New Scientist

WEEKLY September 19-25, 2020

EVIDENCE FOR ALIEN LIFE?

'It's basically either not a big deal, or we just found Venusians and that's incredible'

An extraordinary discovery in the atmosphere of Venus

CORONAVIRUS SPECIAL

ONE MILLION DEATHS

As the world approaches a grim milestone

THE DATA
Can we trust the numbers?

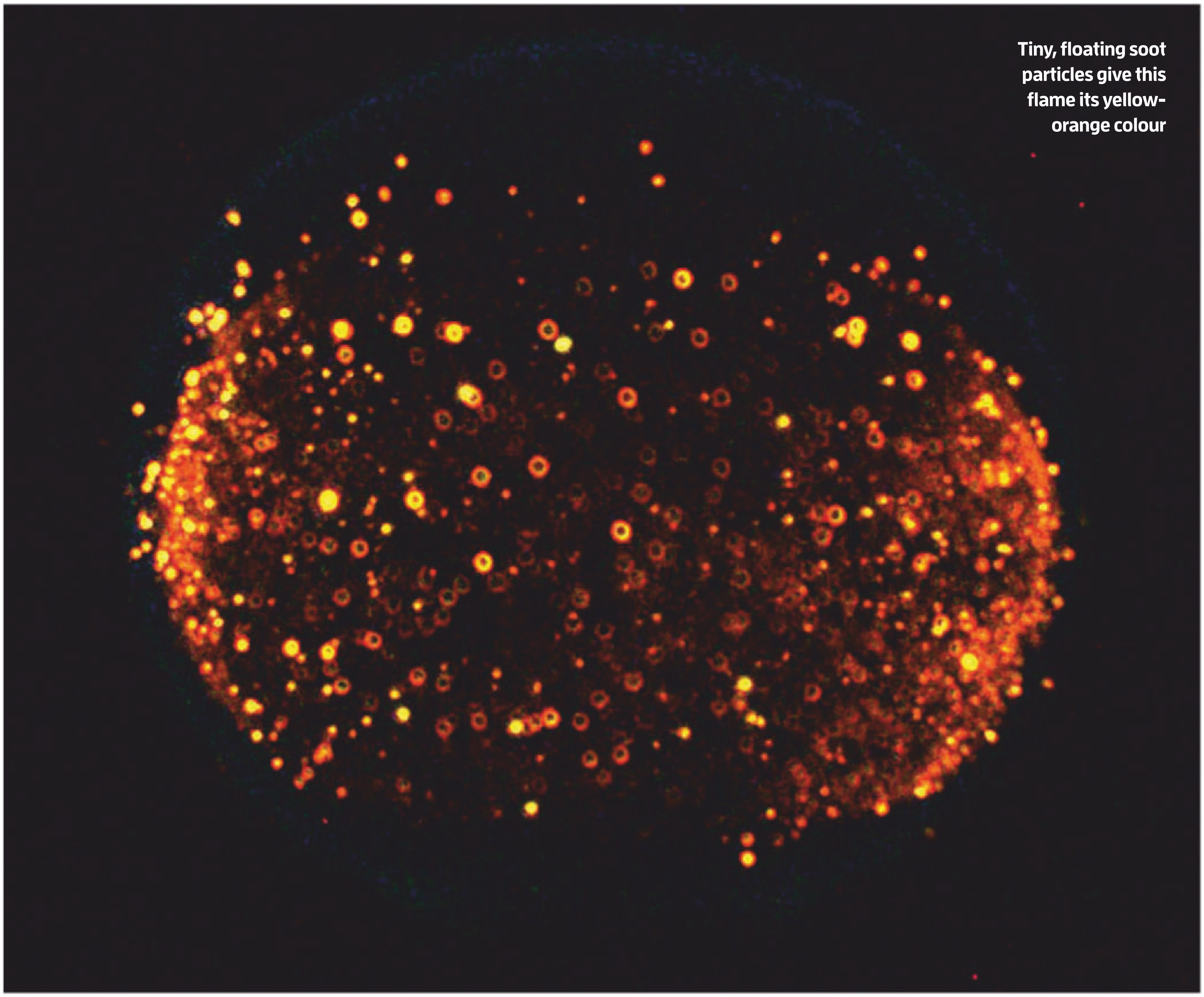
THE VIRUS
How is it mutating?

THE FUTURE
Will a vaccine solve everything?

PLUS FIRE IN ZERO GRAVITY / **VERY COLD HUMMINGBIRDS** / **YOUR UNIQUE GAIT** / BEST PET FOR AUTISTIC CHILDREN

Science and technology news **www.newscientist.com** US jobs in science

No3300
US$6.99
CAN$7.99



Tiny, floating soot particles give this flame its yellow-orange colour

The magic of fire in space

Flames unfettered by gravity are more than just beautiful. Studying them is a powerful way to help us control combustion on solid ground, reports **Philip Ball**

IF YOU are floating in Earth orbit in the life-sustaining bubble of air that is the International Space Station (ISS), surrounded by nothing but a frigid vacuum, the last thing you want is a fire on board. So it may sound worrying that, for the past decade or so, NASA has been lighting fires up there on purpose.

"Any time you mention starting a fire on the ISS, you're going to raise a lot of eyebrows," says Daniel Dietrich at NASA's Glenn Research Center in Cleveland, Ohio. However, these particular incendiary escapades are perfectly safe.

Fires can't start in space itself because there is no oxygen – or indeed anything else – in a vacuum. Yet inside the confines of spacecraft, and freed from gravity, flames behave in strange and beautiful ways. They burn at cooler temperatures, in unfamiliar shapes and are powered by unusual chemistry.

But the reason NASA is starting fires in orbit goes beyond mere aesthetics. It is chasing a deeper understanding of fire itself. Studying combustion in microgravity is beginning to enhance our ability to harness its power down here on solid ground. That could bring huge benefits through flames that emit less polluting gas or allow engines to run more efficiently.

Up in flames

Humans have been entranced by fire for almost as long as we have existed. Archaeological remains suggest that our ancestors were controlling fire 1 million years ago. Doing so was a crucial precursor to the invention of cooking, which allowed us to get more calories out of our food and reduced the infection risk from bacteria. Some researchers think this could have changed the course of human evolution itself.

Flames were no less compelling once we had figured out some of the science behind them. In 1848, in a series of public demonstration lectures, Michael Faraday explored the chemistry of combustion and respiration using nothing more than a candle flame. They proved wildly popular.

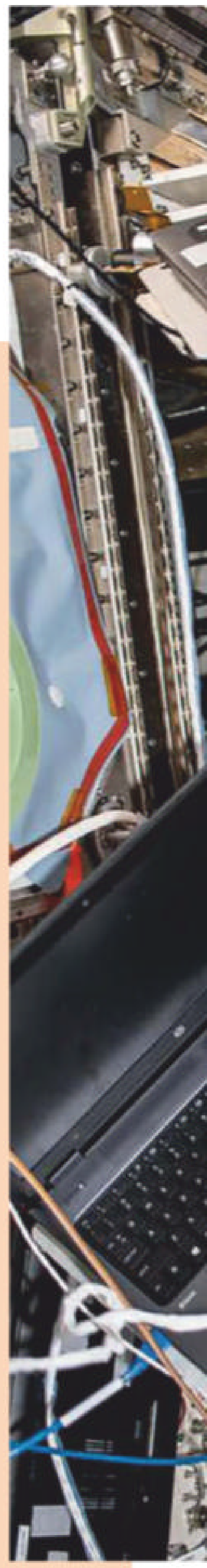
Fire is a chemical reaction in which the atoms in molecules of a fuel and oxygen get rearranged into carbon dioxide and water. But behind the apparently simple transformation is dizzying complexity. The burning of fuels happens via a welter of intermediate chemical compounds, many of them highly unstable and imperfectly understood.

Getting a detailed grasp of what is going on is tough because combustion is sensitive to movements of hot gases. These movements are driven by convection currents: the upward flow of hotter, less dense air and the sinking of cooler air. The flame itself both drives and is affected by these currents. This circle of cause and effect "is one of the key reasons that the problem is so challenging", says combustion scientist Paul Ronney at the University of Southern California.

There is good reason to pick at the problem, though. We may have taken great strides with renewable energy, but about 85 per cent of the energy we generate globally still comes from burning fossil fuels. Better understanding how these fuels burn could have huge pay-offs, like helping us extract heat more efficiently and avoiding unburned, wasted fuel. This would also mean that less pollution – such as carbon monoxide and soot, which are a result of incomplete combustion – is produced. Because so much of our energy comes from burning conventional fuels, "even small improvements in efficiency can be significant", says Dennis Stocker at the Glenn Research Center.

The reason studying fire in space is so attractive is that, with almost no gravity, there are no convection currents to complicate things. With the circle of cause and effect removed, a deeper grasp of what's really going on in a flame should be possible.

There is a way to see what happens to something in microgravity without leaving Earth: drop it. The Glenn Research Center has two drop towers, essentially long pipes in which experiments can free fall for a few seconds. These were originally used decades



"The experiments revealed something distinctly unexpected: fires in space can go out twice"

ISS/NASA

Astronaut Jessica Meir services the equipment used to light fires in space

ago to test how components of spacecraft would perform in low gravity. Since then, researchers have allowed burning droplets of methanol to fall down the tubes and used cameras and other instruments incorporated into the dropped load to record the results. A few seconds doesn't give you long, but the drop towers enabled NASA to conduct precursor experiments with fire before doing them in orbit.

No more teardrops

The agency first ignited fires in space in the 1990s aboard space shuttles. But it was with experiments on the ISS that the research really got started. These tests showed that a flame in microgravity looks very strange. It burns in the shape of a half-sphere instead of the familiar teardrop and it doesn't glow bright yellow but has a dimmer, blue colour (see photo, page 45). The colour difference is thanks to the lack of convective draught wafting fresh oxygen into the flame. Oxygen can then only get into the flame by diffusion, in which gases move slowly from areas of higher to lower concentration. This keeps the temperature lower and means less soot is produced – it is the incandescent heat of soot particles that creates the yellow colour of some flames on Earth.

In 2009, NASA began the Flame Extinguishing Experiment (FLEX), which involved igniting small droplets of liquid fuels such as methanol and heptane aboard the ISS. The experiments are prepared on Earth in an apparatus about the size of a washing-machine drum that is shipped into orbit and operated remotely from the ground. Astronauts aren't much involved, apart from carrying out routine procedures like cleaning. These experiments showed that burning fuel droplets must be within a certain size range to stay alight. Too small, below a millimetre or so, and oxygen can't diffuse into the flame quickly enough. Too big, and too much heat is radiated for the flame to stay hot enough.

That much was expected. But a few years later, the experiments revealed ›

Fire starters

The idea of a fire raging on the International Space Station (ISS), or on a future vessel voyaging through interplanetary space, is frightening. But in space, air doesn't move around in convection currents as it does on Earth because, with there being virtually no gravity, warmer, less dense air won't rise. Without convection, fires aren't fed so quickly with fresh air. They are less intense and spread more slowly than fires on Earth.

Still, the dangers are immense. A serious fire would raise the internal temperature and the pressure of a spacecraft, and use up precious oxygen. None of this can be quickly balanced by venting or admitting air from outside. And with plenty of electronics about, you might not want to use water fire extinguishers to put it out. The recommended procedure on spacecraft is to smother flames with carbon dioxide extinguishers – but if you use too much, you risk asphyxiation.

To make things worse, we don't really know how fires on spacecraft would play out. All the fires lit in space previously "have been about the size of an index card", says David Urban at NASA's Glenn Research Center in Cleveland, Ohio. "They're not fires you can get particularly frightened of, or that we're really worried about."

To wise up, NASA is running a project called Saffire in collaboration with the European Space Agency. This involves setting sizeable blazes that might happen in an accident on a spacecraft. It is too dangerous to do this on the ISS, so Cygnus cargo vessels, which ferry supplies to the ISS, are used instead. They are "like FedEx trucks" for space, says Urban. In their normal role, these disposable capsules are filled with ISS waste and allowed to burn up in the atmosphere.

NASA has lit fires in them several times over the past few years. In an experiment in 2017, the Saffire team found that these fires spread three times more slowly than expected based on experiments done in the ISS (see main story). They also seemed to stop growing once they reached a certain size. That might sound welcome, but it may mean smoke detectors on spacecraft need to be more sensitive to provide a useful warning. It may also mean that fires generate more noxious carbon monoxide.

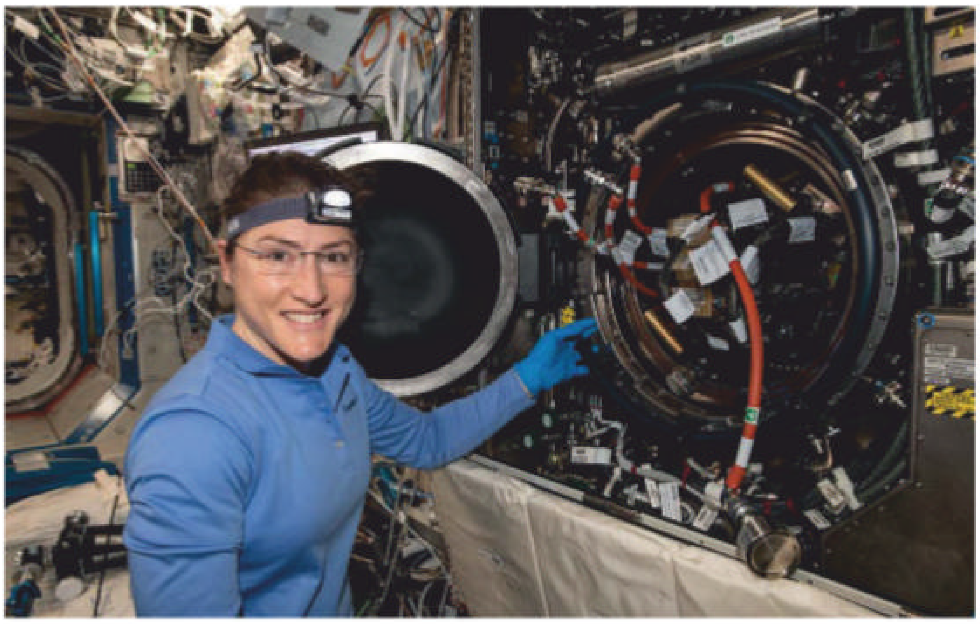
In May, the Saffire team conducted its most ambitious experiment yet, filling a Cygnus capsule with several 50-centimetre-wide swatches of materials to be burned, including a cotton-fibreglass material that mimics clothing, and the plastic used to make the windows of the ISS. The group also tested a filter designed to clean smoke from the air. The results are still being analysed, but Urban says the fires "didn't extinguish as quickly as we thought they would". Two more experiments are planned for October and sometime in 2021.

The biggest fires in space have been lit aboard Cygnus cargo capsules

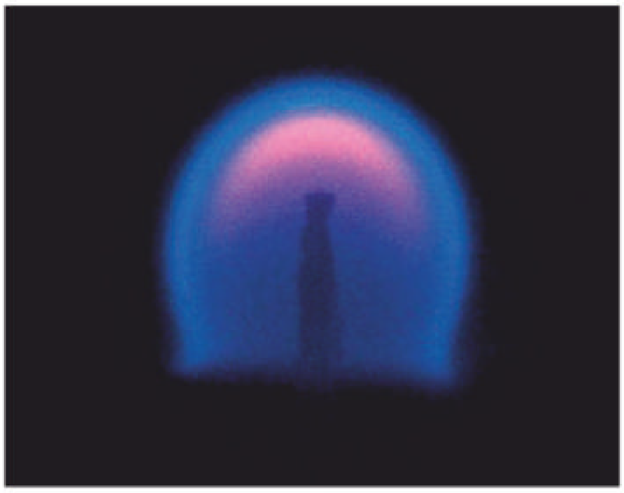
JEFF WILLIAMS/NASA

something distinctly unexpected: fire in space can go out twice. Droplets would burn until they got too small, at which point the visible flame would vanish. But combustion was still going on, even though it was producing no light. The visible flames burned at between 1200 and 1700°C, yet the invisible flames reached just 200 to 500°C. And whereas the hot flames burned fuel completely into carbon dioxide and water, the cool-flame combustion was incomplete, producing carbon monoxide and formaldehyde among other molecules. "The cool flames were a total surprise," says Ronney. They couldn't appear in drop-tower experiments because they need about a minute to form. "We've been trying to understand them ever since," says Dietrich.

This discovery from far above Earth could help improve an everyday technology: the internal combustion engine. We already knew that low-temperature combustion reactions feature in car engines and that they are responsible for misfires. But Dietrich says they were always viewed as an intermediate step in the ignition of hot flames. The fact that they are sustainable in themselves could be useful in a new generation of diesel engines being explored by companies such as car manufacturer Nissan. These homogeneous charge compression ignition engines burn premixed fuel and air at lower temperatures, creating less of the polluting nitrogen oxides that cause smog and acid rain.



ISS/NASA



NASA

Astronaut Christina Koch works on the rig used to light fires on the International Space Station (above). Inside it, flames burn in blue half-spheres (left)

Flame sculpting

To generate power, we burn all the states of matter, not just liquids. Gas-fired power stations provide about 25 per cent of the world's electricity, and NASA hopes that these too might be improved by looking at how gas burns in microgravity.

Investigations began in 2017, with the Advanced Combustion via Microgravity Experiments (ACME). Part of the project is about designing flames that burn more efficiently. In gas flames, sooty particles can form in regions where there isn't enough oxygen for the fuel to burn up properly, so that the carbon-based molecules from the fuel react instead with themselves. The ACME study should help us work out the optimal mixture of gaseous fuel, oxygen and other gases that could be used in a power station to minimise this process – a piece of knowledge that has eluded us on Earth. "Microgravity is a great environment for studying soot formation," says Stocker, who is part of the ACME team. "In normal gravity, all flames tend to look much the same because of the dominance of gravity-induced effects."

ACME will also try using electric fields to sculpt the shape of flames. Some of the molecules produced transiently during combustion are electrically charged ions and so they can be pushed around by an electric field. These flows can sweep up other gaseous components, so that the flames can be guided and deformed. "You can affect the shape of the flames, push them down towards the burner or make them bend in a certain direction," says Stocker. He says this could allow us to control soot formation and engineer flames that burn with less fuel than is usually possible. The lessons from these electric-field studies might ultimately be implemented in gas-fired power stations and other large furnaces, says Stocker, although that would probably be too expensive for a domestic boiler.

Next year, the NASA team will move on to look at how solids burn in microgravity. Here, the focus won't be so squarely on the fundamentals of fire, but on practical hazards. Plenty of spacecraft components are flammable solids and NASA wants to know how they burn so it can mitigate the risks of accidental fires (see "Fire starters", left).

Space-based experiments are sometimes criticised for being frivolous. But NASA's space fires could bring all sorts of benefits here on Earth. In his lectures, Faraday said that "there is no better, there is no more open door by which you can enter into the study of natural philosophy than by considering the physical phenomena of a candle". He probably never imagined quite how far we would take that idea. ■

Philip Ball is a science writer based in London