8

IN THE LINE OF FIRE

Life on the barricades

From the outside, it seems an idyllic scene. It is the autumn of 2010, and the chestnut tree is just beginning to yellow against the red brick of Chicheley Hall, a magnificent Georgian country house set in 80 acres of beautiful gardens in rural Buckinghamshire. The Royal Society, the oldest scientific society in the world, has recently purchased the property for a cool £6 million and spent another £10 million converting it into a conference centre. The Kavli Royal Society International Centre will, they hope, offer scientists an atmosphere of relaxed creativity in which to work.

Inside the conference hall, however, the atmosphere is anything but relaxed. David Brin, a planetary scientist and science-fiction author, is fuming. His mouth is set in an ugly grimace, and from time to time his head shakes in exasperated disbelief. His eyes

hardly lift from the table in front of him, an angry stare burning into the wood. It is clear that when the current speaker, Seth Shostak, Senior Astronomer at the alien-hunting SETI Institute, finishes, Brin is going to explode.

Shostak and Brin are taking part in a panel discussion about whether we should attempt to communicate with aliens. After years of listening – in vain – for alien signals, Shostak is keen that we send out signals from the Earth in a systematic effort to make ourselves known to the universe. Brin thinks that could prove suicidal. When his turn to speak comes, Brin turns on Shostak, all guns blazing. Shostak has displayed a 'stunning ignorance and an incredible lack of imagination,' he says. Shostak, head slightly bowed, shows only a neatly cropped head of white hair and a wry smile. He has heard it all before.

As Brin's comments continue to pour contempt on Shostak's management of the search for extraterrestrial intelligence, it becomes clear that these two have history. Brin makes references to Shostak's 'arguments from ridicule' and his overseeing of 'Potemkin, stage-managed, party-driven Fox News-style meetings.'

This latter jibe is a reference to the times when the pair worked together. Brin was part of an effort by the International Institute of Aeronautics to draft a protocol about whether to broadcast messages into space in an attempt to reach out to alien civilisations. He eventually resigned from the committee in 2006 when Shostak and some other members changed some of the agreed wording, lopping off the proviso that international agreement should be reached before any such messaging took place.

'If they're silent,' Brin says (he means the aliens), 'then maybe they know something we don't know.' He is not scared of bogeymen, he says, he is properly cautious. And he is offended by the way he and people who share his sensibilities have been ridiculed:

'What we care about is the rudeness that's been going on, the failure of wisdom.'

As Brin concludes, the chair opens up the debate. Shostak is happy to get into an argument. If you think it's dangerous to broadcast, he says, you might as well shut down the search for alien signals too. The aliens, he says, 'will have reached the same conclusion'. Brin is still exercised. Back in 1990, he says, 'we were all one happy family here', a stark contrast to the 'mania of the last seven or eight years'. Shostak has had enough. 'You have provoked me,' he says, his voice rising in anger. 'No one was tyrannised.'

A Hungarian professor in the audience stands up and makes a plea. 'Can't we get back to the science?' he says. 'This looks like a TV show!' And he's right. It's like watching Jerry Springer host a science special. What's interesting – and rather funny – is what it takes to clear the air. About twenty minutes into the quarrel, an anthropologist, Kathryn Denning of York University in Toronto, stands up and asks a question about what level of broadcast signal would be detectable. 'I've been watching this debate for a number of years now,' she says. 'People with apparently equivalent credentials, and good brains with the ability to do math that I can't do, don't agree. Why not?'

There is a moment of stillness, as when a parent walks in on a fight between siblings. Then the astronomers close ranks. The agreement is pretty close, one says. No, says another, it's closer than that. A general hubbub rises in the room. There is no disagreement, they say. They are all friends again. Brin starts to talk about how good Shostak is on this topic and says that he listens 'very humbly and respectfully' whenever Shostak talks about SETI; Shostak has a 'wonderful paper' coming out on exactly this subject. The *volte face* is truly remarkable.

Nothing takes the fight out of scientists like the scrutiny of outsiders. They are secret anarchists, you see; open anarchy goes

against the grain. Nonetheless, their concerns do occasionally run too deep to be contained, and then their anarchy is unleashed on an astonished world.

On 5 February 1987, one of the world's best-known scientists was arrested in Nevada. Carl Sagan had been trying to scale a fence and enter the area where the United States military puts its nuclear arsenal to the test.

The arrest was a direct consequence of Sagan's scientific studies. Four years earlier, he had attempted to pull together everything that was known about the aftermath of nuclear explosions. He applied this understanding to the scenario of all-out nuclear war and summarised the arguments in an article entitled 'The Nuclear Winter'. Any such conflict, he said, would most likely involve 'the explosion of 5,000 to 10,000 megatons – the detonation of tens of thousands of nuclear weapons that now sit quietly, inconspicuously, in missile silos, submarines and long-range bombers, faithful servants awaiting orders'. The result, Sagan concluded, would be the rapid death of around half the humans on the planet. Those who survived would have to live in near darkness for months as ash and dust filled and blackened the sky. Plants, unable to harvest enough light for photosynthesis, would cease to grow. Starvation, radiation sickness, looting and barbarous anarchy would be the inheritance of the survivors.

Sagan knew there was a wide margin of error in his calculations, but he presented all the possibilities; the 'tradition of conservatism' generally works well in science, he said, but is 'of more dubious applicability when the lives of billions of people are at stake'. So he published his findings. His analysis was greeted with anger by many atomic scientists, and acute lack of interest from government officials. Aware that he wasn't going to get far by using the standard scientific channels, Sagan joined a group of people who felt that the stakes were high enough to merit direct action.

At the time of his arrest, the United States was continuing with a programme of weapons testing, even though the Soviet Union had called a unilateral halt to such tests. Two years earlier, Mikhail Gorbachev had announced that the fortieth anniversary of the bombing of Hiroshima – 6 August 1985 – would mark the beginning of a Soviet moratorium on the testing of nuclear weapons. President Reagan declared the move nothing more than a propaganda exercise and refused to follow suit.

On that day in 1987, more than two thousand people gathered at the Nevada test site ahead of the year's first nuclear test. Sagan and 437 others were arrested and bussed to nearby Beatty, Nevada, where they were booked, charged with trespassing or resisting arrest (or both) and then released pending trial.

Carl Sagan's fight was against the misguided belief that scientists should not interfere with how their work is applied. He did not endorse the post-war rebranding of science and was not prepared to behave like one of the timid monks that Jacob Bronowski had identified as representing the new, craven spirit of science. It was not just in the sphere of nuclear proliferation: Sagan wanted the walls surrounding science to come down, and did his utmost to communicate the delight, the findings and the implications of science to the public. Sadly, it won him few friends among scientists.

Sagan was passed over for tenure at Harvard and denied membership of the US National Academy of Sciences after becoming famous for talking directly to the public through books, magazine articles and TV programmes. The atomic physics pioneer Edward Teller once spluttered to Sagan's biographer Keay Davidson that Sagan was 'a nobody' who 'never did anything worthwhile'. Yet when *Scientific American* columnist Michael Shermer took it upon himself to analyse the truth of this statement, he found that, in terms of peer-reviewed publications in journals, Sagan was among the greats. For lifetime publications he ranks alongside Jared Diamond, E.O. Wilson and Stephen Jay Gould. From 1983 to 1996, the years in which he was at the peak of his media exposure and popular writing, Sagan was still turning out more than one scientific paper per month. His peers, though, saw him as nothing more credible than 'a publicist' for science. 'What Sagan was most famous for, and what got him in the biggest trouble with the academic establishment, was his Brobdingnagian outpouring of popular articles and interviews,' Shermer says.

After his coming of age in the post-war era, Sagan came to see that science is a tool used for political purposes – and that scientists had largely ignored their responsibilities to make sure that it is used the right way. He became passionately committed to returning science to its proper function of exploring the universe and, where possible, making it a better place to be.

In the early 1970s, environmental scientist James Lovelock wanted to find a way to measure how air moved around the globe. He soon realised that the chlorofluorocarbon (CFC) molecules that were then found in every refrigerator, freezer, can of hairspray or deodorant and myriad other products were a godsend. Once released, CFCs are stable in the atmosphere – they don't break down easily. They are also not naturally occurring: they enter the atmosphere only above populated areas of the Earth. So if you could travel round the globe with a CFC sniffer, you might be able to track the atmospheric currents.

Locking himself away in the laboratory he had built in the garden of his Wiltshire home, Lovelock set about building the most sensitive CFC sniffer the world had ever seen. He called it the electron capture gas chromatograph, and by the time he had finished it, it was sensitive enough to detect concentrations of atmospheric CFC equivalent to a single drop of water in a swimming pool. Ironically, it was so sensitive that he had to make his family stop using products that contained CFCs because they were interfering with his preliminary test results.

When the instrument was ready for service in the wider world, Lovelock booked a passage on the research vessel RRS *Shackleton*, which was making a return voyage to the Antarctic. All the way there and back, he took measurements of the concentrations of CFC in the atmosphere.

After his return, Lovelock attended a conference where he chatted over coffee with a scientist from DuPont, the principal manufacturer of CFCs. Together, the two men idly observed that Lovelock's measurements of the total amount of CFC molecules in the atmosphere tallied almost exactly with the total worldwide production to date. They thought it an interesting coincidence, but nothing more than that. Eventually, though, a chemist called Sherwood Rowland came across this little nugget of information. And he thought it was astonishing.

The news that all the CFCs that had ever been manufactured were still in the atmosphere gave Rowland an idea for a research project. He knew that the CFC molecules would be stable in the lower atmosphere, but he also knew that they would eventually rise into higher layers of the atmosphere and become exposed to increasing levels of solar radiation. This, he reasoned, would break the molecules down into their constituent parts. But what would happen after that? Mario Molina, who was working as a postdoctoral researcher in Rowland's lab, decided that he would be the person to find out. And by Christmas 1973, the full horror of the situation had become clear.

Molina found that the CFCs would take a few decades to reach the stratosphere, the atmospheric layer that sits between 10 and 30 miles above the Earth's surface. Once they arrived there, solar radiation would break them apart, releasing free chlorine atoms. And these chlorine atoms would wreak havoc on the ozone layer.

Ozone is a molecule composed of three oxygen atoms (an ordinary molecule of oxygen contains two). There isn't much of it in the atmosphere. What there is is all in the stratosphere, in extremely low concentrations. If you compressed it all together, the ozone would blanket the Earth's surface in a layer no thicker than tissue paper.

Nevertheless, it does an important job. Ozone absorbs ultraviolet light, shielding the Earth's surface from the harshest of the Sun's rays. Thanks to the ozone layer, we are protected from radiation that induces skin cancer and blindness. According to the World Health Organization, if CFC production had carried on unchecked, the ensuing depletion of the Earth's ozone layer would have caused an extra 500 million cases of skin cancer per year by 2050. Ten years on from that, the figures would have tripled. It is clear that destroying the Earth's ozone would have serious effects on the human race. And it was clear to Molina in 1973 that CFCs *would* eventually cause such destruction.

The ozone molecule is unstable; oxygen is much more stable as a molecule when composed of the usual two atoms. Free chlorine atoms, released from CFCs by solar radiation, would easily knock that extra oxygen atom from an ozone molecule. Together they would form chlorine monoxide, one of the highly dangerous molecules that chemists know as free radicals. Free radicals have a spare, reactive electron in their chemical make-up, and that makes them hungry for something to react with. In the stratosphere, chlorine monoxide would greedily mop up any free oxygen atom, forming a stable oxygen molecule and freeing the chlorine atom to start the reaction all over again. It was a chain reaction, in other words. And Molina knew that was bad news.

His initial reaction, he says, was disbelief – he thought he must have done something wrong in his calculations. But he also says that a chill ran down his spine. He knew that if he was right, then this was dangerous.

Rowland and Molina checked their calculations, discussed them with colleagues and searched for flaws in their analysis. They failed to find any, and in June 1974 they published their findings in *Nature*. A few months later they discussed the results publicly for the first time, at a meeting of the American Chemical Society in Atlantic City. By October, a US Government committee commissioned the National Academy of Sciences to conduct a study into the question of whether the ozone layer really was under threat from human activity.

Not that Rowland was waiting around for the National Academy of Sciences report to come out. The US Environmental Protection Agency calculated that non-malignant skin cancers would rise by 5 per cent for every 1 per cent reduction in stratospheric ozone. Deaths from cancer would increase as fast as ozone concentration decreased. 800,000 tons of CFCs was being released each year, and each chlorine atom they eventually unleashed on the stratosphere was destroying thousands of ozone molecules. It looked as if the ozone layer would eventually be depleted by 20 to 40 per cent. Rowland called for an immediate ban on non-essential CFCs. The industry railed at the possibility – and war was declared.

Unfortunately, most scientists were not willing to fight on Rowland and Molina's side. Some of them even fought for the opposition. In 1975 the Chemical Specialties Manufacturer's Association, a US industry umbrella organisation, brought Richard Scorer, a physics professor at London's Imperial College, to America. His job was to sow seeds of doubt. During his six-week tour, Scorer told anyone who would listen – the viewers of the prime-time TV show *Firing Line*, for example – that tales of ozone destruction were just 'scare stories', and that the supposed impact of CFCs was 'utter nonsense'. The Earth's atmosphere was the 'most robust and dynamic element in the environment. Man's activities have very little impact on it.'

Scorer's tour had no impact on the views of the scientific community, but surveys indicated that it increased by 50 per cent the public's awareness that there was scientific opposition to the claims being made by Rowland and Molina. That was more than enough to keep the controversy alive – and a ban at bay.

By 1976, Rowland was describing himself as 'impatient' for a ban on CFCs. He wasn't alone: at the ironically named 12th International Symposium on Free Radicals, held in Laguna Beach, California, in January of that year, other scientists echoed his concerns that nothing seemed to be happening. But that was not about to change.

When the US National Academy of Sciences issued its report in September 1976, its conclusions were so weak that the next day's *New York Times* reported the Academy as recommending a curb on aerosols, while the headline of the *Washington Post* screamed out 'Aerosol Ban Opposed by Science Unit'. As Lydia Dotto and Harold Schiff, authors of *The Ozone War*, point out, the equivocal nature of the Academy's report meant that both newspapers were 'fundamentally right'.

Things took a long time to improve. Alan Miller, a lawyer working at the Natural Resources Defense Council, has called 1977 to 1985 the 'Dark Years'. Although aerosol sprays using CFCs had been banned in the United States, sales of non-aerosol CFCs

– such as motor vehicle refrigerants – were soaring to new heights. And this was more than a decade after Rowland and Molina had shown CFCs to be profoundly dangerous.

'What's the use of having developed a science well enough to make predictions if, in the end, all we're willing to do is stand around and wait for them to come true?' That was Rowland's outburst to a reporter from *Newsday*. Most of the scientists involved in the ozone wars of the 1970s would describe their attitude as 'properly cautious'. But when the controversy led them to do what one scientist angrily termed 'science in a goldfish bowl', they were crippled by the public exposure, and they reacted badly.

Take the experience of Harvard atmospheric physicist Michael McElroy, for example. Industry representatives singled out his red hair and pale skin as proof that scientists had a 'special interest' in getting CFCs banned. The trade magazine *Aerosol Age* remarked that this man would naturally be an advocate of anything that might cut skin cancers. Even more shocking, perhaps, is this subversive jibe, written by a microbiologist in the pages of *Nature*:

> [O]n the beach at Cape Canaveral in Florida, I saw a red-headed man, sunburned to look like a boiled lobster, applying Novocain cream to his glowing back. The only unusual circumstance was that the man was Mike McElroy, whose field is the physics and chemistry of planetary atmospheres and who has loudly warned us against the ultraviolet perils of destroying the ozone layer ... Surely he, of all people, should have kept his shirt on.

In a 1988 interview, McElroy admitted that he made scientific contributions to the debate for a decade without supporting a CFC ban. He was, he said, more concerned about the 'credibility problem' that science was facing because of the 'gaps in our understanding' than he was about the dangers of depleted ozone. Atmospheric scientist Stephen Schneider took a similar line: he and his colleagues, he says, were 'caught between the exaggerations of the advocates, the exploitations of political interests, the media's penchant to turn everything into a boxing match, and your own colleagues saying we should be above this dirty business and stick to the bench'.

In contrast to this equivocation, Rowland and Molina stuck their necks out and stood up for the ban. Rowland's colleagues shunned him for his activism. Almost no university chemistry departments would have him come and speak for nearly a decade – unthinkable for a chemist of his calibre. Twelve years passed without him being invited to speak to industry groups. Even James Lovelock thought Rowland too rash: he called for a 'bit of British caution' in the face of Rowland and Molina's 'missionary' zeal for a ban on CFCs. Rowland says that taking a political stand over the science of ozone affected his reputation in the scientific community 'on a permanent basis'. Now, he says, be belongs to a group that is 'forever suspect'.

In the end, it was only the terrifying discovery of a hole in the ozone layer over Antarctica that galvanised the scientists. This was the point, McElroy later said, when he decided that it really was 'time to be very serious about regulation'. The hole began to appear in September 1976, just as the National Academy of Sciences issued its equivocating report. But, although everyone was meant to be watching the ozone, no one noticed.

NASA's satellite observation system missed the hole completely. The British observing station on the ground at Halley Bay in Antarctica didn't, but the data it gathered weren't being entered into any computers; instead, they were piling up in a Cambridge laboratory. For four springs (this is the southern hemisphere, remember), the seasonal disappearance of ozone passed all the scientists by. Then, in 1981, some Cambridge students finally got round to inputting the last few years' worth of data.

They didn't take long to notice the anomaly. The most trusted data from the American Amundsen-Scott ground station were indicating 2 to 3 per cent drops in ozone concentration, but according to the British instruments the springtime depletion was reaching 60 per cent. Joe Farman, who was heading the British team, contacted NASA to see whether their satellite had seen the same thing. He received no reply. One of his students got excited, and said they should publish. Farman said no – and tell no one. If they scaremongered, and they turned out to be wrong, all their funding would disappear. Farman decided to wait until he could check that his instruments weren't going awry.

The spectrophotometer at Halley Bay measured the ozone concentration in the sky above by checking which frequencies of light made it through the atmosphere and which didn't. The more UV that made it through, the less ozone there must be in the stratosphere. But Farman's instrument was nearing the end of its life; a replacement was waiting in Cambridge. When that replacement was finally installed and began taking measurements, it found the same seasonal dip in ozone. The 1984 readings showed a 40 per cent dip over a period of around 30 days between September and October. The hole stretched from Halley Bay to a second measuring station a thousand miles to the north-west. It was a big hole, in every sense.

So why hadn't the NASA satellite seen it? A pervasive rumour quickly circulated among the ozone-hunting community: the program NASA was using to analyse the satellite data had thrown out the anomalously low values. Though an appealing idea – *schadenfreude* is alive and well in science, especially when researchers are looking across national and cultural borders – it is not quite

true. The NASA satellite receiver marked the data as anomalous: very different from what was expected, and probably the result of error. The anomalies were 'flagged' for checking later. Unfortunately for the NASA researchers, when they got round to it, they checked the anomalies against the readings of the Amundsen-Scott ground station, and its instruments, unlike Farman's, *were* awry. Amundsen-Scott was recording ozone levels nearly twice as large as those the satellite recorded. And since that was more in line with expectation, the NASA researchers relaxed.

This is not to say that they threw the anomalous data out – they just took their time. It was a delay that the team leader, Richard McPeters, is probably still cursing to this day. We saw in Chapter 2 that data can be slippery. We saw in Chapter 6 that being first to a solid result is everything to the scientist. Perhaps that's why McPeters has since claimed to be the first to report the ozone hole, in an abstract submitted in 'late 1984' to the organisers of a Prague conference. But Farman remains the man officially recognised as finding the Antarctic ozone hole. His team sent their findings to *Nature* in December – they arrived in *Nature*'s offices on Christmas Eve – and they were published, to universal astonishment, on 16 May 1985.

According to the historian of science Maureen Christie, the hole could conceivably have been found as early as 1981; the British team 'could have saved two years if the data backlog had not developed, and up to another two if the team leader had been a bit less cautious'. NASA, meanwhile, had set up their system on the assumption that data on Antarctic ozone would be mundane rather than interesting, with no allowance 'for the possibility of surprises'. So it was that, eight years after the hole appeared, the scientists finally had something with which to shock the politicians into action.

Experts at the United Nations Environment Programme now estimate that the 1987 Montreal Protocol, the international treaty that limited emissions of ozone-depleting chemicals, prevented up to 20 million cases of skin cancer and 130 million cases of eye cataracts. In 2010 they reported that ozone concentrations are no longer decreasing. Though they are not yet increasing, pre-1980 ozone levels are expected to be regained before 2050 over most areas of the Earth. Over the poles, where the most severe depletion occurred, full recovery may take an additional fifty years. In the face of the CFC crisis, no one can pretend that all the inventions of science are an unqualified boon. But at least free, radical scientists can help to solve the problems that progress creates.

In 1963, Dennis Gabor published a book called *Inventing the Future*. It makes fascinating reading now, because Gabor, a Hungarian-born scientist and inventor (of the hologram, as it happens, for which he won the 1971 Nobel Prize in Physics), opens with a startling declaration. 'Our civilisation faces three great dangers,' he says. 'The first is destruction by nuclear war, the second is being crippled by overpopulation, and the third is the Age of Leisure.'

That nuclear war and overpopulation are dangers is not a startling revelation. Gabor's assertion is startling because the idea of a dangerous Age of Leisure seems like a joke. Many of us grew up being told that the best of times were just around the corner, that scientists would be kept busy inventing ways for the rest of us to occupy ourselves while robots and computers took care of everything. But it was no joke to Gabor: this age is 'not yet with us, but it is coming towards us with rapid strides', he wrote. We may now have laughed off the idea of the Age of Leisure, but it is worth noting Gabor's serious tone, because some other twentieth-century pronouncements still have a hold over us. The most enduring is the idea that science is more powerful than nature.

In a 1963 CBS documentary, the chemist Robert White-Stephens looks and sounds every inch the authoritative voice of science. He wears a lab coat, a neat moustache and thick-rimmed spectacles. His phrases are delivered in grave, Churchillian cadences. 'The modern chemist, the modern biologist, the modern scientist believes man is steadily controlling nature,' he says.

White-Stephens was responding to accusations made by a young biologist called Rachel Carson, who had published a book questioning the wisdom of America's new love affair with pesticides. Until 1945, most wars had ended because of insect-borne illnesses such as typhus: too many soldiers were dying of disease for fighting to continue. The invention of dichlorodiphenyltrichloroethane – DDT – changed that, and in the post-war era the chemists cashed in on the kudos they had garnered for themselves. Chemistry, its proponents suggested, could also change peacetime.

It certainly seemed plausible, and so governments invested in giant industrial complexes that churned out tons of chemicals for use in agriculture and city sanitation. US Public Health Department films show DDT being sprayed on happy children eating sandwiches in a public park, on others splashing in the municipal swimming pool, on mothers holding babies while watching community events. The chemists were going to eradicate the insect pest. And, despite the fact that one of the insecticides used, tetraethylpyrophosphate (TEPP), was nothing but the refined essence of a German nerve gas compound, it apparently never occurred to them that these pesticides could harm other organisms too.

It was only when people noticed birds dying that anyone began to express concern. Carson put across the extent of the threat with poetic clarity. The indiscriminate spraying, she said, could quickly lead to a springtime devoid of birdsong: a 'silent spring'. America, she eloquently argued, must rein back its release of chemicals into the environment.

Beset by illness and personal tragedy, Carson took four years to research and write her book. It was published in 1962 to critical acclaim, public alarm and vociferous scorn from many scientists. Emil Mrak, a food scientist and the chancellor of the University of California at Davis, testified to the US Congress that Carson's scientific conclusions were 'contrary to the present body of scientific knowledge'. Loudest among the scientific critics, though, were White-Stephens and his colleagues in the American pesticide industry, backed by a $250,000 anti-Carson war chest. Carson was advancing 'gross distortions of the actual facts completely unsupported by scientific experimental evidence and general practical experience in the field', White-Stephens alleged. 'The real threat, then, to the survival of man is not chemical but biological, in the shape of hordes of insects that can denude our forests, sweep over our croplands.'

Carson's thorough grasp of the science, coupled with the calm demeanour she displayed during her rare public appearances to defend the book – she was fighting a losing battle against cancer – saw off such offensives. The critics were eventually reduced to making crude personal insults: Carson was derided as 'hysterical', 'emotional', a 'tool of Communist menace', and a spinster who could know nothing about safeguarding future generations.

Despite these efforts to discredit and discourage Carson and her supporters (many industry scientists had covertly helped with her research, and those who were openly quoted in the book lost their jobs on its publication), majority opinion gathered behind the message of *Silent Spring*. Spurred into action by public concern, the US Government passed a flurry of laws on environmental protection. Quite rightly, Carson has been called the 'fountainhead of the modern environmental movement'.

Events in science that have had the potential to change humanity so profoundly are rare. Carson's insight seems on a par with

Edward Jenner's invention and championing of vaccination. Until *Silent Spring* was published, few members of the public ever thought that human beings were connected with, or depended on, the environment around them. This was not a result of ignorance, but of scientific arrogance: they believed the assurances of scientists that humans were now in a technological position to take control of nature and harness it for human good. Stewart Udall, then US Secretary of the Interior, remembers this time as the age of 'the atom changing our lives, of the conquest of nature, of technology being the great thing that was going to change the world'. The natural world, he says, was 'pushed into the background'.

That was the spirit in which DDT was sprayed with such astounding abandon on farms, streets, schools, swimming pools and the countryside. *Silent Spring* destroyed that spirit: suddenly, people realised that humans are part of the environment, not standing in isolation above it. Yet despite Carson's extraordinary work, it is a lesson we are still struggling to learn.

The beauty of Rachel Carson's prose is breathtaking – *Silent Spring* was, in part, such a huge success because Carson captured the poetry of nature in her writing. In her last letter to her friend Dorothy Freeman, Carson waxed eloquent about the monarch butterflies of Maine. Carson was in the late stages of her cancer and aware that she was unlikely ever to see the monarchs return to her beloved Maine after their winter migration. She and Freeman had spent that September morning together on the lawn of the Newagen Inn and enjoyed 'the sounds of the wind in the spruces and surf on the rocks, the gulls busy with their foraging, alighting with deliberate grace, the distant views of Griffiths Head and Todd Point, today so clearly etched, though once half seen in swirling fog'. Most of all, though, Carson told Freeman, she would remember watching the monarchs begin their migration: 'that unhurried westward drift of one small winged form after another, each drawn by some invisible force'. Evidently, Carson and Freeman had discussed each butterfly's fate never to return from this closing journey of their lives. The monarchs, Carson said, taught her about the cycles of life: 'it is a natural and not unhappy thing that a life comes to an end'.

Within a few months Carson had died, leaving a legacy – a new sense of environmental responsibility – that we have yet to fully work out. The monarchs are still caught up in that legacy: thanks to shifting weather patterns and the overuse of weedkillers, the inhabitants of Maine and the rest of continental America are seeing fewer monarchs return each year.

It is not necessarily an irreversible trend, as NASA scientist James Hansen will tell anyone who cares to listen. In the summer of 2008, concerned at the monarch's decline, Hansen took his grandchildren out into the wilds of eastern Pennsylvania to find some milkweed, the only plant monarch caterpillars will eat. They dug some up and planted it in his garden. The following year, they found the transplanted milkweed plants dotted with monarch caterpillars. Hansen and his grandchildren now take the seedpods from the milkweed, and plant them around their land in a tiny, near-futile effort to repopulate America with the butterflies that Carson loved so deeply.

But it is only doing nothing at all that is truly futile, Hansen believes. That is why, in 2004, at the age of sixty-three, he embraced life as a climate change activist. Two years later, *Time* magazine named him as one of America's 100 most influential people. That was also the year that Hansen got himself arrested for the first time. Just doing science, he says, is no longer enough.

It's not as if he hasn't done *enough* science. Hansen is one of planetary science's most respected researchers. He has a hugely prominent role as the director of NASA's Goddard Institute for Space Studies, and he is also a professor at Columbia University. He has won numerous awards for his research. Hansen knows, more than anyone, what happens when a planet is in thrall to global warming.

Take a look up into the sky the next time Venus is visible. You won't be looking at its surface: the planet is cloaked in clouds of sulphuric acid and, beneath that, carbon dioxide. Under this thick, stifling atmosphere, the surface of Venus is a barren waste that bakes at temperatures above 450 degrees Celsius. Venus is often referred to as the Earth's twin: its diameter is just 5 per cent less than the Earth's, and it has around four-fifths of the Earth's mass. James Hansen's mission in life is to make sure that those remain the only similarities.

Hansen is one of the scientists who worked out that the searing surface temperature is due not only to Venus's proximity to the Sun, but also to the blanketing effect of the carbon dioxide atmosphere. Knowing this made him deeply concerned about reports that the amount of carbon dioxide in the Earth's atmosphere was growing.

In 1988, the US Congress asked Hansen for an opinion on the 'greenhouse effect'. Some of the Sun's energy that hits our planet is reflected back from the surface. Carbon dioxide and other greenhouse gases absorb some of this reflected energy, preventing it from radiating back into space. A few scientists had begun to warn that increasing amounts of carbon dioxide in the atmosphere would result in rising temperatures on the Earth. If the balance of energy in versus energy out became too skewed in the wrong direction, the atmosphere could eventually heat to disastrously high temperatures.

Hansen's response to Congress was uncompromising. Aware of the claims, he had already stopped studying the atmosphere of Venus and started studying the atmosphere closest to home. 'The greenhouse effect is real,' he told Congress, 'it is coming soon, and it will have major effects on all peoples.' The scientific evidence for this, he said, was 'overwhelming'.

This is not the place to go into the details of claims and counter-claims about global warming (I would recommend Hansen's books for that), but Hansen's testimony to Congress, which stated that human activity is responsible for increased levels of carbon dioxide in the atmosphere, triggered a backlash from the industries, such as power generators and motor vehicle manufacturers, that were linked with carbon dioxide emissions. That backlash, and the political fallout, is continuing.

Right at the centre of the controversy is the IPCC – the Intergovernmental Panel on Climate Change. It is a Nobel Prize-winner: the 2007 Nobel Peace Prize was awarded jointly to the IPCC and Al Gore 'for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change'. But it is clear to many that the IPCC could do better. The influential physicist and climate activist Joseph Romm summed up the problem thus: 'Most scientists – and the IPCC in particular – have tended to overemphasize uncertainty on the key issues.'

Like the panel on alien communications at the Royal Society's Kavli Centre, the IPCC is keen not to be seen as too troublesome when faced with public scrutiny. For all the bold behaviour of some individuals, gather scientists together so that they are forced to speak with one voice, and they naturally, instinctively, make a concerted effort not to be alarmist, not to say things that might be interpreted as problematic. As a result, the IPCC, a collection of scientists speaking to the governments that control their funding, has underplayed the various impacts of the greenhouse effect – on sea level as glaciers melt, for instance. How? By overemphasising the uncertainty surrounding the data on climate change.

Hansen has pointed out that, although general funding for tackling climate change has increased dramatically in recent years, the lion's share has gone to those who are the most cautious. 'It seems to me that scientists downplaying the dangers of climate change fare better when it comes to getting funding,' he says. He has personal experience of this. In 1981, the US Department of Energy reversed a decision to award his research group a grant. They explicitly told him that it was because they didn't like a paper he had published on the likely effects of continued fossil fuel use.

The trouble is, if a body such as the IPCC plays down the likely impact of global warming, how can anyone decide on the most appropriate response to the real situation? As Carl Sagan pointed out when considering the likely effects of a nuclear winter, if scientists don't make the objective view available, how will anyone know what it looks like and understand what to do? Hansen's response to the conservatism of the IPCC is straightforward: 'Do we not know enough to say more?' he asks. In 2004, he broke a fifteen-year 'self-imposed effort to stay out of the media' and began to speak up.

In 2006, the *New York Times* reported on NASA's attempt to silence Hansen. His call for immediate cuts to carbon emissions, made at a meeting of the American Geophysical Union, led to NASA insisting that Hansen's supervisors stand in for him in any future media interviews. His response was to shrug his shoulders and carry on; to Hansen, this is a moral issue that has as much social import as civil rights or fascism.

When governments drag their feet over such issues, civil disobedience becomes the only option for citizens, Hansen says. That is why, in March 2009, he joined a protest against coal-burning power stations held at the Capitol Power Plant in Washington, DC. The organisers celebrated the event as 'the biggest act of civil disobedience against global warming in American history', and it was there that Hansen first declared his willingness to be arrested for the cause.

He didn't have long to wait. On 23 June, West Virginia State Police arrested Hansen and dozens of other demonstrators, including the actress Daryl Hannah, for trespassing on the property of a coal-mining company. Massey Energy were planning to blow the top off a Raleigh County mountain to get at the coal seams beneath, a practice that has been widely condemned for the environmental havoc it wreaks. In September 2010 Hansen was arrested again, this time during a protest – against the same practice – held outside the White House.

Hansen is always careful to make it very clear that in participating in these protests he is acting in a personal capacity, and not as a NASA representative. But, that done, he shows no sign of toning it down. These days he is advocating putting legal pressure on governments who, he says, have a 'responsibility to protect the rights of young people and future generations'.

Unlike Rachel Carson, James Hansen is not a particularly gifted communicator. His writing is plain, sometimes clunky, and almost entirely untroubled by poetic flourishes. It is quite the kind of writing one would expect of a self-declared 'slow-paced taciturn scientist from the Midwest'. One thing Hansen does have, and what seems to have set him on the same path as Carson, is grandchildren. His biggest fear, as a climate scientist with all the facts before him, is that his grandchildren will one day look back and justly accuse him of understanding exactly what was happening, but doing nothing about it. Helping them raise a few butterflies is not enough.

This raises an obvious question. Plenty of scientists – plenty of climate scientists – have grandchildren. So why does Hansen cut such a lone figure on the scientific barricades? We might put another related question here, too: why did the fight to ban CFCs take so long? Naomi Oreskes and Erik M. Conway framed the same issue another way in their revealing book *Merchants of Doubt*. They delve into the details of some of the biggest scientific battles of the last hundred years and find the scientists strangely disappointing. Oreskes and Conway wanted to tell 'heroic stories of how scientists set the record straight' on acid rain, climate change, tobacco marketing and the ozone crisis. But only in a very few cases were they able to. 'Clearly, scientists knew that many contrarian claims were false,' they point out. 'Why didn't they do more to refute them?'

It is clear that the open anarchy we have seen in the actions of Sagan, Carson, Hansen and others, though inspiring, is rather rare. Its rarity is in marked contrast to the prevalence of, say, scientific fraud. Analyse the history of scientists speaking truth to power, and you will find the scientists strangely timid. Sometimes, it turns out, scientists are nowhere near as anarchic as you might – given all we have seen – reasonably expect.

One reason for this is simple human timidity. Some scientists have been reluctant to make strong claims about climate change lest contrarians attack them. An oceanographer once told Oreskes that she would rather err on the side of caution in her estimates because it made her feel more 'secure'. The threat of personal and professional attacks – intimidation and bullying – has put many scientists off correcting the erroneous outpourings of climate change deniers.

Other reasons have much more to do with the downsides of the secret anarchy of science. There is, for instance, the self-interested desire to 'just get on with it'. In the same way that Barbara McClintock revelled in rejection because she could continue her research untroubled by interested colleagues, many researchers avoid controversy because they want to pursue scientific inquiry and nothing else.

Then there is the fact that scientists cling to the notion that the truth will out in the end. It is not the job of the scientist, some say, to get involved with the day-to-day process of informing the public about the scientific case in matters of public policy. Oreskes and Conway focus on this excuse and conclude, magnanimously, that scientists' failures to engage with pivotal issues mostly arise from a hopeless naivety. Scientists, as a whole, have a rose-tinted view of the power of science and genuinely believe that if they just quietly continue their laboratory research, then the scientific quest for truth will eventually triumph. The secret anarchists have, in other words, fallen victim to their own deception.

The final excuse for inactivity may be the most toxic by-product of the secret anarchy. Many scientists have announced that their expertise is of no value when it comes to deciding on a course of action. In a hearing about ozone depletion held before the US Senate, Michael McElroy said that when it came to making policy recommendations, his own advice 'isn't worth any more than the advice of any informed layman'. In 2008 the climate scientist Susan Solomon took the same stance, telling the *New York Times* that, 'If we as scientists go beyond what we know into our personal opinions and values, we begin to engage in the same sort of personal speculation masquerading as authoritative that we dislike when it is done by the sceptics.'

Though it could be lauded as humility, such reticence has much more to do with the secret anarchy. After decades of executing the post-war policy of keeping a bowed and subservient head – for the sake of Brand Science – scientists just aren't comfortable with raising their voices. Even when the world needs someone to say something.

This attitude is the one that most needs to change, according to Michael Nelson of Michigan State University. Hansen's position, Nelson believes, is the only morally acceptable one that scientists can take. Scientists, he says, have a special responsibility to engage in activism. 'When scientists reject advocacy as a principle, they reject a fundamental aspect of their citizenship,' Nelson has said. 'Rejecting one's responsibility as a citizen is unethical.' Assertions that scientists are only there to lay out the facts are dangerous for all of us:

> I shudder when I think about the implications of stripping scientists – those who might know more about some given topic than anyone else – of their citizenship. I do not think people know what they are saying or implying when they say scientists should not be advocates, or when scientists justify their lack of advocacy or criticize their peers on this basis.

Scientists, as highly informed citizens, have their own peculiar set of responsibilities, especially because their colleagues and professional forebears have, with the post-war rebranding of science, helped to create the problems that good science alone can solve. Carl Sagan put it thus: 'It is the particular task of scientists, I believe, to alert the public to possible dangers, especially those emanating from science or foreseeable through the use of science.' The quote comes from a book, *The Demon-Haunted World*, that Sagan dedicated to his grandson Tonio with these words: 'I wish you a world free of demons and full of light.'