It is the story that is easiest to retell.*

⁂

I have been keeping this light, and I would like to stop for a minute, because some of these errors had a body count.

In 1847, in the Vienna General Hospital, a physician named Ignaz Semmelweis noticed that the maternity ward staffed by doctors was killing far more mothers than the ward staffed by midwives. The doctors came from the autopsy room. Semmelweis had no germ theory available to him, because germ theory did not exist yet, so he reasoned about "cadaverous particles" and instituted handwashing with chlorinated lime, and the death rate in his ward collapsed. Depending on the clinic and the month, something on the order of twelve to eighteen percent of mothers down to one or two.

He had the result and no mechanism, and the profession did not forgive him for either. His career was destroyed. He died in an asylum in 1865.

Alfred Wegener stood up in Frankfurt in January of 1912 and said the continents move. He had the fit of the coastlines, matching fossils on opposite shores, matching rock. What he did not have was a mechanism, and the mechanism he proposed was wrong: he thought continents ploughed through the ocean floor, which they do not. So the field rejected the whole thing, and it stayed rejected for decades, and Wegener died on the Greenland ice sheet in November of 1930 carrying a correct idea nobody would take. The evidence that vindicated him came up off the seafloor in the 1950s and 60s. The profession came around by about 1967.

Thirty-seven years after his body was left in the ice.

He was born prematurely in February of 1985, at around twenty-six weeks. He needed surgery to close a vessel near his heart. The operation involved opening his chest, retracting his ribs, and tying off the vessel. For this he was given Pavulon, a paralytic. A paralytic prevents movement. It does not prevent pain, and it does not prevent awareness. He received essentially nothing for the pain, because the standing consensus in medicine at the time was that the nervous system of a newborn was too immature to experience pain in any meaningful way, and that in any case he would not remember it.

He died about five weeks later. His mother, Jill Lawson, only found out afterward what had been done and what had not. When she asked, she was told, in substance, that it had never been demonstrated that premature infants feel pain.

She started writing letters.

The research that ended the practice was led by Kanwaljeet Anand, who did the thing that had never been done: he actually measured. He found that infants undergoing surgery mounted a massive hormonal and metabolic stress response, and that anaesthesia blunted it, and he published it in *The Lancet* and the *New England Journal of Medicine* in 1987. The American Academy of Pediatrics declared it unethical to operate on newborns without anaesthesia that same year. There is now an award named after Jeffrey Lawson, given for advocacy in children's pain relief.

Nobody in that operating room was a monster. That is the part I need you to sit with. Anaesthesia in neonates was genuinely dangerous. Babies died from it. The surgeons were balancing a known, measured, immediate risk against a harm that the literature told them was not real. They had a reason. It was a bad reason, and it was the best reason available, and it was believed by essentially everyone with the credentials to know, and it was never tested because nobody thought there was anything there to test.

> *The belief did not fall because someone was clever. It fell because a grieving mother refused to be quiet and a researcher ran the assay.*

I will add one more, because it belongs to a different category and the difference matters.

Tetraethyl lead went into gasoline in the 1920s. Workers at the plants started dying almost immediately. For roughly the next half century, the authoritative scientific voice on lead safety was Robert Kehoe, who reassured everyone that the lead in human blood was normal and harmless, and who held something close to a monopoly on the research because nearly all the funding for lead studies ran through the industry that made it. By the early 1970s American cars were putting over two hundred and seventy thousand tons of lead into the air every year.

The man who broke it was Clair Patterson, who had established the age of the Earth at four and a half billion years using lead isotopes and who, in the process, discovered that his own laboratory was drowning in lead contamination from the modern world. He invented the clean-room techniques required to measure it properly, showed that modern humans were carrying lead burdens far above any natural background, and went to the Senate in 1966 and said out loud that letting an industry police its own public health hazard was an abdication.

Semmelweis and Wegener and the neonatal surgeons were honest errors. Kehoe was a purchased one. Both produce a consensus. Both kill people. They are not the same thing and an essay like this one has an obligation to say so.

⁂

Which brings me to the trapdoor, and I want to nail it shut before somebody falls through it.

Somebody is going to read everything above and arrive at the following conclusion: the experts have been wrong over and over, therefore the experts are probably wrong now, therefore the thing I already believe is probably right.

That is the single most popular bad argument in the English language and this essay is not an argument for it.

The structure of the move is: they laughed at Galileo, they are laughing at me, therefore I am Galileo. Carl Sagan put the knife in it better than anyone. They laughed at Columbus, he wrote, and they laughed at the Wright brothers. But they also laughed at Bozo the Clown. Being rejected by the consensus is not evidence that you are correct. Being rejected by the consensus is evidence that you were rejected by the consensus. It is, statistically, what happens to almost everyone who is simply wrong.

So what actually separates the people in this essay from the ordinary crank? It is not temperament. Every one of them was stubborn. It is not persecution either. Plenty of people are persecuted and also incorrect.

It is this. Go back and look at what each of them actually did.

Tjio did not announce that there were forty-six chromosomes. He built better preparations, took a photograph nobody could argue with, and then counted two hundred and fifty more cells.

Barry Marshall did not argue that ulcers were bacterial. He cultured the organism, studied a hundred patients, drank the culture himself in 1984, gave himself gastritis, and then cured it with antibiotics. He and Robin Warren got the Nobel in 2005.

Wegener needed seafloor magnetic data to close his case and never got it, and the honest thing to say about him is that he was right and *insufficiently supported*, and he lost for a reason, and the reason was legitimate.

Patterson did not distrust the lead numbers. He invented the only laboratory clean enough to produce better ones.

Anand did not assert that babies feel pain. He measured cortisol.

> *Every single person in this essay who beat the consensus beat it by doing more work than the consensus had done. Not less. They were not sceptics of evidence. They were its fanatics.*

They won on the establishment's own terms, using the establishment's own instruments, held to a higher standard than the establishment was holding itself to.

The person who is merely wrong shows up with none of that. No new measurement. No mechanism. No prediction that could fail. Usually a story about corruption instead, which is emotionally satisfying precisely because it explains away the absence of evidence.

The test is never who is doubting. The test is who brought the better instrument.



Now the good part.

The atmosphere contains something on the order of ten to the forty-fourth molecules. A single human breath is around two times ten to the twenty-second. Divide one by the other and multiply back through and you get a result that has been kicked around for a century: given a couple of thousand years of atmospheric mixing, the breath you are taking right now almost certainly contains at least one molecule from the last breath of Julius Caesar. Not "poetically contains." The probability runs somewhere around ninety-nine percent, and the expected count is a few molecules per breath. It works for anyone. Caesar, your great-grandmother, the last thylacine.

Now, water.

I wanted very badly to tell you that the water in your glass has passed through every human being who ever lived. That the same water was in Mother Teresa and in Hitler and in every ancestor of every person you have ever loved, and that it has been on this planet the whole time, going round.

I went to check it, because that is the entire premise of this essay, and it turns out the popular version is not quite true, and the true version is stranger.

Individual water molecules do not survive centuries intact. Water constantly ionises and reassembles, hydrogen atoms swapping between molecules on timescales that make the notion of a persistent, identifiable $H_2O$ unit meaningless across even short spans. Water is also created and destroyed biologically. Your own body manufactures it as a byproduct of respiration; plants split it apart. New water arrives from volcanoes for the first time. Hydrogen leaks off the top of the atmosphere and is gone.



that persists.

The atom is.

The oxygen is old. The oxygen has been through oceans, and rock, and rain, and the bodies of things with no bones, and things with too many, and it does not keep any record. And that is a better sentence than the one I wanted to write, because it is true, and because it means the continuity is deeper than the pop version claimed. It is not a molecule making a tour of history. It is the fact that there was never any fresh material. There was never a new supply. Everything here was already here.

Which is also the honest answer to the thing about the cosmic background radiation.

The idea that the microwave hum filling the universe might be the accumulated dead is beautiful, and I understand the pull of it completely, and it is not what that signal is. It was found in 1964 by Arno Penzias and Robert Wilson, who spent months trying to eliminate an inexplicable hiss from a horn antenna in New Jersey, including evicting a family of pigeons and cleaning up what the pigeons left behind, before concluding the noise was coming from everywhere at once. It is the moment the universe cooled enough to become transparent, roughly three hundred and eighty thousand years after the beginning, redshifted down over thirteen point eight billion years to two point seven kelvin. When you tuned an old analogue television between channels, a small slice of that snow, often put at around one percent, was that light arriving in your living room.

It is not our ancestors. But here is the thing that is true, and that I would rather have.

Every atom in your body heavier than helium was manufactured inside a star. The calcium in your teeth, the iron carrying oxygen through you right now, the carbon in every cell. All of it was assembled under pressures you cannot imagine by stars that had to *die* and blow themselves apart to release it, billions of years before there was an Earth for it to land on.

That is not a metaphor. That is the manufacturing record.

> *You do not have to make the universe more beautiful than it is. You have to check.*

The Earth is four and a half billion years old. Anatomically modern humans are about three hundred thousand. That is six-thousandths of one percent of the planet's life. Compress the whole thing into a twenty-four-hour day and our entire species, every cave painting and pyramid and war and symphony, shows up in the last six seconds.

There is no oceanic crust anywhere on this planet older than about two hundred million years. None. The floor of every ocean has been completely manufactured and destroyed and manufactured again, more than once, since the dinosaurs were walking around. The rocks you can see out your window are not the rocks that were here. They are the current draft.

Life has been effectively annihilated five times. The worst was about two hundred and fifty-two million years ago, at the end of the Permian, when something on the order of ninety percent of all species and up to ninety-six percent of everything in the ocean stopped existing. The planet did not notice. It kept its orbit, kept its rotation, and carried on being a rock in the correct place, and eventually something else moved into the vacancy.




ORIGINAL FIGURE / IPURPOSE / 1 SECOND = APPROX. 52,500 YEARS

George Carlin did a bit about this in 1992 and it is still the sharpest version anyone has managed. The planet is fine, he said. The people are fucked. The planet has been here four and a half billion years. The planet is not going anywhere. We are. The planet will shake us off like a bad case of fleas.

He was right about the rock and wrong about the word, and the word is doing all the work.

Nobody was ever worried about the rock. The rock has survived being hit by something the size of Mars. The rock will be here, in some configuration, until the sun swells up and takes it. What is at risk was never the planet. What is at risk is *the arrangement*: this particular, unrepeatable configuration of living things that took several billion years of continuous operation to produce and that does not come back on any timescale a human can care about. After the asteroid at the end of the Cretaceous, functional marine ecosystems took roughly two million years to reboot, and full ecological recovery something closer to ten million. Life came back. It came back as something else. Every specific thing that was lost stayed lost.

Current vertebrate extinction rates run, on conservative estimates, up to a hundred times the background rate.

So the honest formulation is not "save the planet." The planet is not the patient. The honest formulation is that we are the thing the arrangement needs saving from, and that what we are actually destroying is not a rock but a library. The ultraviolet patterns on the heads of birds in your yard, the fourth colour cDa29 can see and cannot describe, every language, every animal running a sense we do not have a word for. Not the Earth. The contents.

And since you brought it up, I will say the other part directly.

The geological record is not keeping score on whether you have children. It has no opinion. Four and a half billion years of rock does not contain a single entry about anyone's reproductive choices, and it never will, and if you do not want kids you have a complete and sufficient reason already and you do not need to borrow a planetary one to justify it. And if you do want them, you do not owe the atmosphere an apology for it either.

Take care of the place. Not because the Earth is fragile. It is not. It is the toughest thing any of us will ever encounter. Take care of it because it is the only house, and because the arrangement inside it is delicate and interesting and irreplaceable, and because being a good tenant is its own argument.

The sun gives this planet something like another billion years of habitability. Complex life has more past than future. We are not living at the end of anything. We are somewhere in the middle, which is the only place anyone has ever been.

Let me tell you what I got wrong writing this.

I believed the mantis shrimp thing completely and was going to use it as the centrepiece of a section about the limits of human perception, and it is exactly backwards, and I only found out because I went to look up the citation.

I was going to tell you that the water in your glass had passed through Cleopatra as intact molecules. It has not. The hydrogen will not hold still that long.

I nearly printed 0.0035% as though it meant something, when it is an artefact of where somebody chose to stop drawing the graph.

And I was certain, the way you are certain about things you learned young, that Lord Kelvin's mistake was not knowing about radioactivity. It was not. A man named Perry told him it was convection in 1895 and got steamrolled by a better anecdote.

Four corrections. In one essay. About being wrong. Written by someone who went in specifically looking for the places he might be wrong, with the entire published record open in front of him.

I do not offer that as self-flagellation. I offer it as a measurement. That is the error rate of a careful person operating in good faith with excellent tools. It is not zero and it is never going to be zero, and the moment you think yours is zero, you have become the Swedish team throwing away a correct count because it disagreed with the book.

When one of us encounters something it does not understand, there are four things it can do. It can fight the thing. It can try to mate with the thing. It can decide the thing does not matter. Or it can find the thing interesting.

Only one of those four has ever produced a discovery. Not one of the others, not once, in the entire history of the species. Every instrument, every clean room, every photograph of two hundred and fifty cells at two in the morning came out of the fourth door, and the fourth door has a sound attached to it, and the sound is *huh*.

That is it. That is the whole apparatus. One syllable, made with the face, by a primate who has just noticed that the world is not shaped like the model in his head and has decided, for a moment, not to defend the model.

Somewhere in Sweden, in the early 1950s, three people looked into a microscope and counted forty-six chromosomes and put the result in a drawer, because the number was wrong and they knew it was wrong and everyone knew it was wrong. They were four years and one good photograph away from being right about the thing that assembles them.

I do not know their faces. I know exactly how they felt. So do you.

We are our own gods and our own makers of our own reality, and the only tool we ever had for checking our work is that one small embarrassed noise, and the monkeys who made it out loud are the reason you know what is inside you.

# What this essay checked

An essay arguing that careful people propagate wrong numbers has an obligation to show its working. Every factual claim above was verified against the primary or authoritative record. Four did not survive that process and were corrected in the text rather than quietly dropped.

### THE CHROMOSOME COUNT

Painter, 1921 and 1923. Tjio & Levan, *Hereditas*, 1956. The Hansen-Melander / Melander / Kullander unpublished counts are documented in the peer-reviewed history of the error.

### N-RAYS

Blondlot, *Comptes Rendus*, 1903. Wood's debunking, *Nature*, September 1904. The figure of roughly 120 scientists and nearly 300 papers is from Lagemann, *American Journal of Physics* 45(3), 1977.

### THE MARTIAN CANALS

Schiaparelli's 1877 *canali*; Lowell, *Mars* (1895), *Mars and Its Canals* (1906), *Mars As the Abode of Life* (1908). Refuted by Mariner 4, July 1965.

### SONGBIRD ULTRAVIOLET DICHROMATISM

Eaton, spectrophotometric survey of 139 species, 2005. Roughly 90% of species classified as monochromatic proved dichromatic under UV.

### CDA29

Jordan & Mollon, *Journal of Vision* 10(8):12, 2010. One functional tetrachromat identified among 24 carriers tested.

### MANTIS SHRIMP COLOUR DISCRIMINATION / CORRECTED

Thoen, How, Chiou & Marshall, *Science* 343(6169):411–413, 24 January 2014. Discrimination thresholds of 12–25 nm against 1–5 nm in humans. The popular claim is inverted, not merely exaggerated.

### KELVIN'S ERROR / CORRECTED

England, Molnar & Richter, *GSA Today*, 2007, and *The Physics Teacher*, 2014. Perry's convection objection dates to 1895, before the discovery of radioactivity. Radioactive heating does not repair Kelvin's model.

### NEONATAL ANAESTHESIA

Anand & Aynsley-Green, *The Lancet*, 1987; Anand & Hickey, *New England Journal of Medicine*, 1987. American Academy of Pediatrics position, 1987. Jeffrey Lawson, born February 1985.

### LEAD

Patterson's 1965 contamination paper and 1966 Senate testimony. Kehoe's funding monopoly is documented across the occupational-health literature.

### DEEP TIME AND EXTINCTION

End-Permian losses of roughly 90% of species and up to 96% of marine species. Post-K–Pg marine ecosystem recovery of roughly 2 million years (Alvarez et al., *Nature*, 2019); full recovery closer to 10 million. Vertebrate extinction rates up to 100× background: Ceballos et al., *Science Advances* 1(5), 19 June 2015.

### CARLIN

"The Planet Is Fine," *Jammin' in New York*, HBO, 1992. Quoted accurately and then argued with.

### WATER CONTINUITY / CORRECTED

The intact-molecule version of the claim does not survive hydrogen exchange, biological creation and destruction of water, juvenile volcanic water, or atmospheric hydrogen loss. The atomic version does.

### THE SPECTRUM FIGURE / CORRECTED

0.0035% is scale-dependent and therefore close to meaningless. On a logarithmic scale the same arithmetic yields roughly 2.3%. Human vision spans approximately one octave of an unbounded spectrum.

IPURPOSE · ESSAY NO. 01
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