METHANE ON MARS: On Earth, it's a sign of life. But there's a problem...

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(How to stop leaving it.)

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ISSUE #116, JULY 2018

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Are We There Yet?

Dirtsider pessimists say humans will never develop interstellar travel, because apart from everything else, the light speed limit means it takes years to get anywhere. To which I say: so what?

Our experience of travel, in 2018, is quite unique in human history, and not just because of the heavier-than-air flying machines. No, it's mainly because of the way we assume everywhere *can be* only a matter of hours away. And taking, say, two weeks to cross an ocean, is a deliberate choice to "go slow".

Bold as the claim may seem, there really is almost no significant population centre on the planet that can't be reached from any other in less than 100 hours (assuming no transfer stuff-ups, malicious customs agents, ongoing war etc). Even cities in far-western China. Even Antarctica, if you're prepared to pay.

Before the advent of international jet air travel, no Australian thought of England as a place you could go to for a week. The old journo's joke about New York PR junkets - that we Aussies travel for 30 hours to spend 24 hours on the ground - would have seemed beyond science fiction to PopSci's New York based editors, in 1919.

Meanwhile, back in space, and while spending twelve years of your life getting to Alpha Centauri in a tiny can might seem unthinkable today, is it not merely a matter of degree over what used to be our reality - that it could take up to three months to get from England to Australia?

And would leaving Earth forever be such a big deal if you've already lived here for 40, 50, 100 years, and your life-expectancy was 200? Or 300?

Because modern Australia only exists beause people did pretty much this, just on a smaller scale. Many of my own relatives abandoned England in the 19th century, because they couldn't get permanent work, of any kind. After living half their adult lives in the Old Country, they said stuff it, and came out on a leaky wooden boat, never to return.

Of course, 12 years to Alpha Centauri implies a ship capable of 0.33 *c* and that's getting ahead of our current technological roadmap a bit. Okay, a lot.

Any interstellar First Fleet will necessarily be made up of so-called generation ships, crawling across the great empty and taking many decades, if not centuries, to reach their destinations. It sounds wild, because the idea that people might be born, live, and die aboard a ship and dedicate their lives to the "altruistic" goal of helping others settle a world they'll never see, flies in the face of early 21C individualism.

In 2018 it's all about YOU, your needs, your dreams and ambitions. But what are we striving for, right now? To not all die in a nuclear war? Noble enough goal but not exactly something you can point at and say "that way!"

Again, humans have already done the thing where they spend generations crawling across a vast distance in hopes of reaching some fabled paradise. After the ice nearly killed the lot of us 12,000-odd years ago, the scattered family groups fled the megafloods and the mud and crossed endless land bridges to reach the Americas, and to repopulate western Europe.

Those people spent generations saying "nope, not here, let's keep going." The idea of living your entire life on a possibly endless journey is part of the human tradition.

Yes, reaching a new star will make crossing the Bering Strait dressed in nothing but the fur you stole off some horrible toothy thing that really fought to keep it, will seem trivially easy compared to interstellar space travel.

But you know what happened to those people who just folded their arms and sat in the mud and refused to take the journey? They all died of malaria.

ANTHONY FORDHAM
afordham@nextmedia.com.au

Contents

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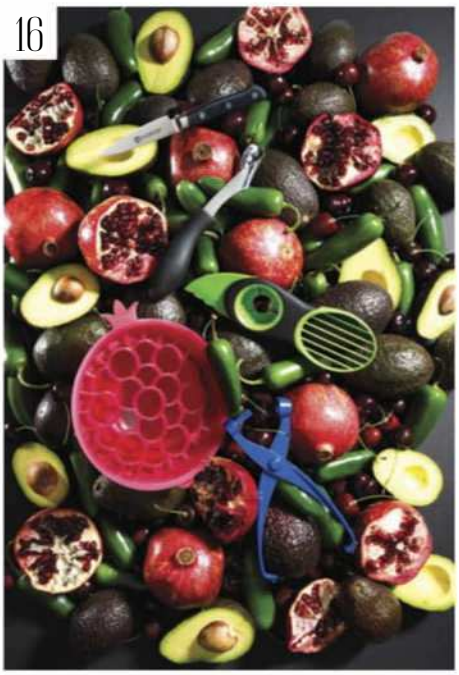
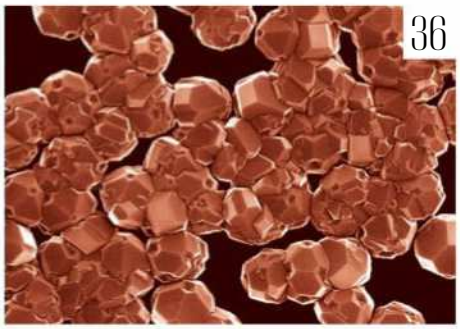
40 Gardener to the Stars (Literally)

Growing plants aboard the International Space Station wasn't easy, but we did it. The next step is to apply what we've learned to an interplanetary voyage.





UPDATE

All the science and tech news that's worth reallocating to your forebrain or whatever.

Compiled by Anthony Fordham and Staff Writers.

MBDA's Licorne C2 system co-ordinates data from "field deployed" sensors, and feeds it to other systems that can disrupt mini-drone data links.

Taking Down Drones Without Firing a Shot

The latest missile defence systems get new capabilities to face off against the rising threat of "mini-drones".

Need more proof that unmanned aerial systems are being taken very seriously by the world's armed forces? European missile systems manufacturer MBDA has announced its Licorne C2 "command and control" system now handles anti-drone defence, right out of the (very expensive) box.

We're not talking USAF style Predator drones, though. MBDA says Licorne co-ordinates very short range air defence (VSHORAD) systems to protect against what it calls mini-drone attacks.

Rather than use lasers (which MBDA also has, see right) or some other destructive system to take down the drones, Licorne instead uses datalink detectors and jammers to disrupt the drone's ability to be controlled, or even maintain level flight.

These detectors were originally developed to stop people flying contraband into prisons using store-bought quadcopters.

Since the drone needs a constant radio link with a controller to fly, Licorne doesn't need to use guns or missiles, it just needs to detect and then block this signal.

As a C2 system, Licorne's job is to provide data to a whole range of different sensors and weapons, and allow operators to decide exactly how to respond to a threat. MBDA calls it a "pocket" system, in that it can be transported into the field and connect to a huge range of different defence assets.

It's essentially a data processing and management system, and can be hooked up to everything from 360-degree cameras to radars, even acoustic sensors.

The rise of cheap quadcopters with decent range and payload capability remains a potential threat, but also one that is already well recognised. Here's hoping that with systems like Licorne already available, the idea of launching an attack with a store-bought drone might already be obsolete.

500m

Range of a *laser effector* developed by MBDA in 2015 to track and destroy free-flying mini-drones. So-called micro-UAVs are difficult to take down quickly or safely with conventional weapons, especially near the public. Laser effectors combine precise tracking with very accurate strikes, and other tests have shown they can even be used to take down mortars or rocket-propelled grenades in flight.

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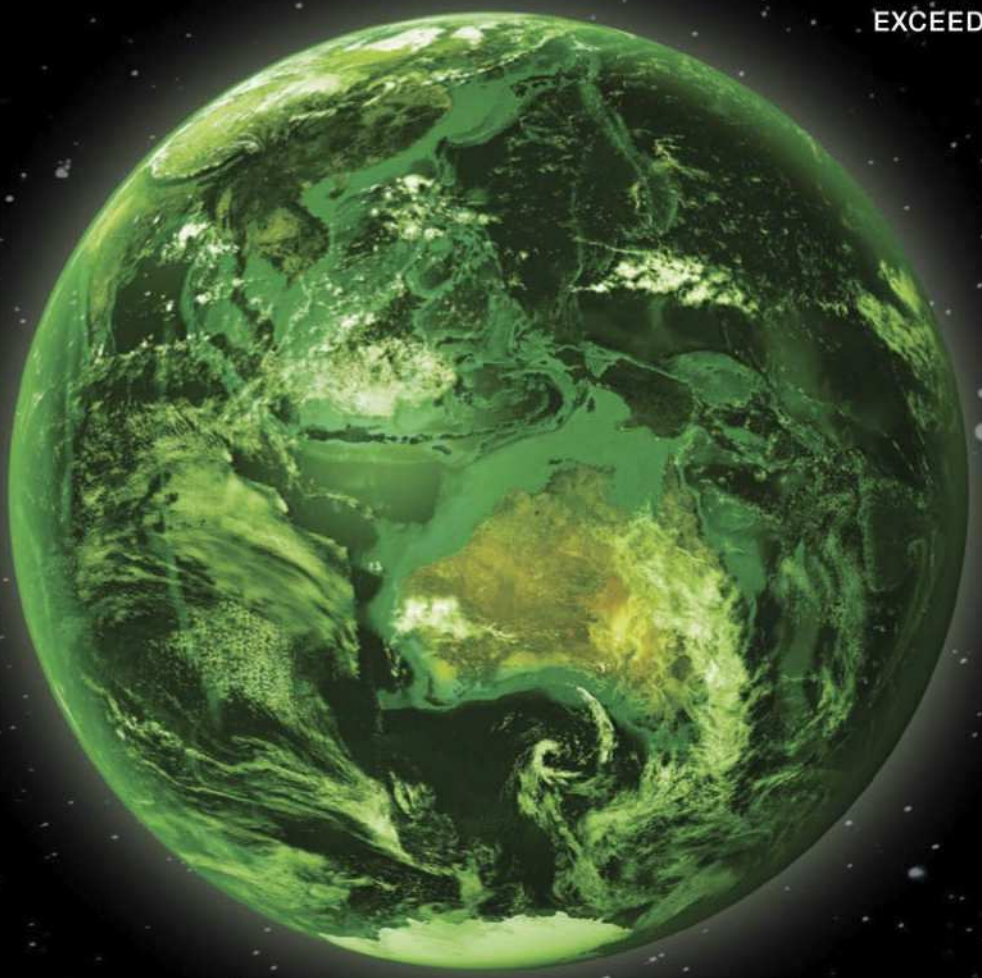

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IKHANA MAKES PUBLIC DEBUT

While MBDA is figuring out how to shoot down drones (p.06), NASA is busy figuring out how to enable them to fly by themselves, safely, in public airspace.

Previous flights of the Ikhana saw it shadowed by a chase-plane, with humans aboard ready to wrest control in the event of a glitching AI. But in this latest test, the Predator-sized UAS flew alone, through multiple air traffic control jurisdictions, without human intervention.

Of course, NASA insists that the technology inside Ikhana is intended for civilian use, like helping co-ordinate fire fighters, or search and rescue.

Even so, even if this tech does end up in military systems, it still stays on the right side of the debate over "killer robots". That's because Ikhana just flies where you tell it, and can't decide whether or not to drop a payload.

This is the line AI ethicists say should not be crossed: the ability for a machine to make a "kill decision".

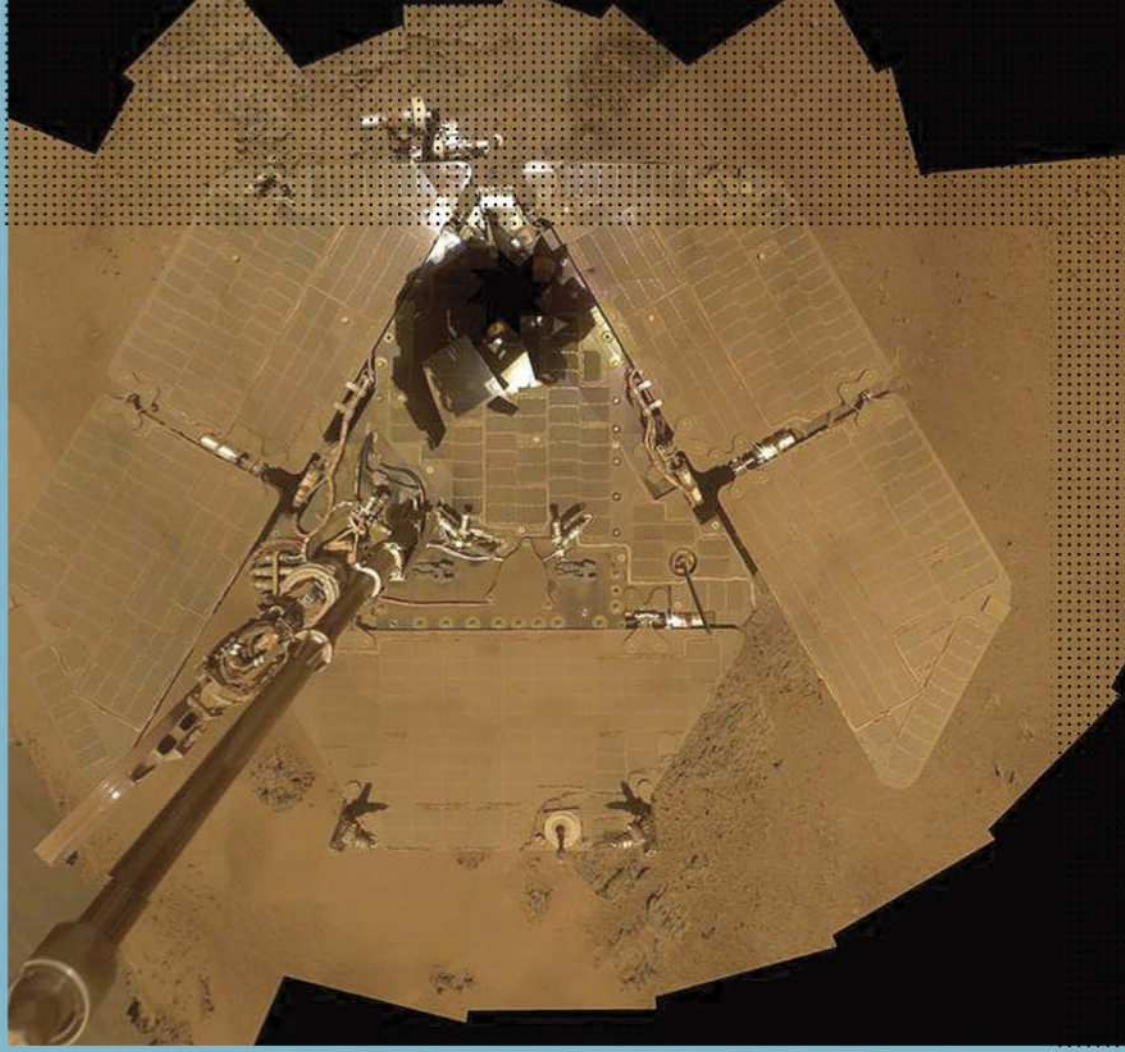
In the meantime, that NASA can already build an aircraft capable of independent flight, just shows how close we are to being able to make what many believe would be a terrible mistake.

FUTURE SHOCK
CHINA WATCHES YOU DRIVE

As part of a country-wide push to get citizens to use trackable systems to do, well, pretty much everything, all car registrations in China from 1st July 2018 will get an RFID tag, which can be read by roadside detectors. Drivers get a year to install the tag, and then the Ministry of Public Safety will insist. According to US media, the Chinese government says only the car's colour and license plate number will be recorded, so "the security of citizen's privacy will be ensured". You might think this is just one more cog in China's growing panopticon. We couldn't possibly comment.

TESLA INSISTS: HANDS ON THE WHEEL!

We recently reported on a (very illegal) device being sold to defeat the Model S's Autopilot safety systems. Now, in the wake of this and a number of high-profile crashes, Telsa has released an update to Autopilot that ups the nag-factor. Previously Autopilot only bugged drivers to hold the wheel every two minutes. Now it does it every 30 seconds. It also clarifies that by "hold the wheel" it means "exert slight turning pressure on the wheel" rather than just gripping it very tightly. Owners, naturally, remain extremely annoyed by the whole thing, and cynics remain convinced the problem ultimately stems from Telsa's decision to call its active cruise control system "Autopilot."



Dust Storm Limits *Opportunity*

One of the big criticisms of Andy Weir's space-survival novel (and film) The Martian, is that the dust storm that supposedly blew hero Mark Watney away from his fellow astronauts, was unrealistically strong.

And while Mars' wispy atmosphere means a planet-girdling dust storm would, in reality, feel like little more than a gentle breeze on a human cheek, NASA was just given a harsh reminder that dust doesn't have to hit you hard to mess you up.

After sitting through a truly epic dust storm, solar-powered rover Opportunity found itself critically short on juice. Earth-based operators have instructed Opportunity to engage various low-power modes, but the concern is if power drops below a critical level, the rover will no longer be able to heat its systems during the Martian night.

While the rover can still rely on its eight plutonium slugs each generating a single watt, there's a real chance that Opportunity's 14 year mission could end, not with a bang, but with an almost undetectable whisper of falling dust...

Retro Future Vertigo

At this year's E3 videogame conference, developer CD Projekt Red revealed new details of its upcoming role-playing title Cyberpunk 2077. The very specific science fiction sub-genre of cyberpunk combines the proto-internet predictions of 1980s authors like William Gibson, with a grab-bag of martial arts and action films. Mercenaries with guns grafted to their arms hack virtual reality banking systems to make ATMs spit out wads of paper cash, before the merc drives off in a petrol-powered car that looks like it was designed in about 1982. It's an intriguing mix of anachronisms that reminds us of a future that it's now pretty safe to say will never be. There's no word on a release date, but don't expect to see the game in 2018.

A ROOM FROM EXTRUDED WASTE

VENICE, ITALY, JUNE 2018: Since 3D printing became the hot "near future" tech of our current decade, more than one science fiction writer has imagined buildings not so much contructed, as recovered from plastic waste. The Cloud Pergola, an art installation for the Croatian Pavilion at the Venice Architecture Biennale, is (almost) exactly that. It's made from 300kg of biodegradable plastic, and was indeed 3D-printed. Sure, it's art first and architecture second, but it was created with an algorithm and a "portable robot". Back in April, the company behind the tech, Arup, used essentially the same system to build a full-size showcase home in just 48 hours.

VOXEL SPACE

A digital image is a grid of "picture elements" or pixels. A 3D structure is made up of volume elements, or **voxels**. Expect to see this word around more often, as 3D printing becomes more widespread.

Audeze Mobius Gaming Headset
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www.audeze.com

State of the Art

3D Headphones for a 3D World

by ANTHONY FORDHAM

ONE OF THE BIGGEST MARKETS FOR traditional over-ear headphones right now is gamers. As a result, most gaming headphones are, shall we say, *good value*. Yes, that's code: sub-$200 pricing means that, for all their team-chat and virtual-surround capabilities, most cans don't really cut the mustard for audiophiles.

Audeze wants to change this with its Mobius headset. Along with 100mm planar transducers (instead of cones) for drivers, it also packs amps, a microphone, Lithium-polymer battery, Bluetooth module, accelerometer, and gyroscope into a pair of headphones weighing 350g.

Wait, accelerometer and gyroscope? Indeed: the Mobius' real party trick is tracking the user's head movement in real time to create what Audeze claims is remarkably accurate 3D audio positioning.

While the cans can be used in standard stereo mode, the user may go nuts with configuring the width and depth of the sound field, emulate different room types, and engage head-tracking mode.

This 3D mode first sets a position as straight-ahead. If the user turns or tilts their head, the sound is adjusted so it keeps coming from the "correct" direction.

While that's of limited utility for music, for gamers it makes a huge difference, especially in complex environments with lots of (virtual) sound sources all over the scene.

This is because, in reality, humans constantly use small head movements to disambiguate the exact positions of similar sound cues in the environment. After all, we only have two ears, so how do we know when something is a bit-ahead-off-to-the-right-but-not-that-far? By processing the slight differences in the arrival time and waveform of the sound reaching our ears.

As a result, in games especially, the head-tracking function helps the brain position sound much more accurately in a virtual world full of exploding dinosaurs.

Along with 3D head-tracking, the Mobius is also a combination wired/Bluetooth headset. Pull the plug and engage Bluetooth mode, and the listener gets up to 10 hours of playback from the built-in battery.

To the average audiophile, it might sound like a case of more is too much. But this hasn't stopped Audeze raising over $1.2 million on Indiegogo to put the Mobius on gamer heads around the world.

Indeed the only obviously critical thing that can be said about the Mobius is that, while its 3D head tracking seems perfect for VR, its traditional headband design is awkward to wear over proper gaming headsets like the Oculus Rift or the HTC VIVE.

Of course that might just be our heads. Your head may vary.

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State of the Art

Seed Solvers

BY JASON LEDERMAN

BEFORE YOU CAN ENJOY CULINARY DELIGHTS SUCH AS guacamole and cherry pie, you first have to endure the tedious and finger-numbing process of pit removal. A sharp knife and some skill can extract any seed. But, if you have an insatiable appetite for kitchen gadgets (guilty), there's a purpose-built tool for almost any job.

1 Anything

Kikuichi began as a samurai-sword maker in 13th-century Japan but pivoted to knives—like this 80-mm paring model—in 1868. Its birch handle balances the weight of its stainless-steel blade.

2 Jalapeños

Williams Sonoma's stainless-steel **Jalapeño Corer** has a rolled, serrated blade. Shove it inside the chili, twist, and remove the seeds and pith, which contain the veg's mouth-scorching capsaicin.

3 Avocados

A&E visits due to botched avocado cutting incidents are on the rise. The plastic edge on the **OXO 3-in-1 Avocado Slicer** cuts only the fruit, then a trio of steel blades easily grab and extract the pit.

4 Pomegranates

Place a halved pom onto the **Shoham Pomegranate Tool**'s circular sieve, then cover with its rubber dome, and whack with a spoon. The husk stays in place as flavour grenades fall into the bowl below.

5 Cherries

The **Ionox Cherry Pitter**'s scissor mechanism ejects hard fruit cores. Just place the produce in the cup and squeeze. A narrow zinc-alloy column pops out the pit, leaving behind only sweet red flesh.

PHOTOGRAPH BY BRIAN KLUTCH / PROP STYLING BY WENDY SCHELAH FOR HALLEY RESOURCES

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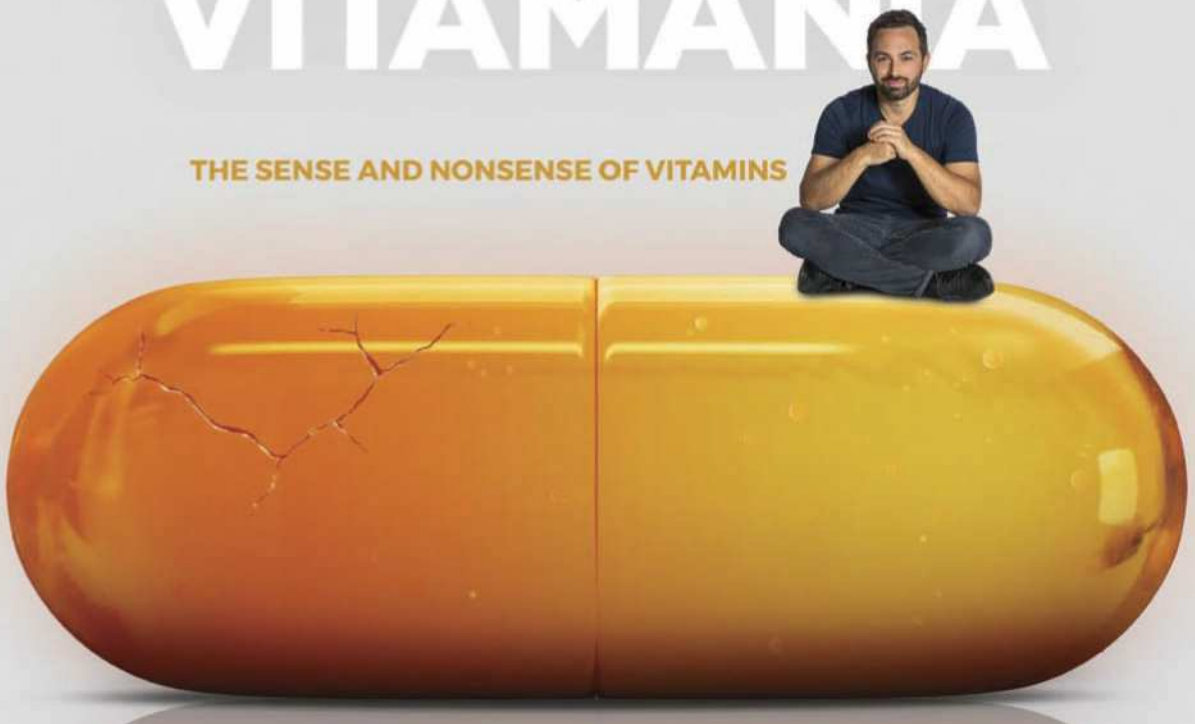

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State of the Art

Lives, Camera, Action

BY STAN HORACZEK

FLIP THROUGH THE PHOTOS YOU'VE TAKEN OVER the course of your life, and you can watch yourself (and your waistline) grow. For most of us, it's a tale spun through strings of same-looking selfies on smartphone camera rolls. *Bor-ing!* A stand-alone camera—from any generation—can capture distinctive memories worth keeping.

1 Past

The **Polaroid Originals OneStep 2** works like its predecessors, so your photos will have the same vintage flare your elders' snapshots did. One pack of colour film gets you eight 80-mm shots that instantly develop with the soft look that inspired your favourite Instagram filters - no, really. Each snap costs roughly $2, so choose your shots with care.

2 Present

Pros still gravitate to bulky DSLRs, but the **Panasonic ZS200** will do for the rest of us. Its 15x zoom lens starts wide enough for group shots but can go long to catch expressions at 50 metres. The 20.1-megapixel sensor is almost double the resolution of a phone, so today's pics could fill the huge screens our grandkids will stare at.

3 Future

AI-powered cameras such as **Google Clips** absolve you of your duty as family photographer. Set up the 50-mm box in the corner of the playroom, and its face and smile recognition ID big moments. When the robo paparazzi spies a playful pup or grinning kiddo, it takes a seven-second photo burst, which later offloads to an app.

PHOTOGRAPH BY BRIAN KLUTCH / PROP STYLING BY WENDY SCHELAH FOR HALLEY RESOURCES

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State of the Art

Porsche's Electric Dreams Get Real

by ANTHONY FORDHAM

FIRST REVEALED AT THE FRANKFURT Motor Show in 2015, Porsche's electric four-door "coupe" has been known by the suitably evocative code name *Mission E*.

Now, the car maker has confirmed its first all-electric vehicle will be available from 2020 - and we have to call it the Taycan.

It's Turkish, more or less, for "lively young horse", because Porsche wants to remind us that it too has included a horse as part of its badge since 1952. (The other prancing pony, Ferrari, is a very similar age, but got a horse-badged car out five years earlier, in 1947.)

The Taycan is a new platform for Porsche, built from the ground up.

It's hard to pretend that the Taycan isn't, at least on some level, Porsche's response to the Tesla Model S. It has similar dimensions, but comes packed with Porsche goodies like torque vectoring, dual "permanently excited synchronous electric motors", and a 350kW charging system Porsche's calls, well, *Porsche Turbo Charging*.

Total power will be around 440kW, although it's tricky to compare this directly with an internal combustion engine (since driveline losses are different). This is somewhat less grunty than the full-spec Tesla Model S P100D (580kW), but Porsche makes a big deal of how the Taycan is able to do multiple launches in a row without "loss of performance". Maximum range is the de rigueur "over 500km".

The Taycan will be the first model out of Porsche's massive six billion euro ($9.3 billion) investment in what it calls "electromobility". Part of this goes to building pure-electric vehicles, but there are also plans to hybridise existing product lines.

Today, the marque's most hardcore fans (typically 911-owners) will no doubt curl their lips at the idea of an electric Porsche. But as Europe cracks down on emissions, and the other advantages of electric drive become more significant, a new generation of car lovers may not have the same prejudice.

And anyway, you purists, it's not like the 911 wasn't already ruined by water-cooling, is it?

STRIPPED BACK TO THE ROOTS

To reassure Porsche fans that the company is by no means done with petrol, here's a concept car you can't buy, but are certainly free to drool over.

As part of 70th anniversary celebrations, the Speedster Concept is styled to create a link with Porsche's 356 'No. 1' Roadster, which rolled out in 1948.

The Speedster Concept is mostly for us to look at. Sure, there's more carbon fibre than usual, a 370kW flat-six engine that revs to 9000, and no roof, but you're supposed to take in the low fly-line, historically accurate (or is it evocative?) ~~paintjob~~ livery, special mirrors, and the fuel-cap in the middle of the bonnet.

Porsche's Speedsters were always ultra-exclusive models, but the last was in 2010. The company is considering whether to actually build and sell a handful of these in 2019.

Price? Put it this way: even if you could afford to buy one, odds are you're not already a good enough Porsche customer, to be allowed to.

As well as plug-in, the car can be charged via an induction-plate.

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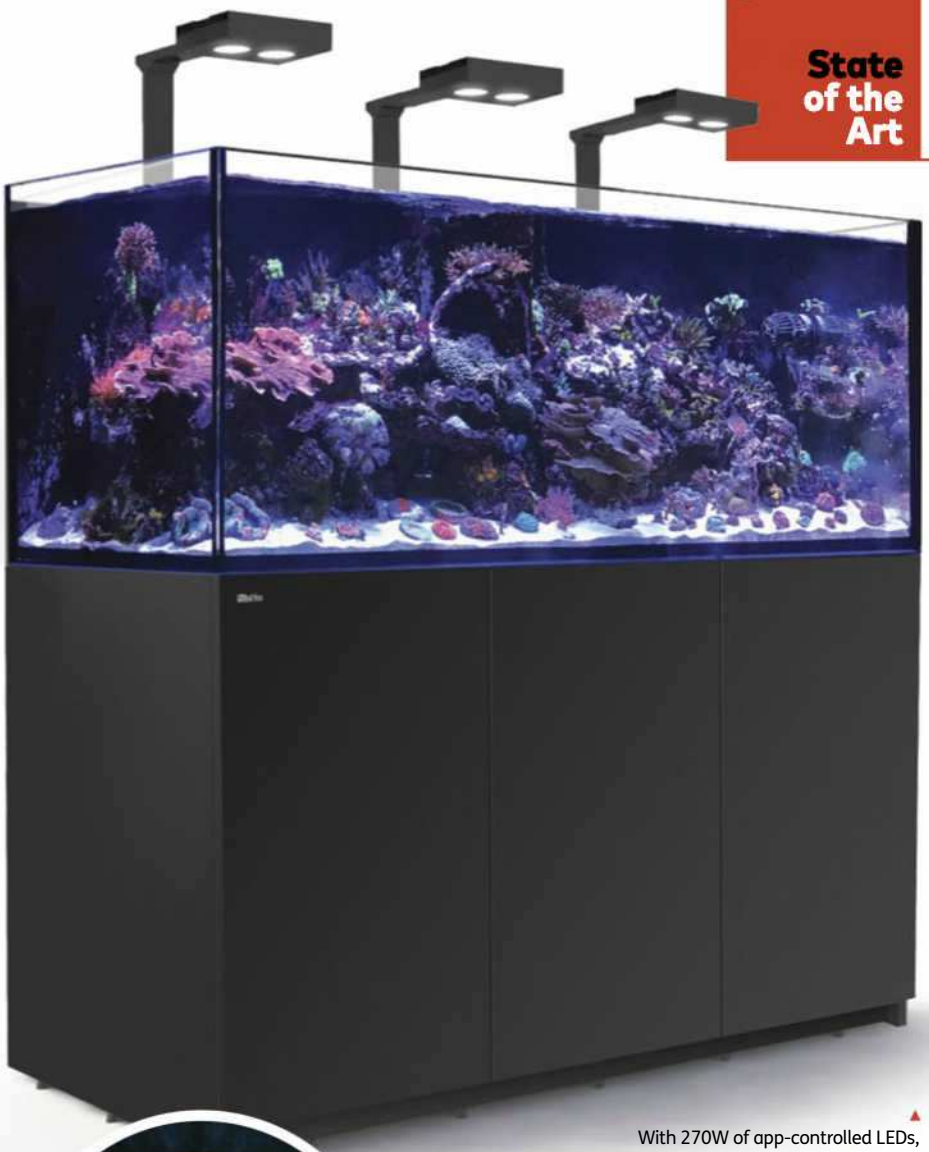
State of the Art

Clever Kit for Keeping Corals

by ANTHONY FORDHAM



With 270W of app-controlled LEDs, this massive 650+ litre aquarium gets as much light as 1200W of metal-halide bulbs, without the excess heat.

HAVE TROUBLE KEEPING A COUPLE OF goldfish alive? Then a reef aquarium full of live corals probably isn't for you. Or maybe it is. Because keeping a marine tank has become much more manageable in recent years - and much easier on your power-bill.

Corals, being photosynthetic, require specialised lighting to thrive. Traditionally, this was supplied best by metal-halide incandescents. These hobby-specific bulbs were expensive to buy, and even more expensive to run. A lighting rig over a 1200mm wide tank can chew anywhere from 500 to 1100W for the 11-12 hours of daily operation corals need. Add heating and a (very) complicated filtration and circulation system, and a reef tank can easily draw a 24-hour average of 2000W. That's like running a blow heater, all the time.

LED has made a huge difference to the hobby, with the advent of extremely high-output lights that consume a fraction of the power of incandescent equivalents.

Consider the Aqua Illumination Hydra 26 HD lights on this tank (left). Each of the three units pulls a maximum of 90W, but provides photosynthetically-useful light equivalent to a 400W metal-halide bulb.

Even better for reefkeepers, each light is equipped with Wi-Fi and enough smarts to communicate with an app - available on Android and iOS. The app replaces bulky timers, and allows the lights to be programmed with a day-night cycle.

Also, because each light unit is made up of several individual LEDs of different wavelengths, it's possible to tweak the colour and intensity of the light, to simulate dawn and dusk, cloudy days, phases of the moon, even the occasional thunderstorm (with flashes of lightning).

Keeping a marine aquarium is mostly about staying on top of changing tank conditions. Corals - and the fish that live alongside them - are tough animals, but only if the water remains at more-or-less 24 degrees, and at a particular salinity. Think of a reef tank as a garden - but one that can die in four hours if something goes terrible wrong.

The rise of apps and cheap Wi-Fi transmitters has been a boon to coral fans. Monitoring systems are now much cheaper, and can even send mobile notifications, or sound alarms if water parameters (or water levels) stray outside programmed limits.

LITTLE IS HARDER

One of the odder truths in reefkeeping is that smaller tanks are more challenging. A 500L tank resists changes in water chemistry, better than a 50L tank. Even so, LED lighting has reached the world of these so-called "nano" reefs too. AI's Prime HD light isn't much bigger than a desk lamp (it even has a bendy arm) but puts out enough light to keep a small, square chunk of ocean alive, and thriving. It too communicates over Wi-Fi with the same app.

State of the Art

Infant Oasis

BY CLAIRE MALDARELLI

AN ADORABLE BABY MAKES home an exciting place, but new parents need an occasional break from that postpartum party for things such as, oh, eating and sleeping. These nursery essentials will help turn a babe's room into a haven that provides both the little one and their tired caregivers a little peace.

1
No-touch night light
Nursery navigation is tricky after dark, but the **Hatch Baby Rest** lamp lets you control the intensity and colour of its light with an app. Little ones won't mistake a red glow for morning.

2
Baby's first sleep tracker
The **Nanit** baby monitor observes your little one's slumber, and uses an AI-driven app to alert you of environmental variables such as room temperature and humidity that can affect dream time.

4
Eye-exercise equipment
The high-contrast patterns on the **Wimmer-Ferguson Stimmobile** catch baby's attention, even during the early months when they're still learning how to focus.

3
Robo-swing
Movement calms babies, so the **mamaRoo4** chair uses two motors to mimic motions captured from recording real mums. There's rocking, swinging, and quick bounces.

PHOTOGRAPH BY BRIAN KLUTCH / PROP STYLING BY WENDY SCHELAH FOR HALLEY RESOURCES

TERRAFORMING

From Sea to Desert to... Forest?

by ANTHONY FORDHAM

ONE OF THE FIRST REALLY HIGH profile victims of globalisation, the Aral Sea, began drying up in the 1960s after its feeder rivers were diverted. The USSR used the water to grow cotton, and proved that massive feats of geoengineering are quite easy to achieve if you don't care much about the knock-off effects.

The Aral Sea became a multi-layered environmental catastrophe. Lower water levels meant higher salinity, which killed the fish, while runoff from the same cotton fields concentrated toxic chemicals on the sea bed

The result: a poisonous desert, where every windstorm sent (and still sends) toxic particles into the lungs of the locals.

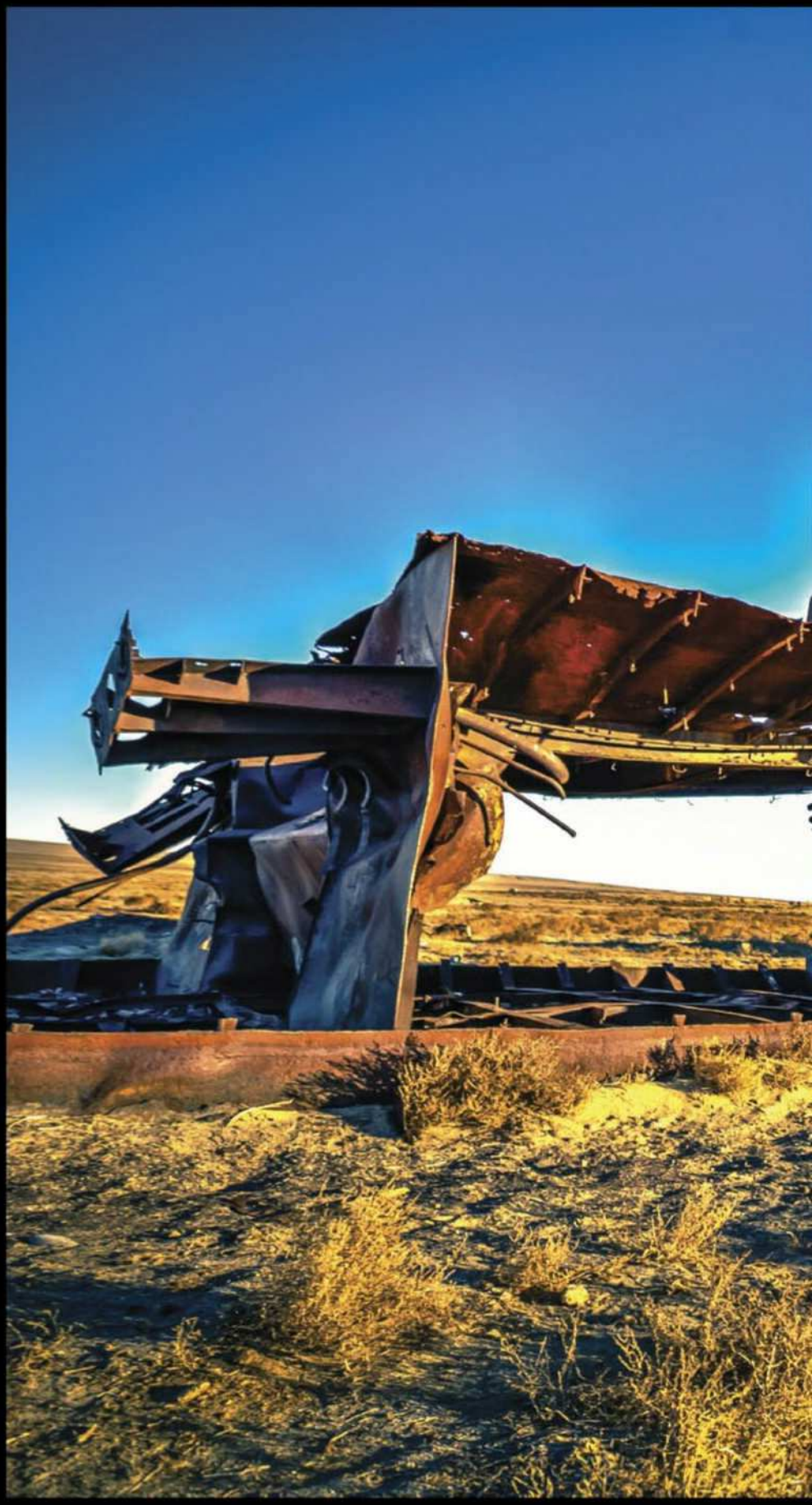
Incredibly, this was all kept more-or-less secret until the fall of the Soviet Union in the early 1990s, and the problem is, perhaps unsuprisingly, proving much harder to fix than it was to create in the first place.

Refilling the sea comes later. For now, the focus is on keeping that toxic dust out of the air.

One solution is to plant millions of trees. Specifically, the saxaul tree, more of a shrub really. It's plant superpower? To jealously hold on to as much as ten tonnes of soil around its roots. The toxins don't bother it.

With little government support and even less money, locals and environmental groups have planted half a million hectares of saxaul so far. That means only a little over three million hectares to go before this modern-day desert becomes a forest.

Some estimates say at current rates, the job won't be finished for 150 years. That's roughly five times as long as it took to ruin the Aral Sea in the first place.



NOT EXACTLY A RAINFOREST

It's not that planting millions of saxaul trees will "cure" the Aral Sea from being a desert. The saxaul (*Haloxylon ammodendron*) is a tough arid-country survivor, already used in China to combat deforestation. Its bark stores drinkable water which can be extracted by pressing. The 2008 Central Asia energy crisis - where severe cold and high electricity prices threatened lives - put the saxaul at risk of extinction. So, ironically, the Aral Sea could also save the saxaul. It's all interconnected...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Insight

BODY HACKING

When Eating Healthy Makes You... Sick?

by SARA CHODOSH

The internet is covered in keto flu germs. Keto, the nickname fans have given to the ketogenic diet, has swept the globe in a fat-burning storm and left many a groggy dieter in its wake. Wait, groggy?

Diet-culture influencers and motivational Instragramites with abs like the metal ice tray from your gran's old fridge, have a new favourite buzz-phrase: keto-flu.

Keto-flu is what you get when you're so awesome at dieting and smashing that workout, your own body rebels and makes you feel gross. Does that sound unspecific? It kind of of is: "keto flu" is a loose collection of general symptoms that many people going onto the keto diet experience.

They describe a wide range of symptoms from brain fog to fatigue to nausea and everything in between. Not everyone even gets it (in the sense of, not all people will suffer this, rather than... never mind), but nutritionists describe it as just "generally not feeling well". They also confirm that it's a real condition. But what actually is it?

NOT ENOUGH TOO SOON

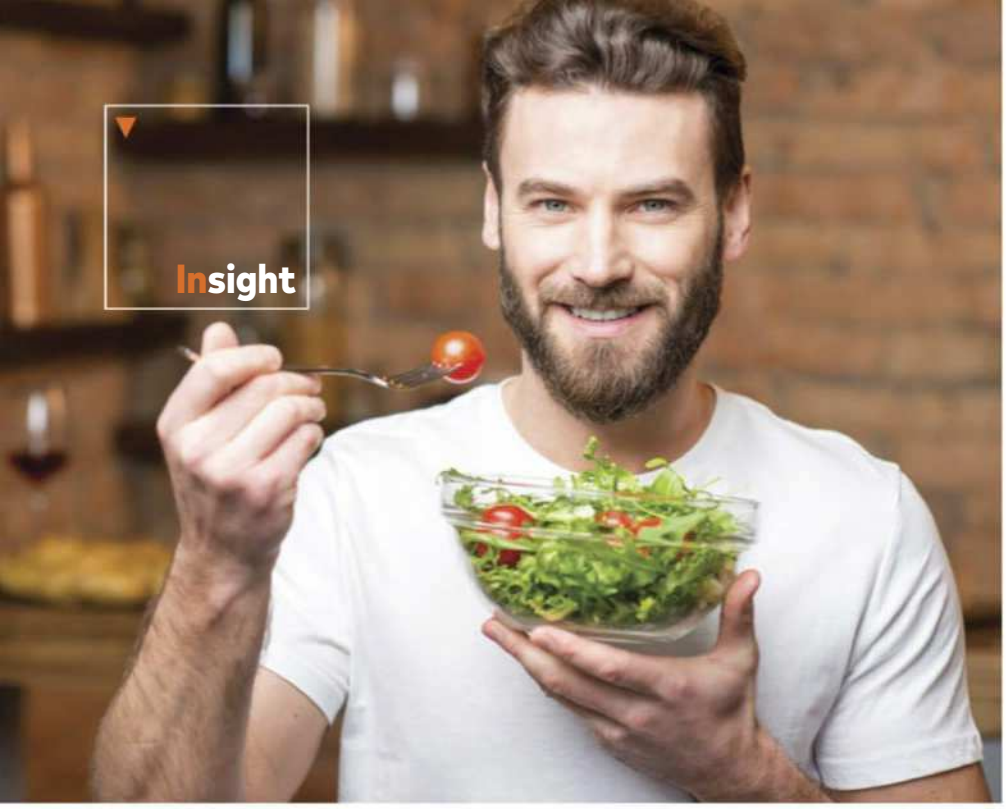
"Metabolically I'm not quite sure what causes it," says Teresa Fung, a professor at Simmons College and a clinical nutritionist, "but usually when people have a big change in their diet their body needs some time to adjust."

Which is why trying keto to lose significant weight (as opposed to using it for a week or so to maximise muscle definition for your big topless scene on Game of Thrones), can still give dieters issues.

The most obvious is fatigue, which likely comes from cutting down so drastically on carbohydrates. Carbs provide a quick and easy store of glucose molecules for the body to use as energy. Without carbs, it's easy to feel more tired than usual. And then there are the other shifts.

"They're cutting out a large chunk of the

The Keto Diet aims to induce "ketosis" by denying the body easy access to glucose from food. Fat must be broken down instead, which ideally helps in weight loss.



usual foods they eat and starting to eat a huge amount of fat," Fung explains. "It's very heavy and the stomach doesn't necessarily feel good about that."

Fung says those new to keto might also fail to get enough fibre, since "supermarket bought" fibre comes largely from whole grain bread products and fruits or veggies — many of which have too many carbohydrates to fit into the keto diet.

Without fibre, you're likely to get constipated within a few days, which can limit your capacity to crush epic reps in the gym.

Fung also points out that the keto diet is fairly high in the kind of high-fat foods that often contain lots of sodium, which just exacerbates the problem. "You're getting lots of salt, not enough fibre — it's just generally not that great in terms of your bodily comfort."

THINK OF YOUR LITTLE FRIENDS

But you know who really suffers during keto? Your guy bacteria. Fung points out that a lot of the foods that support a healthy gut microbiome get cut out in the keto diet.

Beans and legumes are too starchy and carb-filled to make it onto the meal plan, as are whole-grain bread products, but all of these are prebiotic benefactors. They foster a gut environment that can support good bacteria.

"There's so much connection between gut bacteria and the brain that I wonder whether the brain changes come from the changes in gut bacteria," Fung says. This is in reference to how the microbiome also helps regulate mood, which may be why many keto-flu victims complain of irritability.

Of course we don't really know, and

> **WE DON'T KNOW ABOUT THE EFFECTS. AS A NUTRITIONIST, FUNG DOESN'T ADVISE THE KETO DIET AT ALL UNLESS YOU'RE TREATING EPILEPSY**

Fung stresses there's still so much we don't understand about the effects various diets have on our bodies. She's speculating based on her knowledge, but there's no real data to look to. Yet.

Like all fad diets, keto throws up similar flags: cutting out fruit, vegetables and especially beans and legumes is widely regarded as unlikely to improve your health, long term.

In fact, as a nutritionist, Fung doesn't advise the keto diet at all unless you're treating epilepsy (if that seems out of left field, then see boxout).

As always, people who switch to extreme diets don't generally stick with them long-term, and as soon as they return to their normal eating habits they tend to gain back more weight than they lose. Between that and keto flu, it may not be worth the time and energy you won't even have enough of to dominate and destroy all the appliances at your local gym.

Now drop and give me twenty. Or have a lie down, whatever.

CRUSH THAT JARGON LIKE YOUR EPIC WORKOUT!

Keto refers to a metabolic state called "ketosis" (see below) and is an extreme version of a high-fat, low-carb diet.

In the strictest sense, you're supposed to get around 80-plus percent of your calories from fat, consume one gram of protein per kilogram of bodyweight, and eat just 10 to 15 grams of carbs daily. The average Western diet provides half of the calories from carbs, so blasting your abs into epic smashed awesomeness via Keto, is going to involve a major shift in the way most people eat.

At the risk of taking the ripped edge off crushing your glutes, by talking history of medicine: the ketogenic diet originally treated not obesity but epilepsy.

Some forms of epilepsy, where quality of life is hugely impacted by frequent seizures, can sometimes be managed by forcing the body into a state called ketosis.

This prompts the brain to use ketone bodies for energy rather than glucose - or in oversimplified terms, burn fat instead of sugar. You want to burn your fat, right?

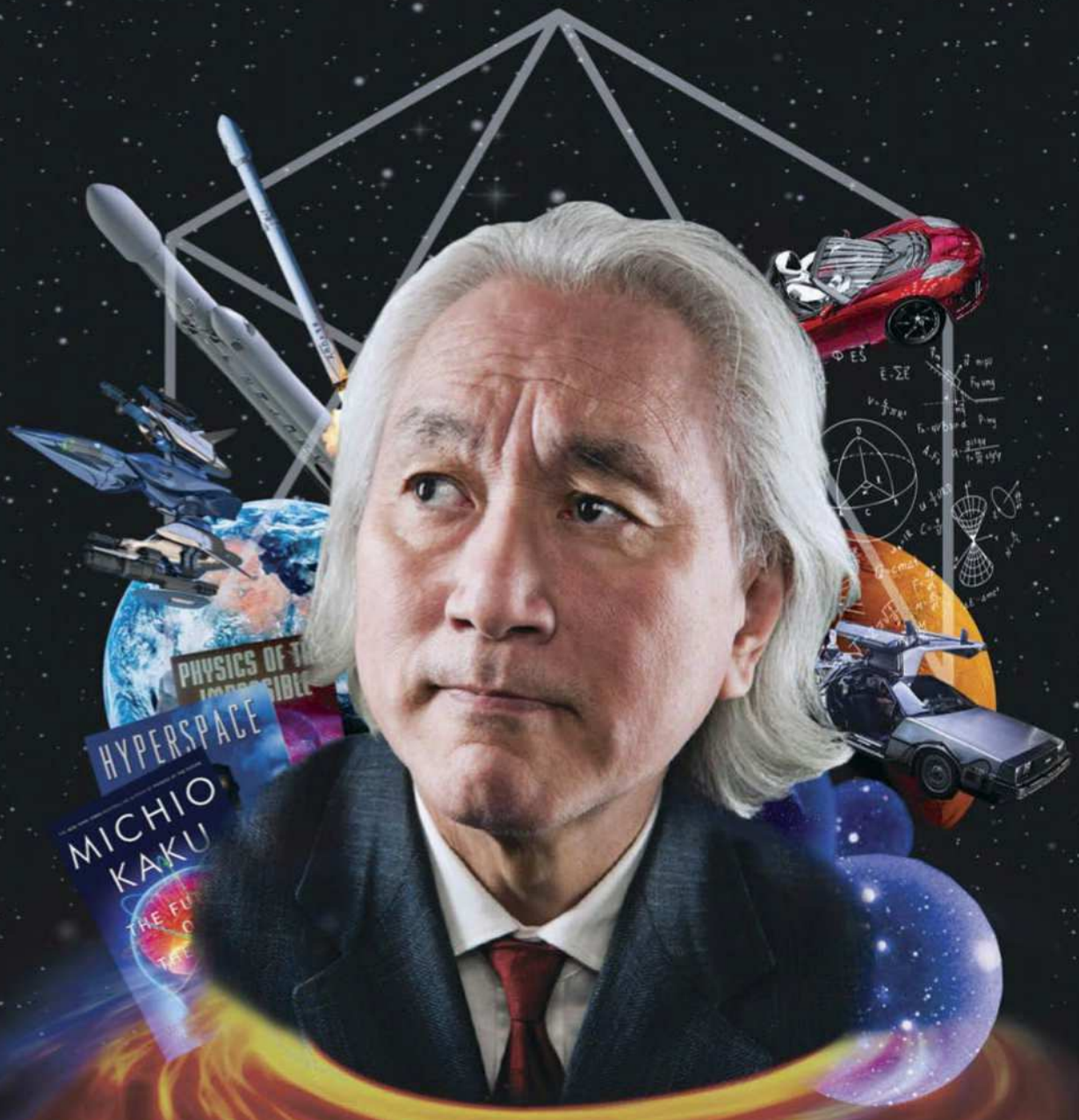
Every extreme dieter today at least knows about ketosis, and think it's just the best, but this is ironically at odds with the scientists who cam up with the idea in the first place.

Not all epilepsy patients respond to the diet and in any case, it's generally reserved only for children, because it's so hard to get adult bodies into the level of deep ketosis required to treat epilepsy.

As a way to make you, the fatty, reduce your overall kilojoule intake while doing exercise - the only two guaranteed ways to lose weight - it works just fine.

MICHIO KAKU

THE FUTURE OF HUMANITY



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WAR ON PRIVACY

Are You Leaving Digital Fingerprints Everywhere?

by ROB VERGER

Your browser has a fingerprint. It's not as obvious as the real ones on your fingertips, but it exists nonetheless. And advertising networks can use it to track your browsing.

While there's nothing fundamentally wrong with advertisers promoting their products to an audience, there's definitely a line between "marketing skill" and "marketing guile". Apple, among others, is becoming increasingly leery of what it's come to view as exploitation of some of the features of its own products.

Among the software updates highlighted during the keynote address at the company's Worldwide Developers Conference were anti-digital-fingerprinting details, about the next version of Safari, the internet browser made by Apple.

Craig Federighi, the company's software engineering lead, mentioned two developments that people interested in staying private online may like: Apple will fight the ways that advertising networks can use your browser's digital fingerprint to track you, and battle another tracking method — using webpage elements, such as a Facebook Like button, to follow and track your browsing behaviour, too.

WAITING TO SELL YOU STUFF

First, fingerprinting: That's when a tracker tries to identify your device (be it PC, phone, or whatever) based on seemingly innocuous, but actually quite specific, details like the system fonts you have installed.

It sounds evil, but the technique actually has two sides to it—security experts can use it to try to identify the computers used in an attack, for example, and that's vital information in the fight.

But a typical internet user who values their privacy wouldn't want their device, and behaviour, tracked and identified with this technique.

"Fingerprinting is just little bits of data that lead up to something specific," says Jarrod Overson, the director of engineering at Shape Security, a cyber-security company. "And it gets to be problematic when those data bits end up leading to individual people."

At the Apple keynote, Federighi explained how the next version of Safari, included in a future MacOS update, will fight this tracking strategy.

"We're presenting web pages with only a simplified system configuration," he said, meaning these pages will only be able to see the basic details of your device.

"As a result, your Mac will look more like everyone else's Mac, and it will be dramatically more difficult for data companies to uniquely identify your device and track you."

IS MY BROWSER HISTORY SHOWING?

If you're interested in seeing what elements of your browser are trackable, search up an Electronic Frontier Foundation page called Panopticlick; click "test me," and then check out the results.

Click "Show full results for fingerprinting" to see what kind of details the test noticed about your browser.

In testing it on Chrome, Safari, and Firefox, I noticed that none of them performed very well when it comes to fingerprinting protection.

And while you might hope that Safari's Private browsing mode or Chrome's Incognito Mode keep you anonymous

Panopticlick provides a huge amount of information, most of which is fairly impenetrable. But the aim here is to NOT be a special, unique snowflake. Individuality is something companies can use to track you, and, ironically, bombard you with ads for mass consumer products.

online, remember that those features are more about shielding your internet history from others who might have physical access to your machine, as opposed to data trackers online.

Shape Security's Overson compares the situation to an arms race: "Incognito mode limits the ability for people to collect and store a variety of data on your browser and device," he says. "But it's not going to limit the creativity of people who are explicitly out to track you."

SOCIAL EXPOSURE

Fingerprinting wasn't the only tracking technique that Apple discussed. The Facebook, Twitter, and other social buttons you see at the bottom of an article, expose you to tracking.

Apple's Federighi said that in the forthcoming version of Safari, these elements won't give trackers useful information about you.

Shuman Ghosemajumder, also of Shape Security, and the former head of product at Google for click fraud, explains how this kind of tracking works.

Say you visit one website, then another, and they both have a Facebook button on them: "The way that 'like' button ends up getting served [appearing on the page], is actually from the Facebook domain," Ghosemajumder says.

"What that means is that when you visited both of those sites — neither of them Facebook — there was a call that was actually made by your browser to Facebook servers. Now Facebook has the ability to correlate those two calls, and it's aware of the fact that you've visited both of those websites."

The same is true of the other buttons you see. And that is not great news, from a privacy perspective.

During Apple's event, Federighi said that the way they'd fight the use of those social buttons is by presenting a dialogue box that asks you if you want to allow a company like Facebook to track your activity.

THE GIFS HAVE EYES

Asking for permission to track your browsing seems like something that should have been a rule right from the start. So maybe you don't want to wait around for Apple, Google and others to "fix" this problem they created (or at best, failed to prevent from emerging).

If you want to take a step now to make your online browsing a little less trackable, consider installing a tool called Privacy Badger, also made by the Electronic Frontier Foundation.

With Privacy Badger installed on Chrome, I ran a Panopticlick test. The results were good in terms of personal information — except for the fact that it said my browser still has "a unique fingerprint."

So while "they" might no longer know what it is I'm browsing *for*, my computer is still identifiable as a unique internet user. They know it's me, they just don't know what I'm doing.

Is that good enough? Ultimately, the answer to that is up to you.

Insight

TOYBOX

China's Theatrics Tease New Stealth Bomber... Probably

by JEFFREY LIN

During the Cold War, the US would slowly let the public "discover" super-secret military programs like the SR-71 Blackbird and the F-117A Nighthawk, by "accidentally" flying them over populated areas in the daytime. These days, it's all about the YouTube teaser.

Stealth platforms pose the world's militaries a conundrum. On the one hand, they want a near-invisible way to attack potential enemies, using advanced tech that no-one else has. On the other hand, to work as any kind of a deterrent, it's necessary for the public to know these stealth platforms exist.

Before the internet, the Pentagon relied on rumour to spread the idea that it had incredible, unbeatable stealth platforms like the B-2 bomber, before eventually declassifying the existence of the real plane.

It's great propaganda. The US claims it has a "flying wing" stealth bomber with impossibly advanced avionics? Ha ha they really expect us to believe... OMG it's real!

China is taking a more... direct approach. AVIC, a leading Chinese weapons conglomerate, teased audiences worldwide with a glimpse of the country's first stealth bomber.

The preview comes at the end of an eight-minute video made to celebrate the Xian Aircraft Corporation's (XAC) 60th anniversary. The visual resemblance to Northrup Grumman's 2015 Super Bowl ad showing off the B-21 Raider stealth bomber is presumably deliberate. After all, we already know flying wing stealth bombers *can* exist, so it's worth it for China to be explicit that it now has one. Or wants us to think it has one.

So. Any useful details? The profile of that massive wing suggests that the bomber, tentatively identified as the "H-20", may utilise a cranked wing design, in which the outer edges of the wings have less sweep than the blended fuselage (looking front- or rear-on).

The is similar to the USAF's own X-47B. Of course, the X-47B is a drone, and too small to carry a crew. That means the H-20, if it really does have this design, would become the world's largest cranked wing aircraft.

China's willingness to promote its next-generation bomber in public media is part of a wider trend.

Slick sizzle reals for projects like the J-20 stealth fighter and its much-anticipated aircraft carrier, are part of China's need to project power. Indeed, this deliberately derivative teaser for the H-20 sends a clear message. While YouTubers hit "like", military analysts have to wonder: how far off is China from deploying this?

AVIC's teaser video mimics a USAF video announcing the B-21 Raider, right down to the lighting in the background.

This isn't an official render, it's an educated guess by artist and Twitter personality Bai Wei.

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SPACE ODDITIES

Diamond DJs Play Havoc With the Celestial Radio

by MARY BETH GRIGGS

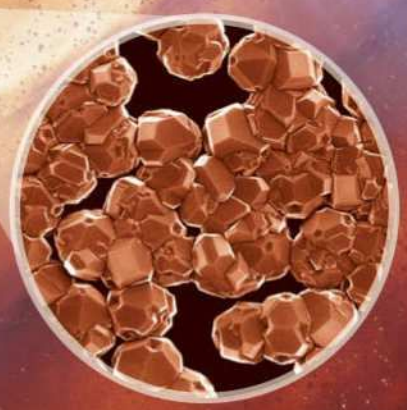
Astronomer Jane Greaves wasn't looking for diamonds, or strange microwave emissions. What she really wanted to look at was dust, but the numbers she got back, didn't match up with anything that she expected to see.

Greaves studies the early stages of planet formation, and several years ago, she went to Green Bank, a massive observatory in West Virginia to take a closer look at some protoplanetary discs. But the facility's sensitive and unique instruments returned some very strange results.

"I was looking for emissions from small dust particles that would get steadily brighter. But this emission got brighter and then got fainter again as you went along in the wavelength—and that's a really difficult thing to make by most astronomical processes," Greaves says.

The odd shape and pattern of the wavelengths around the distant, hot star would vex her for years.

"I've been staring at this set of numbers for about eight years or so going 'those are wrong, those are wrong,'" Greaves says. But the numbers weren't wrong, they were just something completely different from the dust she'd gone looking for.



Ultrafine dust made up of trillions of nanoscale diamonds could be responsible for mysterious radio emissions in space.

COSMOLOGY METAPHOR!

The answer was in the nature of the dust itself, or more specifically, nanoparticles.

Greaves explains the phenomenon: "Imagine you're walking along in the dark and you're holding a flashlight and you keep turning the flashlight over and over in your hand. If someone was looking at you they'd see a wavy light trail behind you as it turned. It's kind of like that, but it's a radio wave instead of a flashlight."

But what kind of nanoparticles were they? That's where Greaves' research comes into play. Thanks to readings made over the course of decades, researchers had observed three star systems with protoplanetary discs that also contained a distinct spectral signature that pointed to one thing: these nanoparticles were actually trillions of tiny diamonds.

These diamonds aren't like the ones that you might wear, and the emissions they give out aren't 'sparkles' in any sense of the word. It's closer to diamonds used in industrial applications, for drilling or grinding other materials, than anything you'd buy at a jeweller.

DE BEERS DOESN'T CARE

"Industrial diamond powders aren't very exciting when you look at pictures. It's disappointing, but maybe there are slightly bigger ones out there — the ones found in meteorites that are slightly larger chunks of diamond are a bit more exciting," Greaves says.

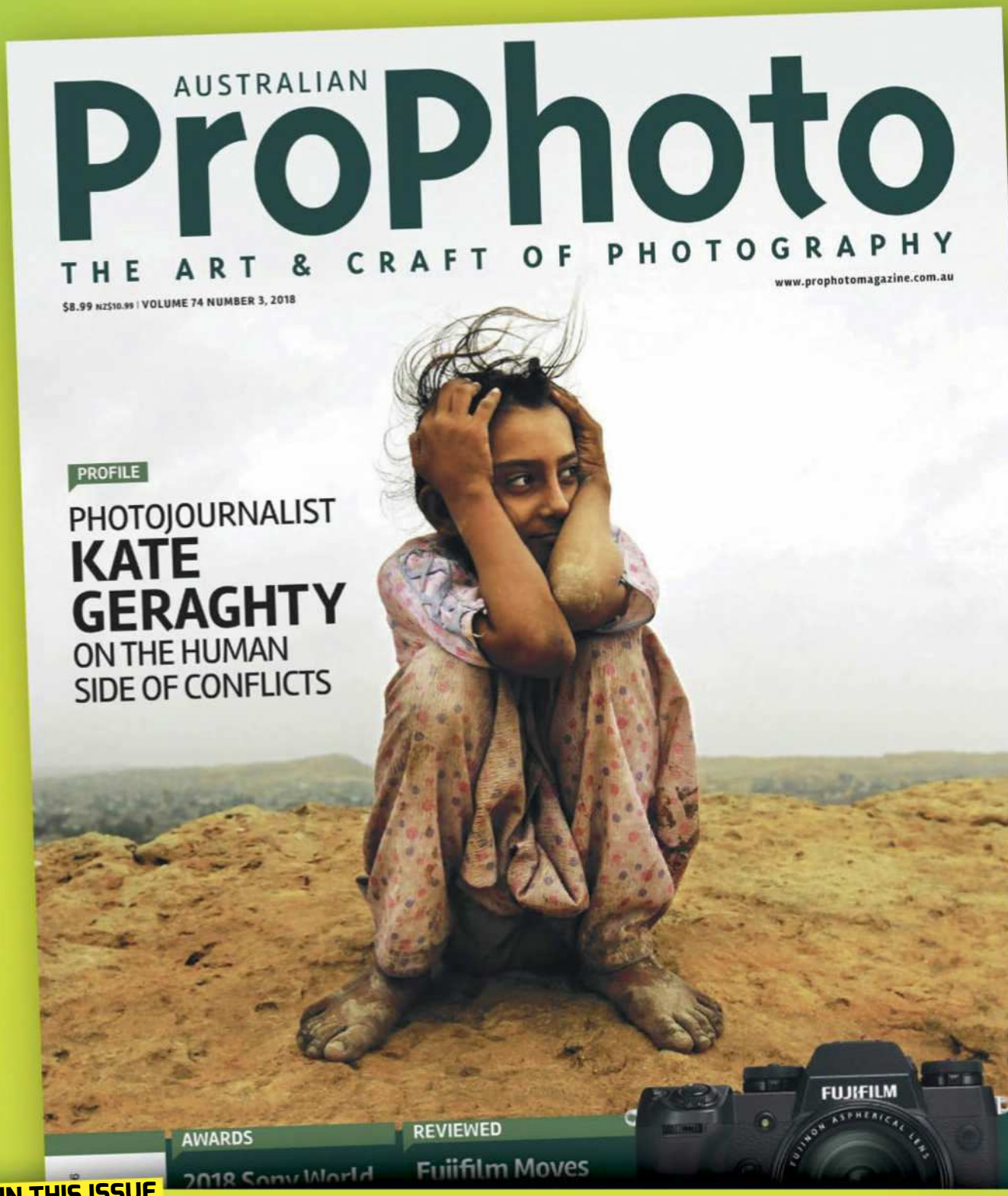
These diamonds are only a few nanometres across, and are also coated with a layer of hydrogen atoms, picked up as they travel through the hydrogen gas in the solar system.

They may be small, but they could also help solve a big puzzle—where anomalous microwave emissions, or AMEs, come from.

Most AMEs come from deep space, not from areas close to stars. Are vast clouds of nanodiamonds responsible? It's not possible to answer that, yet.

Objectively, dust made of a particular crystal form of carbon is no more "special" than particles of water ice or iron or some other common mineral. But of course, to humans, diamonds will always be a little bit special.

And maybe it's not just that diamonds are forever. They're also everywhere.



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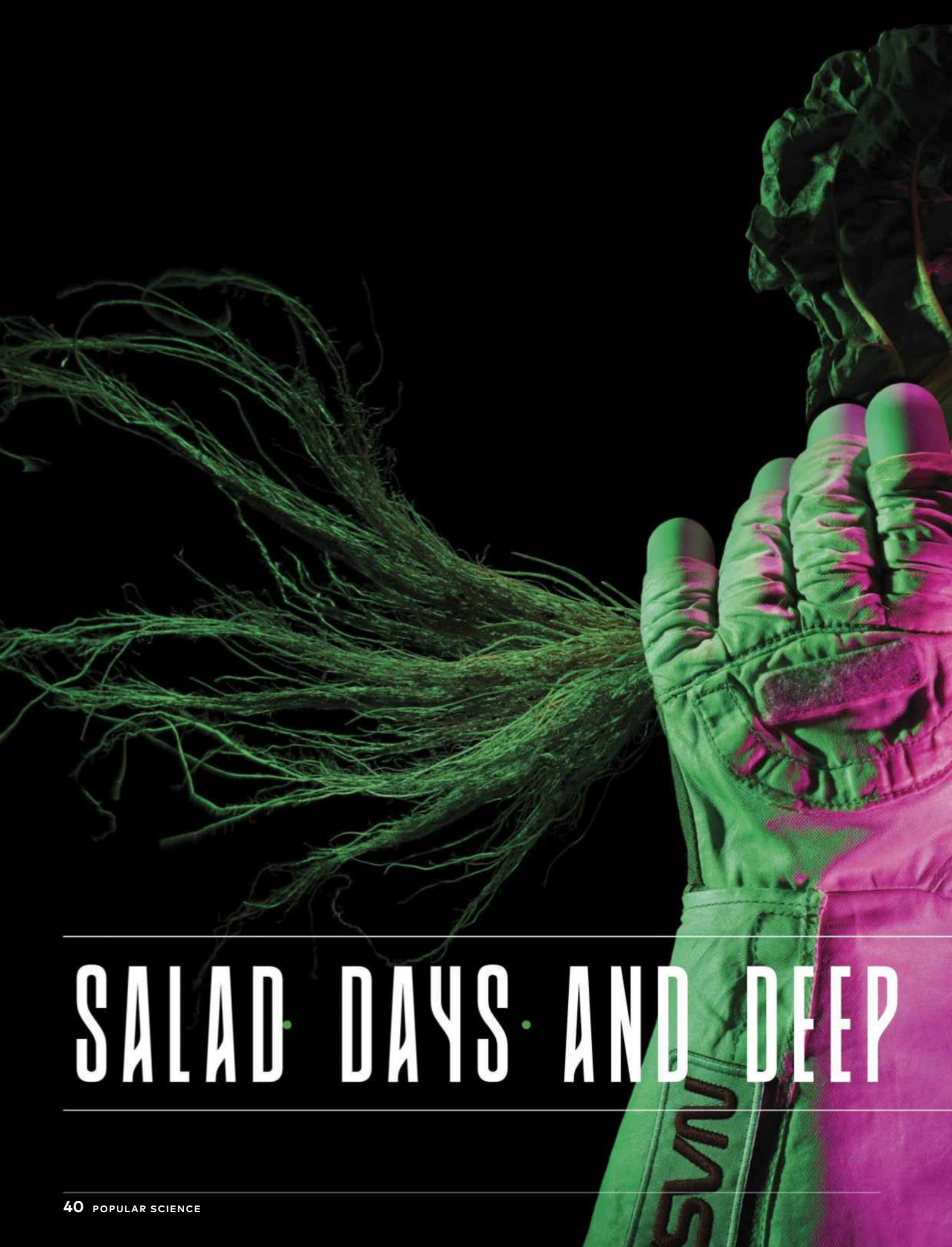


SALAD DAYS AND DEEP

SPACE NIGHTS

Can gardens help astronauts go farther?

BY SARAH SCOLES
PHOTOGRAPHS BY THE VOORHES

SPACE GARDENS WILL BE ESSENTIAL SOMEDAY IF ASTRONAUTS ARE TO GO BEYOND LOW-EARTH ORBIT OR MAKE MORE THAN A QUICK TRIP TO THE MOON. THEY CAN'T CARRY ALL THE FOOD THEY NEED.

"Our plants aren't looking too good," astronaut Scott Kelly tweeted from the International Space Station on December 27, 2015. He was right: The attached picture showed four baby zinnias bathed in magenta light. Three of the four leafy stalks were discoloured and curling in on themselves. The station's garden was struggling to recover from a mould problem. It's an issue familiar to terrestrial gardeners. And while on Earth, the problem means a trip to the local nursery for replacements, in space you can't do that.

The zinnias, brightly coloured flowers in the daisy family, were part of an experiment called Veggie, whose ultimate mission is to provide crews with a long-term source of food. In prior tests, astronauts had successfully harvested lettuce. The zinnias had a longer growth period—60 to 80 days—and then would bloom, producing neon-hued blossoms that look like they belong in a psychedelic corsage. They were practice for something finickier and tastier than leafy greens: tomatoes. If station crews were ever going to grow something that intricate, they needed to figure out—among other things—how to vanquish mould.

Veggie (the experiment) is a way for astronauts to develop their green thumbs. "It's a very simple system," says Gioia Massa, one of the project's lead scientists. "It doesn't control much at all." Instead, the humans do.

Space gardening will be essential someday if space travellers are to go beyond low-Earth orbit or make more than a quick trip to the moon. They can't carry on all the food they need, and the rations they *do* bring will lose nutrients. So astronauts will need stash they can replenish, with extra vitamins. They'll also require ways to make more oxygen, recycle waste, and help them not miss home so much. Space gardens can, theoretically, help accomplish all of that.

Veggie and other systems aboard the space station are helping researchers figure out how radiation and lack of gravity affect plants, how much water is Goldilocks-good, and how to deal with deplorables like mould. Just as important, scientists are learning how much work astronauts have to put in, how much work they *want* to put in, and how plants nourish their brains as well as their bodies.

FOR ALL ITS POTENTIAL IMPORTANCE, Veggie is pretty compact. It weighs 18 kilograms, just a hair less than the station's 19.5 kilogram coffeemaker. The top—an off-white rectangular box that houses the grow lights—resembles an old VCR. From this, a curtain of clear plastic hangs to encase the 1500-square-cm planting surface. Astronauts preset how long the lights stay on each day; how brightly they emit red light to optimize photosynthesis, and blue light to control the plants' form and function. They can also activate a built-in fan to adjust the humidity.

The most important part of Veggie, though, is the fragile bounty it is meant to cultivate. That begins as seeds encased in little Teflon-coated Kevlar pouches. The scientists call them plant pillows. "You can think of it like a grow bag," Massa says of these packets stuffed with seeds, water wicks, fertiliser, and soil.

People have anticipated this scenario for more than a century. In 1880, science-fiction author Percy Greg wrote *Across the Zodiac*, a novel about an astronaut who travelled to Mars with plants to recycle waste. Fifteen years later, Konstantin Tsiolkovsky, a Russian rocket scientist, wrote *Dreams of Earth and Sky*, which laid out how spacefarers and flora could live together inside a closed system.

In the 1950s, green things burst from book covers and into the lab. NASA and the US Air Force started growing algae to see if it could help with life support (turns out, it tasted bad, was full of indigestible cell walls, and had too much protein). Then, Soviet scientists experimented with nearly self-sufficient ecosystems in which humans survived on oxygen, water, and nutrition produced mostly within an enclosed habitat. In the longest run, a 180-day trial inside a facility called BIOS-3, an earth based crew got 80 per cent of its food from its own wheat and vegetables. Finally, in 1982, plants in space became a reality when Soviet cosmonauts grew *Arabidopsis thaliana*, a flowering species related to cabbage and mustard, to maturity aboard their Salyut 7 space station. The yield was too small to be a source of food.

Around this time, in the mid-'80s, Veggie's Massa was in middle school, and her seventh-grade teacher returned from an astro-agriculture workshop at Kennedy Space Centre with reams of information on the topic. Inspired, a teenage Massa kept taking ag classes as she moved on to high school, and later

LIQUID REFRESHMENT
Astronauts dispense precise amounts of water to the plants inside Veggie.

NASA

teamed up with her middle-school mentor for a hydroponics project.

While Massa continued her studies and self-guided experimentation, NASA began building orbital plant-growing apparatus, most notably the Biomass Production System. Designed to be used for experiments on the space station, it was a rectangle with sides each about the length of an arm. Four cube-shaped growth chambers rested like safes inside. Designed by scientists at a Wisconsin-based company, Orbitec, the Biomass Production System joined the space station in 2001. There, *Brassica rapa* field mustard soon sprouted tall, illuminated by plain white fluorescent light.

When researchers compared the harvest to a control plant on the ground, though, they found that the space mustard had more bacteria and fungus. "The significance of the difference is uncertain," states NASA's official conclusion. By which the agency meant it didn't know why the microbes proliferated, not that their presence wasn't important. In fact, as Veggie's mould would soon show, it was *critically* important.

NASA retired the Biomass Production System in 2002, but Russian cosmonauts picked up where the US left off. Over the decade, they successfully grew dwarf wheat, leafy mizuna, and dwarf peas. Bonus: In four successive generations of orbiting dwarf peas, the vegetables didn't show signs of genetic degradation.

Meanwhile Orbitec, in consultation with NASA, cultivated another plant-growing instrument. So when NASA awarded a grant in 2012 for a new space garden, the company had something to show for itself: Veggie, which, unlike its predecessor, was meant to produce food on an edible scale. Massa, by then a postdoc, tested different types of media and crops for the plant pillows. It was the kind of tinkering she'd been preparing for since she was 12. The United States' first real space garden launched in 2014, not long after Massa advanced from her postdoc to become a Veggie project scientist at the space agency.

ALL WENT PRETTY WELL FOR VEGGIE until the flower flap. Most of its initial edible plants—a lettuce variety called Outredgeous—sprouted as they should have in 2014, and the astronauts shot them back down to Earth for testing. Massa says they're still working on all the analyses. "But in general, the plants are pretty similar to our ground samples." When they're finished, they'll know about chemical contents like antioxidants, anthocyanin (pigments), and phenolics, which protect plants against stress. Short term, the priority was mealtime: *Could we have consumed the harvest?* The crew, Massa, and NASA all wanted to know. Yes, it turned out, the produce was microbially safe to eat.

Still, when the astronauts planted a second set of seeds, in summer 2015, Massa ran into a new challenge: With harvest approaching, NASA had no protocol to approve the crew chowing down on the leaves of their labour. "We said, 'We have only 28 days, and then they're going to have to eat it,'" Massa recalls. With the clock ticking,

management found a way to officially add the lettuce to the astronauts' diet.

On August ninth, Kelly snapped a picture, standing in front of the unfurling greens. His brow was furrowed, faux serious. "Tomorrow we'll eat the anticipated veggie harvest on @ space_station!" he tweeted. "But first, lettuce take a #selfie."

Soon he crunched the harvest live on NASA TV. It might seem like no big deal, but a single leaf can make a big difference to someone who's been eating rehydrated fare for months. During a later harvest, astronaut Peggy Whitson would use them to wrap a reconstituted lobster salad. "Even with a really good diet with hundreds of items, there's dietary fatigue," Massa says. "People get bored. Adding a new flavour or texture—like something crisp and juicy—could spice up your regular meal."

That's not the only brain boost. Sure, astronauts can gaze down at Earth and see its most beautiful spots—almost all of them—every 90 minutes. But those places are always out of reach, reminders of how far away sea level is. Having something nearby that photosynthesises, might cheer the crew. "It's the psychological aspect of something green and growing when you're far away from home," Massa says.

In the next growing cycle, the astronauts fostered the ill-fated zinnias. About two weeks in, Kjell Lindgren saw the first warning signs. Water leaked from the wicks that hold the seeds. Then moisture began seeping from the infant leaves, which started to curl in on themselves. Veggie staff on the ground, in charge of the operation, decided it was time to turn the airflow fan from low to high. But an impromptu spacewalk to fix a broken robotic arm delayed the change because, in space, nothing is as simple as flicking a switch on your way out of the spaceship. While reprogramming Veggie's settings takes only about 15 minutes, NASA prefers astronauts move anything lower priority out of the way when they have a high-priority task.

And then the leaves started to die.

That's bad enough on its own. But, worse, dying vegetation can be a breeding ground for mould, which had somehow come to space with the astronauts and cargo. Soon, menacing white fuzz began choking the plants.

By this time, Lindgren had returned to Earth, and Kelly had taken over the garden. On December 22, with instructions from ground control, Kelly snipped away the mouldy parts like bad spots from a piece of cheese, and swabbed the remaining zinnias and equipment with cleaning wipes. He left the fans on high to help dehydrate the setup.

Farm to Table
From top: Kevlar-coated pouches help protect seeds from microbial contamination; fully grown Outredgeous lettuce; On-Orbit Gardeners Kjell Lindgren (left) and Scott Kelly. The fast-growing salad green was the first plant to be grown, harvested, and eaten in space.

It was a good try but not without a cost: It made the plants thirsty. Kelly relayed that to ground control and asked to water them. Sergeants who were set on sticking to the drill told Kelly it wasn't time yet. Not till December 27. "You know, I think if we're going to Mars, and we were growing stuff, we would be responsible for deciding when the stuff needed water," Kelly told them, according to NASA's write-up of the event.

Eventually, they gave autonomy to the person who was actually next to the plants, along with one page of instructions called "The Zinnia Care Guide for the On-Orbit Gardener."

Under the On-Orbit Gardener's thumb, half of the zinnias revived, unfurling and growing green. NASA spun the whole thing as a positive: They now knew that crops could survive floods, drought, and disease, and that excising the problem plants and cleaning the remainder could keep the fungus from taking over.

Kelly loved the now-flourishing flowers and carried their container all over the space station for photo shoots, like those people who snap shots of themselves in Hard Rock T-shirts all over the world. "He asked if he could harvest them on Valentine's Day," Massa says. He'd been in space, away from everyone except his smelly crew mates for more than 300 days. NASA let him make the bouquet.

It was one of Massa's favourite moments. "We had been a part of something that gave him pleasure," she says.

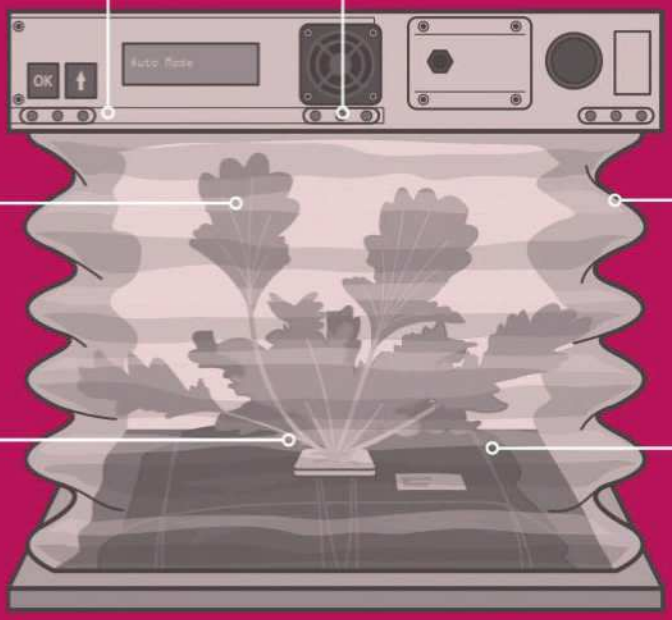
IN UPCOMING VEGGIE EXPERIMENTS, scientists will learn more about that part of gardening—the mental part. "We've heard a lot anecdotally," Massa says, "but we've never been able to collect data." They'll also investigate how much farming crew actually want to do, how much is fun versus how much is a chore, how their sense of taste changes in orbit, and which plants can best survive human error (no offense, astronauts).

Veggie's experiments will continue in tandem with those of a brand-new Type-A companion, the Advanced Plant Habitat, an 120-cm-square self-sufficient laboratory with more than 180 sensors and automated watering. Scientists can establish their variables and thus nail down the specific conditions that cultivate plants—and how those plants can cultivate humans. A temperature-control system keeps the air within 0.5°C of the

NASA (3)

GREEN SPACE

TWO SYSTEMS—ONE HANDS-ON, ONE AUTOMATED—FOR GROWING PLANTS IN SPACE



Lights
Grow lights in the top of the unit can be preset to mimic a Terran day/night cycle , or can be left on for 24 hours.

Fan
A fan pulls in air from the space station and circulates it around the vegetation, helping to regulate humidity.

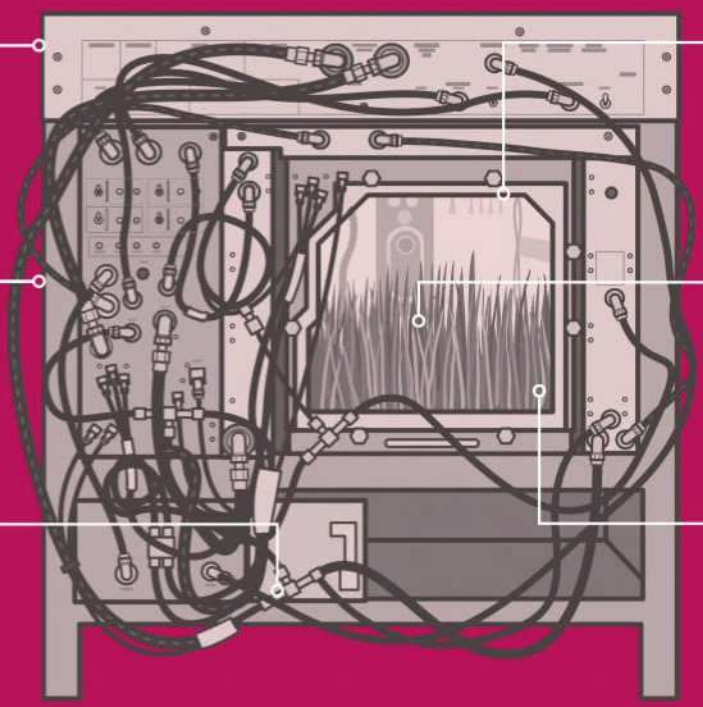
Growth
Chinese cabbage, green lettuce, mustard, red romaine lettuce, and zinnias all sprouted in space thanks to Veggie.

Plastic Covering
The clear covering maintains humidity levels inside Veggie, and keeps any detritus from escaping into the rest of the station.

Plant Pillows
The garden sprouts out of pouches called "plant pillows," which cradle seeds, baked clay, and a time-release fertiliser.

Water Injection
The astronauts tend the plants nearly every day. One of their tasks is to carefully inject water into the plant pillows using a syringe.

VEGGIE



PHARMER
The Plant Habitat Avionics RealTime Manager in EXPRESS Rack, aka PHARMER, sends data to NASA scientists on Earth.

Lights
A system of LEDs in red, green, blue, white, and far-red (not quite infrared) keeps all the plants healthy.

WRADS
The so-called Water Recovery and Distribution Subassembly distributes H_2O to plants as needed.

Plants
Dwarf wheat and *Arabidopsis* (a plant related to cabbage and mustard) will be the first crops to sprout in the APH.

CO_2 Bottles and Regulation
This unit feeds precise amounts of carbon dioxide into the APH from adjacent reservoirs.

Growth Chamber
The 180-plus sensors and cameras in the 45 cubic centimetre enclosure keep close watch on the plants.

ADVANCED PLANT HABITAT (APH)

by Mary Beth Griggs / illustration by Robert L. Prince

thermostat setting. Sensors relay data about air temperature, light, moisture, and oxygen levels back to base. While the Advanced Plant Habitat will quantify the circumstances for successful gardening, Veggie will help qualify how—and why—humans can facilitate their own food supply. In other words, through the habitat's tight controls, researchers can learn how to grow which plants best. Then, using those parameters, they can set up a system like Veggie that astronauts get to interact with.

Astronauts assembled the habitat over six hours in October 2017, after it rumbled into space in two shipments. The automated contraption looks like a microwave that could survive, well, being shot into space. Wires stream from here to there and there to here on a control panel. Red indicator lights blink next to toggle switches. And inside the plant chamber, LEDs beam from the ceiling, illuminating the plants below with concert-stage colour combinations. It has red, green, and blue lights like Veggie—plus white, near-, and far-infrared ones.

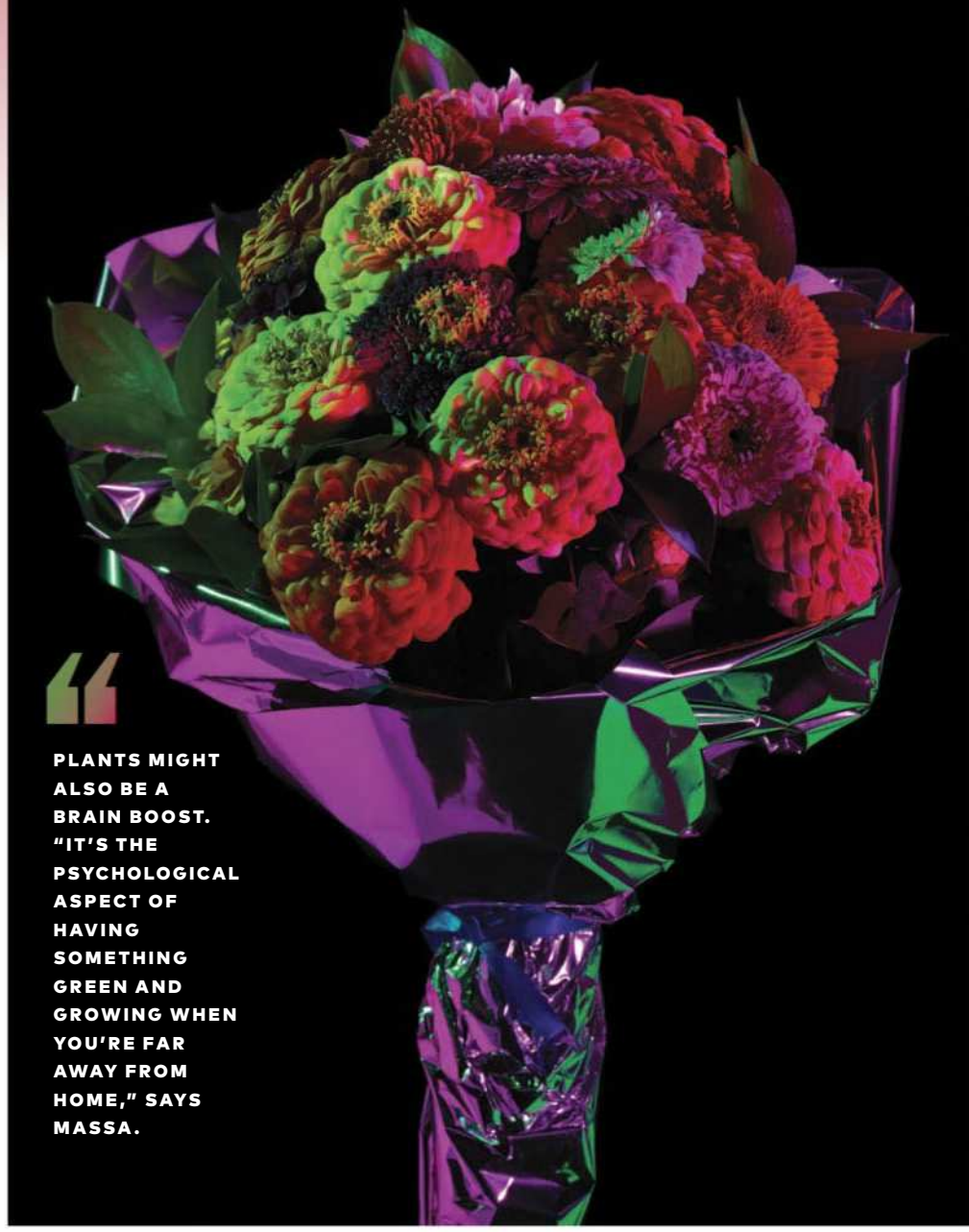
Robert Richter, director of environmental systems at Sierra Nevada, which acquired Orbitec in 2014, monitored its progress from the earthbound Space Station Processing Facility. He'd helped design and build the new lab, as well as Veggie and Biomass. When he started in the field, almost 20 years ago, he was a bit naive. "I thought, *How hard is it to grow plants?*"

He's partly joking, of course—and he knows, now, that when you're trying to keep the humidity level within three per cent of a given number, when you must make and measure light and moisture, and when you maintain the temperature to a fraction of a degree, there's a long row to hoe between growing some basil in a cup and farming lettuce in space.

The team powered up the unit in November 2017. And by February this year, test crops of *Arabidopsis thaliana* and dwarf wheat sprouted. Soon, they'll begin experiments like investigating plants' DNA and physiological changes.

A lot of the previous plant research has been focused on whether things would grow at all, says Robert Morrow, Sierra Nevada's principal scientist. Will they reproduce from generation to generation? And are they as productive in space as on the ground?

Yes, he says. Scientists are beyond those basics now. They need to dig into the dirtier details and more-complicated ecosystems. Astronauts, for instance, exhale carbon dioxide that plants can inhale. The plants then exhale oxygen, which humans can inhale. Human waste can become plant fertiliser and hydration. Nothing wasted, everything gained.



"PLANTS MIGHT ALSO BE A BRAIN BOOST. "IT'S THE PSYCHOLOGICAL ASPECT OF HAVING SOMETHING GREEN AND GROWING WHEN YOU'RE FAR AWAY FROM HOME," SAYS MASSA.

Ultimately, Morrow believes, a garden on a deep-space mission will be more like Veggie than like the Advanced Space Habitat. "It's really not practical to put all the stuff you have in APH in a system like that," he says. With so many sensors and tubes, lots can go mechanically wrong, and it's easier to repair a Veggie than an APH. For now, scientists need APH to home in on optimal guidelines for plant growth and understand how leaving the planet changes them so they can instruct future astronauts how to better manage Veggie-esque systems.

Looking toward the future, Massa is interested in observing astronaut interactions with the instruments. "Do you always want to pick your ripe tomatoes, but maybe you don't want to have to water them every other day?" she wonders. She'll have a chance to find out because Veggie will grow its first dwarf tomatoes, a variety called Red Robin, early next year.

Other nations continue to experiment too. China, for instance, intends to send silkworms and potato seeds to the moon this year aboard its *Chang'e-4* spacecraft. When the silkworms hatch, they'll create carbon dioxide, which the potato plants will suck up and turn into oxygen, which the silkworms will then take up.

All this research doesn't just help people above the atmosphere. Creating self-contained growth systems might help farmers on Earth grow crops year-round or foster plants with extra protein and high yield. Someday, the work will lead to gardening systems substantial—and stable—enough to support space travellers. Then, those travellers can wrap anything they want in lettuce and crunch their way through the cosmos.

Contributing editor Sarah Scoles is the author of *Making Contact: Jill Tartar and the Search for Extraterrestrial Intelligence*.

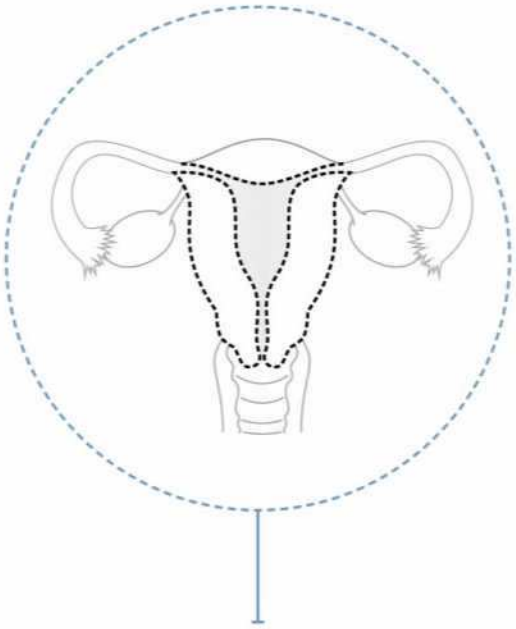


Fig. 1

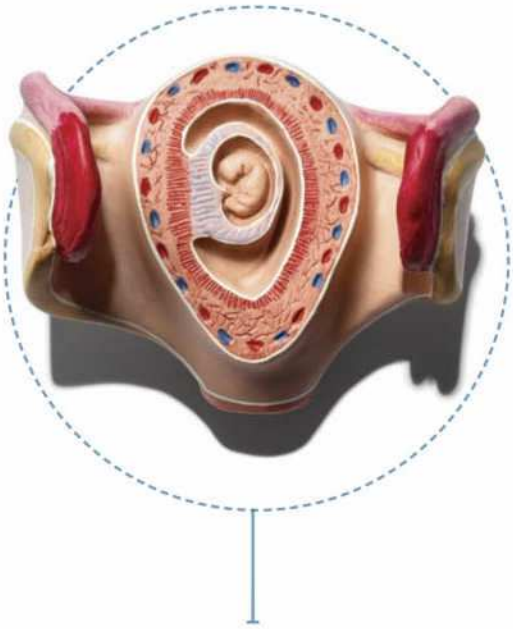


Fig. 2

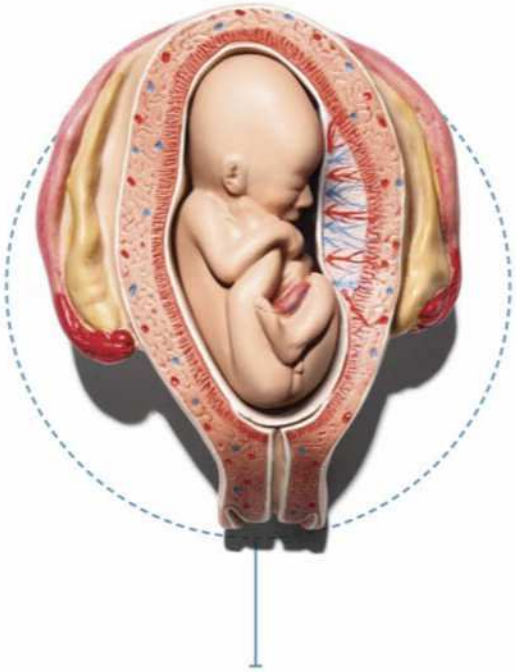


Fig. 5

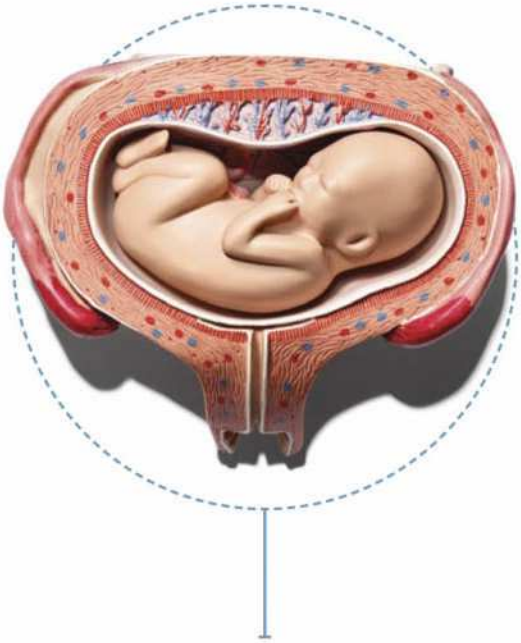


Fig. 6

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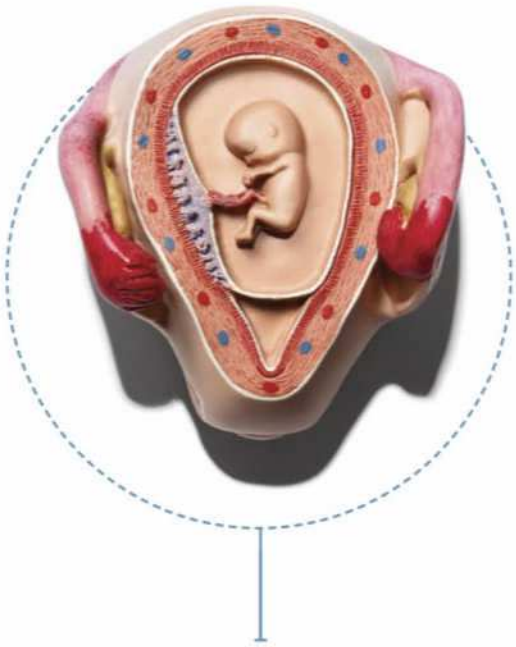

Fig. 3

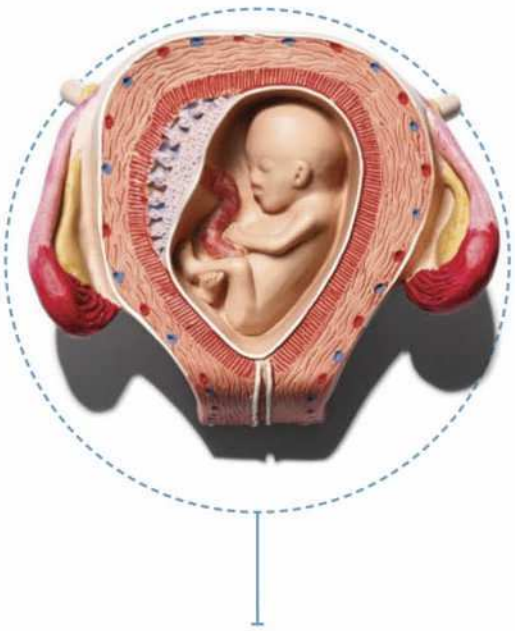

Fig. 4

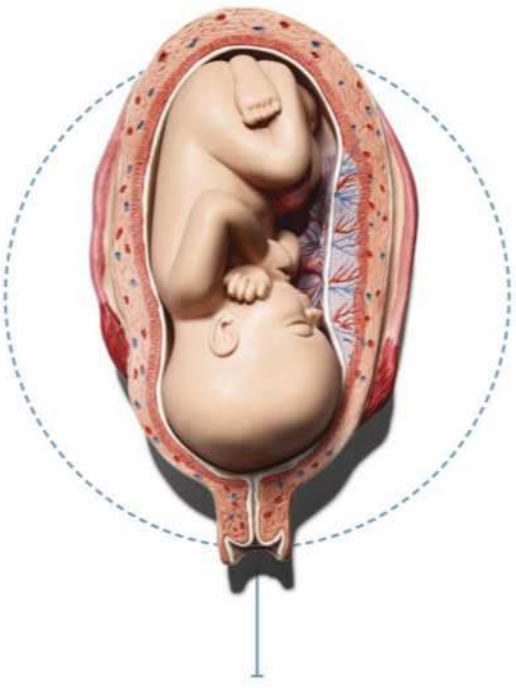

Fig. 7

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Something Borrowed

Pioneering surgeons have made it possible to transplant a human uterus that can bear children—offering hope to millions of infertile women who never thought they could give birth.

BY ERIN BIBA

photographs by The Voorhes

The first baby was born in secret.

On September 4, 2014, in Gothenburg, Sweden, his 36-year-old mother lay on an operating table, suffering from pre-eclampsia—a pregnancy complication associated with high blood pressure. The baby's heartbeat showed signs of stress. Normally the woman's doctors might have taken a wait-and-see approach, treating her with medication and hoping to give the nearly 32-week-old foetus time to grow to full term of about 40 weeks.

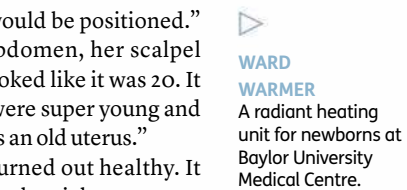
But this was no normal gestation. This was the world's first human nurtured inside a transplanted uterus. He was the product of more than a decade of research. For years, no one had been sure he could exist in that womb—let alone be born. This was not a wait-and-see situation.

As gynaecologist and surgeon Liza Johannesson prepped to deliver the child via caesarean section, she was nervous. Not for the baby—she was used to delivering those—but for the uterus. It was 62 years old. The patient had been born without her own womb, and this one had been donated by a family friend. The last time it had sustained a life was nearly three decades earlier. "We didn't know what to expect," Johannesson says. "We didn't know if we were going to see [scar tissue] from the transplant surgery or how the new vessels would look, and how they would be positioned." But as she cut into the woman's abdomen, her scalpel revealed a uterus that, she says, "looked like it was 20. It reacted the same way it would if it were super young and super healthy. You couldn't tell it was an old uterus."

The baby and the mother both turned out healthy. It would be a month before the journal article announcing the birth would appear, and allow the Swedish-led medical team to tell the world: Uterus transplants are possible. And they can bear life.

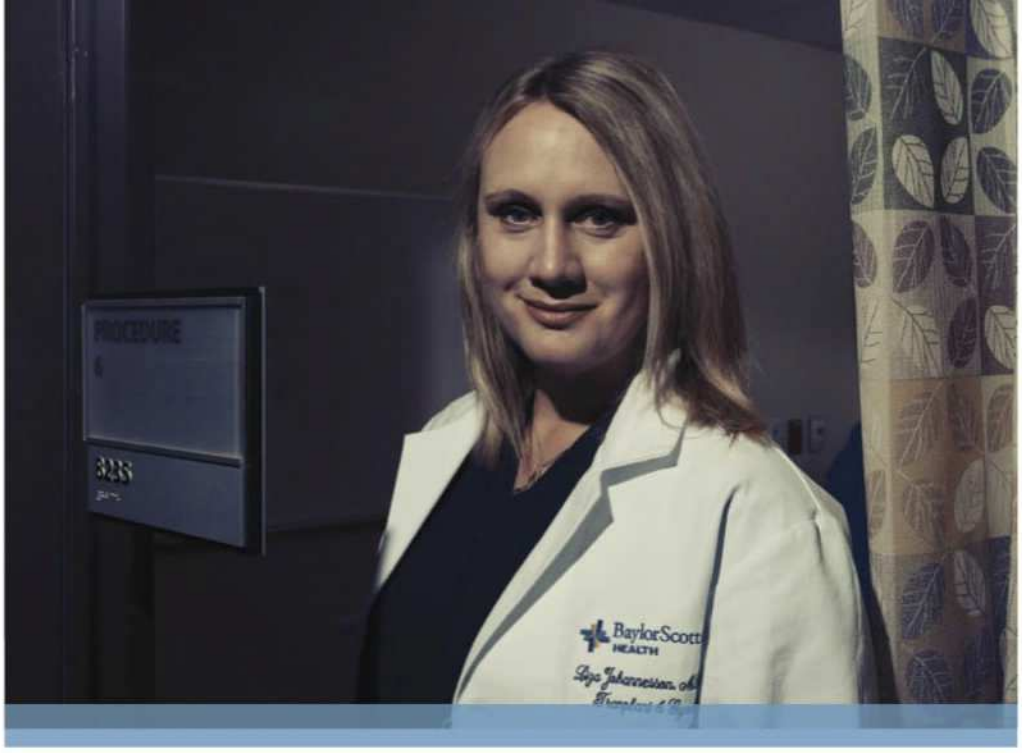
That team has since delivered seven more babies via donated wombs, and this past November, with Johannesson's help, Baylor University Medical Centre in Dallas achieved the first such birth in the US. In February, a second. A leading organ-transplant centre, Baylor has reported that two more women are trying to conceive as part of a large-scale clinical trial involving medical experts in nearly a dozen specialties. Under the guidance of transplant surgeon Giuliano Testa, Baylor hopes to build on Sweden's research-based work to develop a proof-of-concept system that could be adapted around the world.

Hundreds of fertility advocates have applauded Baylor's work, and other transplant centres have contacted



WARD WARMER
A radiant heating unit for newborns at Baylor University Medical Centre.

photographs by Jack Thompson



STEADY HEAD
Surgeon Liza Johannesson perfected her skills by operating on mice, rats, and small baboons.

it to learn its methods. The need seems great.

Consider that kidneys, the most commonly transplanted body part, account for around 19,000 of the procedures each year. Then compare that to what may be as many as two million women in the US, with what doctors call "absolute uterine factor infertility." Some have undergone hysterectomies due to cancer, fibroids, excessive bleeding, or uterine prolapse. Some are among the approximately 1 in 5,000 girls born each year without a uterus, a medical condition known as Mayer-Rokitansky-Küster-Hauser syndrome. And there is another category that hasn't yet been tabulate: the hundreds of thousands of women who represent a portion of America's 1.4 million transgender people. They too might one day be able to choose to bear children thanks to this new surgery.

Of course, there are caveats that need to be negotiated before the uterine transplant can become an everyday surgery. First, there are ethical concerns. Critics question the necessity of the procedure, given that women have other paths to motherhood, such as surrogacy and adoption. Some wonder if surgeons are undertaking the challenge simply because they can. And then there are the risks. The donor must undergo a "medically unnecessary" surgery to remove her womb. The recipient must undergo three surgeries: one to insert the uterus, another to deliver the baby via C-section, and a third to remove the organ after birth. (Doctors do not want patients to spend a lifetime taking immuno-suppressive drugs, which come with risks, to prevent rejection of a part not needed for survival.) And finally, there are the costs, which Testa estimates at around $250,000, which in the US puts the operations beyond the reach of any but the most affluent, and perhaps the most desperate.

Undeniably, the research that went into the procedure is ground-breaking. And Testa thinks Baylor's clinical trial—monitored and supervised by the hospital's internal review board and following the rules of the United Network of Organ Sharing, a nonprofit that manages the US organ transplant system—will one day allow thousands of women to carry children. "It makes no sense to innovate if it stays for only one case," says Testa. "It becomes a stunt. We're

How to Relocate a Uterus

A womb isn't loyal to its original surroundings. As researchers have demonstrated, a uterus will nurture a baby regardless of the body that hosts it. But finding a viable organ—and then applying meticulous suturing skills—is the challenge. Here's how surgeons go about transplanting one of the most amazing structures in the body.
—Claire Maldarelli

1.

Sourcing

As with any donated organ, surgeons need to know in advance that the womb will work in the recipient. For this baby-bearing part, which weighs about 55 grams and resembles an upside-down pear, there's a simple litmus test: It must have already borne a life. Even an organ from a menopausal donor can work. But, no matter what, it must also prove free of abnormal cells, and be clear of diseases such as endometriosis or an infection such as HPV.

+

2.

Donor Surgery

Surgeons cut the abdomen from pubic bone to belly button. Once they reach the uterus beneath, they sever its ligaments and an adjacent sheet of tissue near the bladder. This layer will later help the uterus graft to its new body. As doctors prepare to finish, they clamp and detach the major blood supplies: two large arteries and two veins. This last-minute step is key; it keeps the blood (and oxygen) supply to the womb intact until the last possible second.

talking about helping people at large. I hope this is the spark that turns into a furnace."

IN 1931, a German surgeon performed the first-known uterine transplant, on a Danish transsexual named Lili Elbe. She died soon afterward, probably due to tissue rejection. Decades later, in 2000, a Saudi Arabian woman who had lost her uterus during childbirth wanted another baby and came up with the transplant idea on her own. Her doctors agreed to attempt the procedure; the implanted womb lasted three months before its tissue began to die and it had to be removed. The woman survived. "They were criticised," says Johannesson, because of a lack of clinical and ethical transparency and the procedure's failure.

But other, more-rigorous attempts were underway at that time, none more advanced than that of Swedish transplant surgeon Mats Brännström, who had faced a similar patient request in 1998. Rather than plough ahead in the dark, he created a team at the University of Gothenburg and attempted to puzzle out just how to do the surgery in a way that wouldn't fail. Johannesson joined his team in 2008 during her gynaecology residency, having decided to pursue her doctorate in this area.

The first goal of the study was to perfect the surgery in animals. The team had started with mice and rats, removing and attaching each tiny uterus under a microscope. Later, Johannesson headed up the final phase of research: working on non-human primates, specifically baboons, whose abdomens reflect the anatomy she would face in people. For the next several years, she travelled to Nairobi, Kenya, eventually performing uterine transplants on 66 such human-resembling primates.

The goal in all these animal surgeries was twofold. Connect the uterus to the body, and secure its blood flow. To attach this triangle of tissue, Johannesson learned to stitch it to the vagina and a group of ligaments. The uterus, which in humans weighs 55 grams and is about the size and shape of an upside-down pear, has multiple blood supplies (two arteries and two veins) that keep it, and a foetus, alive with oxygen and nutrients. During a pregnancy, blood volume increases by up to 50 per cent, enlarging these passages. (Both the Swedish and Baylor teams require donors who have carried a child to term, as proof that the organ works.)

During the animal trials, Johannesson monitored each patient for rejection. Not all transplanted organs react the same way in a host body. There's a legion of soldiers in our immune system whose job it is to detect foreign objects and eliminate them. Watching how rejection works on these foreign body parts helped Johannesson and her team stave it off with the right cocktail of immuno-suppressive drugs.

By late 2011, they were confident they could succeed in humans. But it would take the Swedes four months to convince a national medical ethics board that the surgery could be morally justified. The group wrestled with dozens of questions: How do you explain the risks and benefits? Is it right to offer hope when results aren't guaranteed? Why perform such a procedure when so many children need adopting? Why perform it when surrogacy is an option? That option, Johannesson points out, is similarly morally fraught, since it requires women to pass the risk of pregnancy to another person. In Australia it's legal if done for "altruistic reasons" (money for medical bills only), but in some states and

3.

Organ Prep

Surgeons carry the uterus to a table in the back of the operating room. There, they flood it with a heparin solution that flushes out the donor's blood and helps preserve her uterine cells. To protect the organ, they pack it in a saline-filled plastic bag and put the whole thing on ice. At this point, the chilled womb is ischaemic—or lacking a blood supply. Doctors keep it that way for up to 30 minutes, until they're ready to implant it in the recipient.

4.

Recipient Surgery

To minimise the organ's time without a blood supply, surgeons prep the recipient in a nearby room. By then, they've also mapped her abdominal arteries and veins via CT and MRI. This helps them locate the internal end of the vagina, called the vaginal vault, where a uterus attaches. Surgeons connect the organ's artery to a vessel that leads down the leg and suture the uterus to the recipient's vagina. The doctors check blood flow before they close and wake the patient.

5.

Implantation

To prevent organ rejection, patients take regular doses of immuno-suppressive drugs. After three to six months, and after the woman has a normal menstrual cycle, doctors implant an embryo produced by standard in vitro fertilisation techniques. Because doctors are unsure how the disconnected nerves of the uterus will behave during labour, they deliver the child via caesarean section. Then, because the organ is no longer needed, they remove it.

illustrations by Hubert Tereszkiewicz

countries, including Sweden, surrogacy is banned.

"It's a necessary thing to do," Johannesson says of the ethics discussions. "These are people's lives we have in our hands. We need to be sure we're [making] good decisions. We have to question ourselves."

By spring 2012, the research group had received permission to move forward. Two years later, the first patient gave birth to a boy. A year after that, Johannesson joined Testa in Dallas as he prepared a trial that, if successful, would allow them and others to scale up the procedure to help thousands of women.

TO ensure the success of their trial, and their patients' health, the Baylor team requires subjects to meet strict criteria. Recipients must be extremely healthy and no older than 35, to reduce the chance of pregnancy complications. Both the donor and the intended mum must undergo psychological evaluations to determine their reasons for participating and to confirm that they can provide informed consent.

Since this is no ordinary hysterectomy that ends with a discarded organ, the procedure requires the expertise of a gynaecological oncologist, to remove the donor's uterus through her abdomen. Normally in a hysterectomy, the surgeon begins by cutting the blood supply. But because in this case she must maintain that supply to keep oxygen and nutrients flowing to the organ, she does this last. "This means there is much higher risk of accidentally nicking an artery and having to deal with blood loss," says team surgeon E. Colin Koon, who is an expert in radical hysterectomies.

Koon must remove more tissue than he normally would; he takes more of the blood vessels than in a typical hysterectomy. "It's a very big dissection," he says. Also the head of Baylor's robotic surgery, Koon is exploring the possibility of performing this procedure less invasively, extracting the organ through the vagina rather than the abdomen. This would be less traumatic for the donor, who must currently stay in the hospital for up to six days after the surgery so staff can monitor her recovery.

Minutes after removal, a team member takes the uterus into the other operating room. There, the surgical plan follows a 3D map of the inside of the recipient's abdomen. This has been created by the team's radiologist and imaging specialist, using a combination of ultrasound, MRI, and CT angiography. A dye added to the blood "lights up" the arteries and veins, some no more than a millimetre in diameter, says team radiologist Greg de Prisco. Because blood vessels are never in the same exact location in every body, the dye lets doctors pinpoint their target. "The surgeon wants to know before they go in: 'Where should I cut?'" says de Prisco.

Testa and Johannesson then get to work. They insert the uterus and attach it to the blood supply, suturing the organ's arteries to an aortic vessel that runs down into the leg. After that, they attach the vagina and anchoring ligaments, and the transplant is complete.

Three to six months later, provided the patient has experienced consistent menstruation, IVF doctors implant an embryo, the result of eggs harvested earlier from the mother and sperm from her partner. She will be able to feel the baby move, but, because surgeons do not connect the mother's nerves to the baby's cocoon (it is a complicated and medically unnecessary step), she does not experience labour pains. A lack of working nerves also makes doctors unsure if the uterus will contract normally, so they deliver the child via C-section. Vaginal birth might be possible in the future, Johannesson says, though it is not a part of the current trial.

IT'S early February, and Kristin Wallis is on the phone with a woman interested in receiving a uterus. Wallis is the nurse coordinator for Baylor's clinical trial team. She vets prospective patients and women wanting to donate. Since Baylor announced its trial in 2016, more than 500 women have emailed or called Wallis. She is an advocate for each patient in the trial, following them through every stage of surgery, sometimes sleeping in the hospital with them, and answering their calls day and night.

Baylor has not yet announced a second trial, and its current one has already selected all of its recipients. But Wallis still listens to everyone's tale in case they could be candidates for future studies, and also because she feels each woman deserves to be heard. Today's caller tells Wallis she lost her uterus to fibroids when she was young. Unfortunately, Wallis quickly knows the woman is ineligible. She's too old and has a heart condition. Still, Wallis spends 45 minutes sympathising with her, while also telling her candidly that she cannot have a transplant.

"If I cut them off after the first sentence, they don't get to tell their story," says Wallis, after she hangs up the phone. "I do want to hear them, but it does take a long time."

Increasingly, callers might have elsewhere to turn. According to the US National Library of Medicine, doctors have either started or plan to start as many as 12 additional uterine-transplant trials around the world. This past March, in an attempt to spread its knowledge, Baylor hosted dozens of surgeons from across the US (from places such as Harvard, the University of Pennsylvania, and the Mayo Clinic) eager to learn about setting up their own programs.

That widespread adoption offers hope to the transgender community, which has been watching the progress of uterine transplants. Katelyn Burns, a member of that community and a freelance journalist who covers its issues for media outlets such as *The Washington Post* and *Vice*, says circles of trans women regularly discuss one day giving birth. Many, says Burns, would opt for the surgery if it were made available. "There's a quiet confidence" that they will gain access to this, says Burns, adding, "If I were young enough, and if I could afford it, I would probably try for it."

Right now, uterine transplants are experimental. That means risks abound for everyone involved. Even if patients who receive the organs remain healthy, there's always a chance they could undergo a painful operation only to have it fail. But even recipients whose new wombs have been unsuccessful have expressed to Testa and Johannesson they were glad to have gone through the process. They contributed to furthering the science. Their transplant, though it did not give them children, still moved the world that much closer to fulfilling for their fellow women what once had been an impossible dream.

Johannesson doesn't mind when people criticise (it's a part of the process) or ask if it's really worth it for anyone to undergo experimental surgery to bear a child. After all, surgeons have been successfully grafting penis replacements on men since 2014. Is a uterus really less essential? Zachary Rubeo, the team's maternal foetal medicine specialist who monitors the transplant pregnancies, notes that since medical science has tackled many other aspects of infertility—from hormone injections and freezing eggs to artificial insemination and IVF—ignoring the physical womb itself makes no sense. Not only that: "To look them in the face and say, 'We won't help you,' that's sort of unfair," he says. The "unnatural" science of obstetrics has saved millions of lives, it's true. But there's nothing more natural than giving a woman the chance to bear her own child.

Erin Biba is a freelance journalist based in New York City. She writes about science for publications such as the *BBC* and *Scientific American*.

△

THE RIGHT STAFF
Far left: Surgical pathologist James Mitchell monitors the transplant for signs of rejection. Above: Head of Baylor's clinical trial, Giuliano Testa; Johannesson; labour and delivery specialist Robert T. Gunby Jr.; transplant surgeon Gregory J. McKenna; and gynaecological oncologist E. Colin Koon.

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RETHINK

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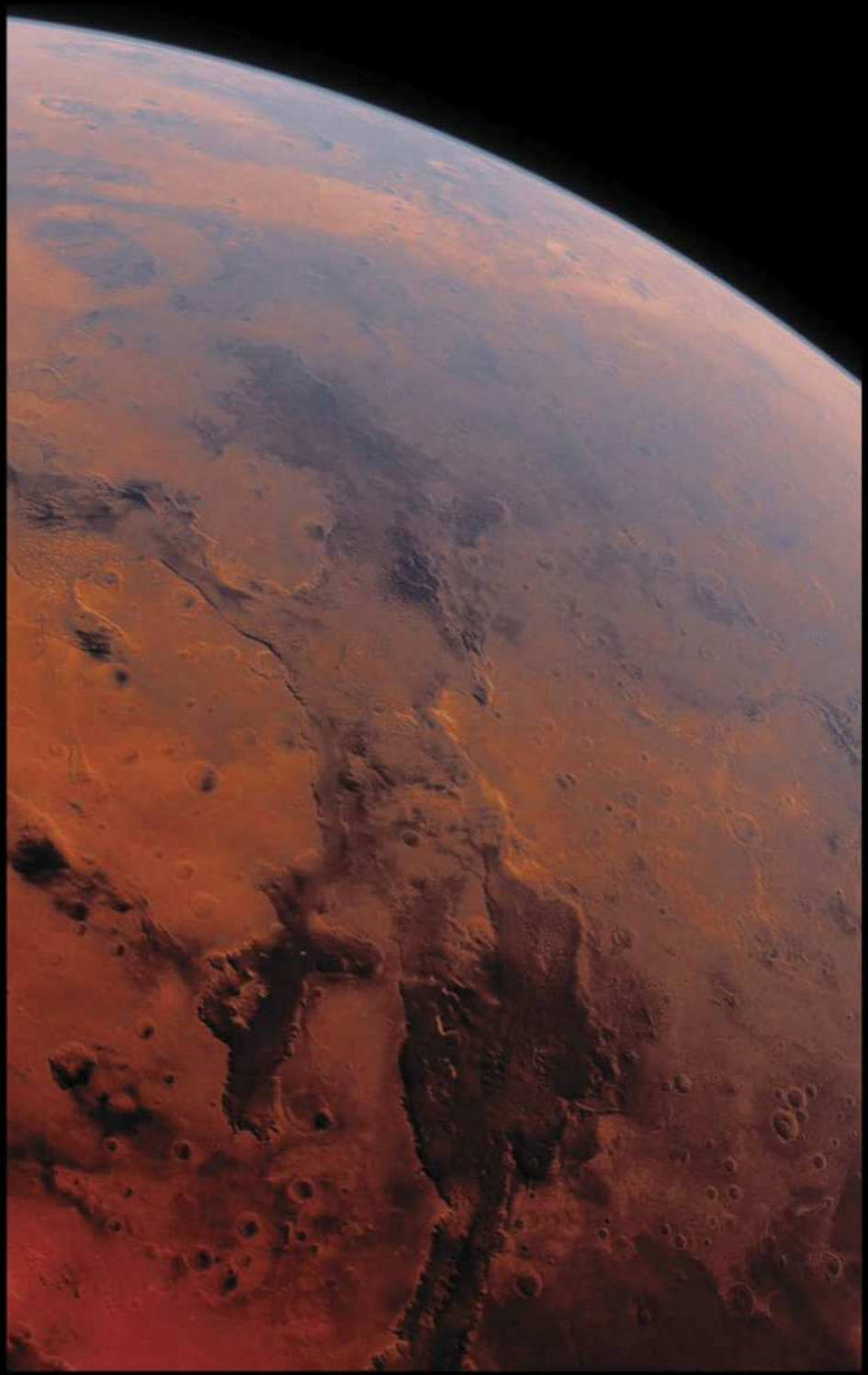


Rethink

BUGS in the Rocks...

The ever-changing landscape of the search for life on ***Mars***

The canals were an optical illusion. The surface looks like a sterile desert. Evidence of multicellular life seems absent. Nevertheless, our scrutiny of the Martian surface will continue, leaving (almost literally) no stone unturned. Here's how the latest discoveries strengthen the case for long-ago life, even while proof remains tantalisingly out of reach.

by MARY BETH GRIGGS

SCIENTISTS HAVE BEEN LOOKING for organic material on Mars for decades, ever since actively testing the soil of the red planet during the Viking missions.

In the years since, rovers, telescopes, and landers all maintained the dogged pursuit of the big the question: whether the organic molecules similar to the ones that dominate Earth might also exist on our neighbouring planet.

Now, two new studies published in Science present exciting findings. Broadly, these are the detection of organic material in 3.5 billion year old rocks; and seasonal changes in methane happening in the Martian atmosphere.

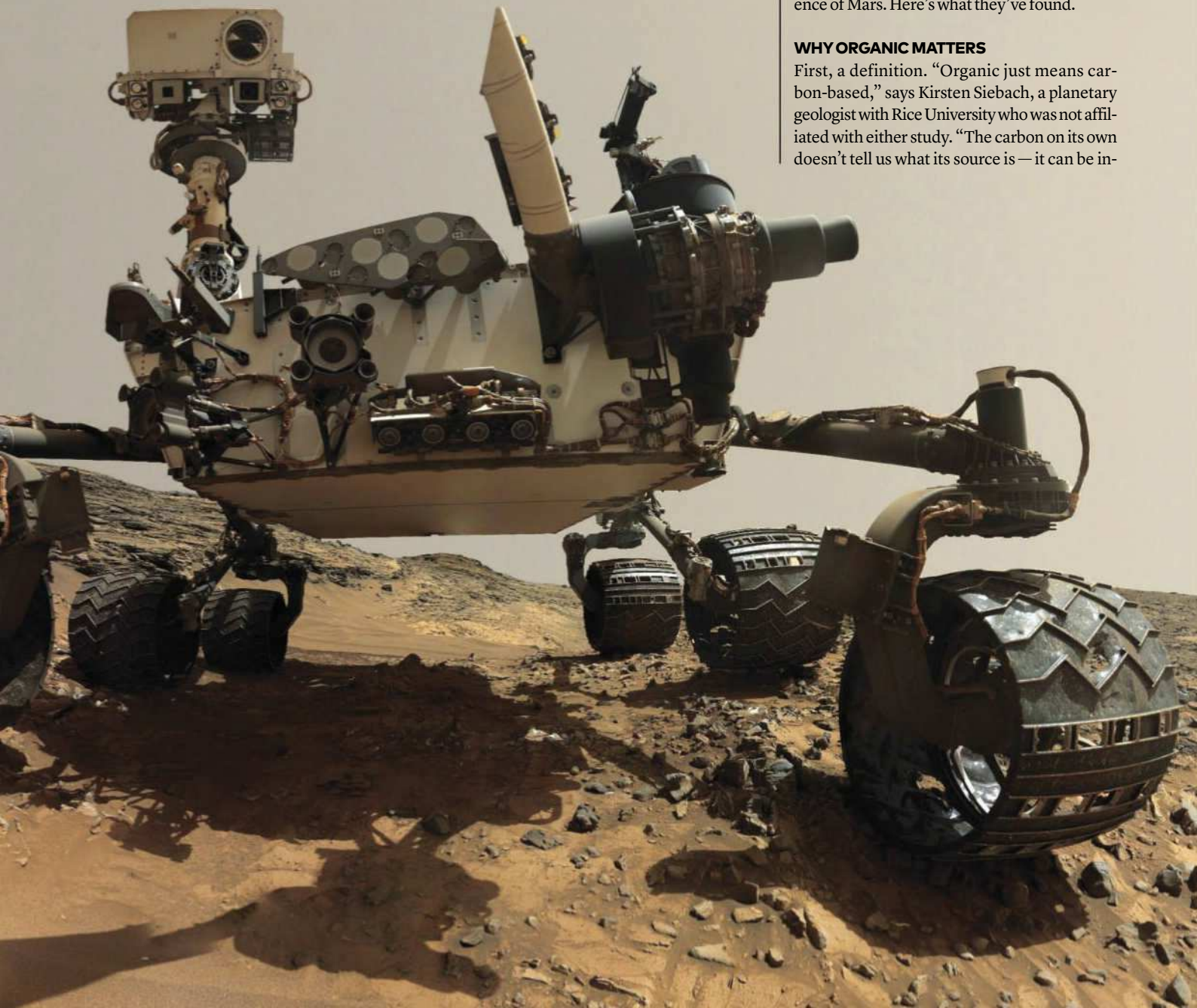
First up: no, neither finding proves that we've definitely found life on Mars, recent or ancient. That's a bold claim that would require way more data and corroboration to confirm. But the findings do give researchers looking into the question of whether there was once life on Mars hope that one day, they might be able to figure it out.

Both studies made use of the Sample Analysis at Mars instrument suite (but you can call it SAM). Chris Webster, a scientist at NASA's Jet Propulsion Laboratory and lead author of the methane paper, describes SAM as "undoubtedly the most sophisticated chemistry lab ever sent outside planet Earth."

It's capable of processing samples of both gas and rock, allowing researchers to piece together more about the past and present existence of Mars. Here's what they've found.

WHY ORGANIC MATTERS

First, a definition. "Organic just means carbon-based," says Kirsten Siebach, a planetary geologist with Rice University who was not affiliated with either study. "The carbon on its own doesn't tell us what its source is — it can be in-



organic sources delivered by meteorites, it can be from volcanoes on Mars. However, it is a key ingredient for life to form, and for life to grow."

The researchers used SAM to heat up drilled samples of rock collected from a 3.5 billion year old lake bed.

"We take this powder and we put it in an oven and we heat it up," says Dawn Sumner, an author of the paper. But she says actual analysis of the sample is more like walking into a kitchen when the baking is already underway, and having to guess what's in the oven.

"Say someone else put cookies in the oven," she says. "I can recognize how chocolate chip cookies smell, and it's different from chicken or tamales. Similarly, you can smell the organic compounds that come from the oven and know more about what's in the oven."

Of course, components of Martian rocks are a bit harder to identify than chocolate chip cookies. The smells coming off these compounds are much harder to pinpoint, especially because they don't register as a single, easily-identified compound.

"Imagine you have a giant molecule with all these bits and pieces glued together with chemical bonds. As you heat that sample up, the large molecule has bits and pieces of it cleaved off and the gases get swept down the pipeline to the instrument," explains Jennifer Eigenbrode, a scientist at NASA's Jet Propulsion Laboratory and lead author of the organic matter paper. "That's what the instrument sees — bits and pieces of something bigger in the sample."

Eigenbrode and others still aren't totally sure what that larger organic molecule or molecules might be. They're also trying to figure out how it managed to stay so well-preserved for more than three billion years.

AN EXTREMELY OLD SURVIVOR

Organic molecules tend to not survive for very long periods of time, often breaking down when they encounter water, radiation, or extreme heat and pressure.

But while Mars does get bombarded with a lot of radiation, it isn't sopping wet like the Earth, and unlike our own active planet, its rocks aren't constantly churned and recycled by plate tectonics. This may give this organic matter, whatever it is, a better chance at surviving.

Eigenbrode and her team took pains to make sure that what they were seeing really was organic material.

"I had my first inkling we were really onto something about a year ago, and then it was 'if the data is telling us what we think it is we better make sure'," Eigenbrode says. She repeated the tests over and over, making sure that her results were reproducible.

"I did it three times," she laughs. "Because its is a very big finding and there's a lot of data processing involved, because we looked at a lot of different samples. The moment I finally realised it was there was a moment of awe. We've been looking for these organic compounds since 1976."

This doesn't mean that these are the fossilised remains of 3.5 billion-year-old microbes. It could be something that ancient microbes ate, or there might have been no microbes at all. It's possible these molecules formed purely from atmospheric or geologic processes, like volcanism, or a meteorite bombardment.

But the fact that the Curiosity team has definitively ID'd organic matter is still important, even if this isn't evidence of life.

"If there was life, it's typically very hard to find, but we now know that conditions were right for it to be preserved. We can look ahead with renewed vigour for that specific evidence," Siebach says.

THE MYSTERY OF METHANE

As Eigenbrode and her team concerned themselves with the rocks beneath Curiosity's treads, another team was busyworking on a vexing issue more to do with the air - or, on Mars, the barely-there whisper of CO_2 and other gases that counts as an atmosphere - surrounding the SUV-sized rover, and more specifically, one gas within it.

"Methane represents the simplest organic molecule, and on Earth it is primarily considered a biogenic gas that comes from life on the Earth's surface," says Melissa Trainer, a research scientist at NASA Goddard Space Flight Centre and an author of the paper.

"Variable methane has been detected on Mars, but it's eluded our understanding for over a decade. Over multiple missions the appearance and disappearance and behaviour [of methane] has been something that we haven't been able to understand."

Early observations of methane on Mars had been from ground telescopes in Hawaii that measured those plumes. Then an orbiter called Mars Express took measurements over long periods of time, slowly building up an estimate of the abundance of methane on the planet.

But it wasn't until Curiosity descended by skycrane that researchers like Webster and colleagues were able to get the first in-situ measurement of methane on Mars.

"We've been able to observe that over multiple Mars years, which is unprecedented," Trainer says. They found that the methane in the atmosphere changes a lot by season, reaching its peak at the end of summer in the Northern hemisphere, then dropping. The seasonal range of methane in the atmosphere is between 0.24 to 0.65 parts per billion

LAND OF PARADOXES
Mars is home to the solar system's largest volcano, but unless you're at one of the cliffs, Olympus Mons is so wide it feels like standing on a plain.

THE BROWN PLANET
This landscape, taken by Curiosity, gives a truer sense of the real colour of Mars.

EPIC SNOW DAY

Curiosity is located in Gale Crater, a spot near Mars' equator. But even there, the rover has a good vantage point to monitor the changes in the seasons on the planet.

"We're a bit like Hawaii in terms of our experience of the seasons," Webster says. "We don't have strong seasonal effects locally, but even locally the temperature changes are quite significant, they're maybe 30 degrees [Celsius] from summer to winter. So there's a significant surface temperature and air temperature change."

In addition, Mars' atmosphere mixes easily, with changes in one part of the planet affecting other areas. So along with methane, SAM also monitored the presence of other gases that were better understood, including nitrogen, argon, and carbon dioxide.

Nitrogen and argon also tend to vary seasonally on Mars, getting pushed around as each pole experiences winter. At that point, carbon dioxide in the atmosphere freezes, falling onto the polar ice caps.

"Up to a third of the mass in the atmosphere just freezes out. If that happened on Earth, we would really notice," Trainer says. "When that happens the rest of the gases in the atmosphere get pushed around with the CO_2."

Despite this understanding, the observations showed some unexpected results. The argon and nitrogen increased in concentration as the CO_2 froze and sublimated, but the methane was doing something very different. Though it was only present in small amounts in the atmosphere, the degree to which it increased and decreased didn't match the observed changes associated with carbon dioxide.

The amount of methane detected by the instruments over the course of five Earth years is too large to be comprised only of methane delivered by meteorites, one potential source of the gas on the planet.

> **"ON EARTH WE'D BE ABLE TO ANALYSE A SAMPLE IN GREATER DETAIL, WITHOUT HEATING IT UP AS MUCH, AND HOPEFULLY FIND OUT ANY EVIDENCE WE COULD ABOUT WHAT THOSE ORGANIC MOLECULES WERE LIKE"**

Researchers also ruled out the possibility that the methane readings might be from the activity of the rover itself. And the seasonal change in the amount of methane in the atmosphere, while small compared to Earth's standards, was significant enough to surprise the researchers when they saw it.

The team thinks it's possible the methane might be coming from a subsurface reservoir somewhere on the planet, leaking out through cracks and vents. They're not sure where this reservoir (or reservoirs) might be, and what form they might take.

Here on Earth, large stores of methane are trapped in clathrates — cages of water ice that lock gases like methane inside.

It's possible that similar deposits exist on Mars. But no one has ever observed clathrates on Mars, leaving them stuck in the realm of possibility.

PATIENCE AND CURIOSITY

The next rover mission, Mars 2020, will also take rock samples. But instead of analysing all the samples on site, it will also collect specimens with the intention of sending them back to scientists on Earth.

The robot will pack some samples in a specialised capsule that will keep them safe during their journey to Earth's more advanced labs.

"If we could bring back anything like what we found in the sample, on Earth we'd be able to analyse it in greater detail, without heating it up as much, and hopefully find out any evidence we could about what those organic molecules were like," Siebach says.

Webster is interested in seeing what happens if the rover encounters a large plume of methane, which could contain enough material for the team to examine the carbon isotope ratio in the gas. That could tell them whether or not it's likely to have a biological origin.

He's also looking forward to seeing results from the European Space Agency's Trace Gas Orbiter, currently in orbit around Mars.

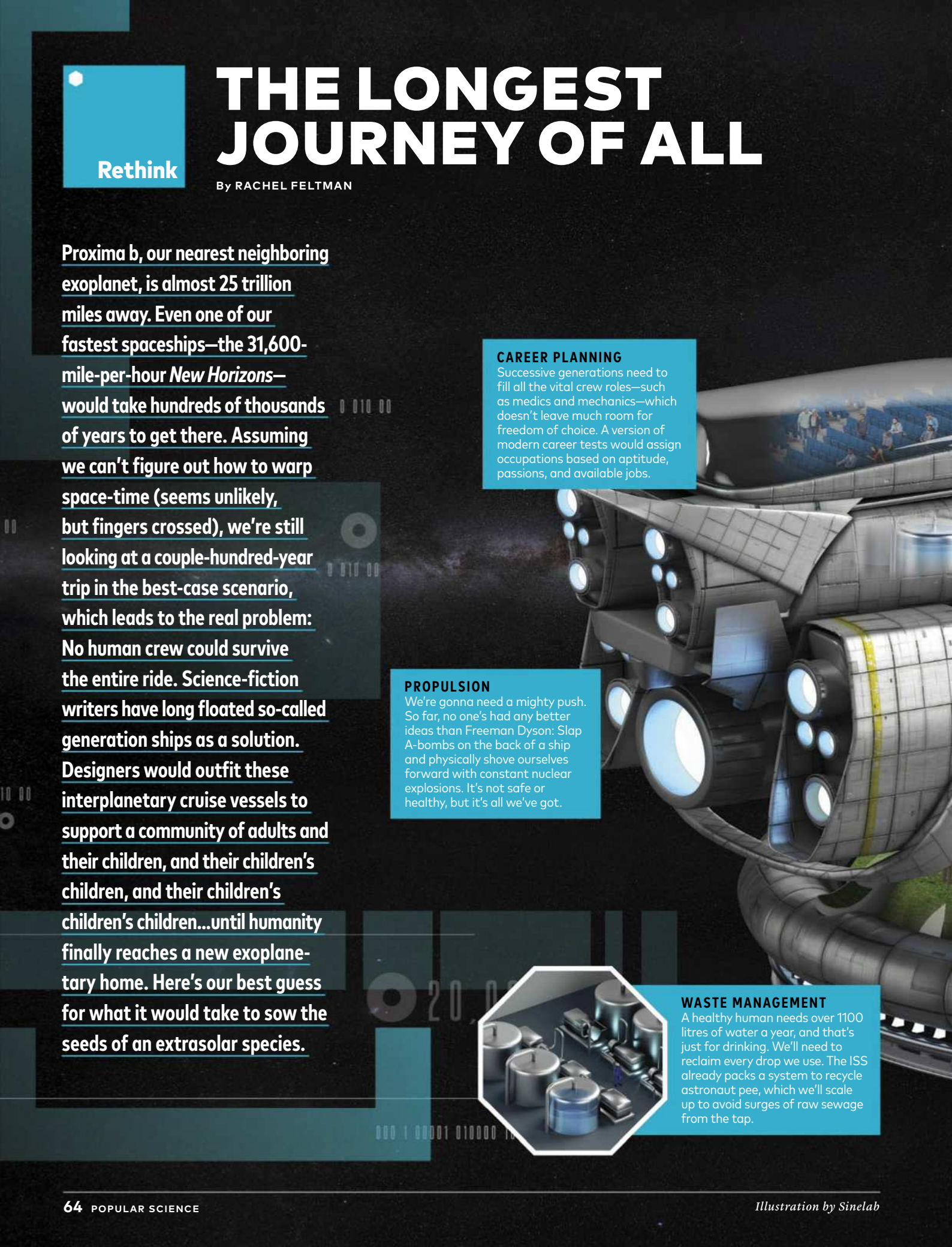
"They will be able to map the methane globally, which will be a huge step ahead," Webster says. "In particular, if they see plume or patches of methane that tend to be associated with certain areas of Mars — a certain topography, cliff faces or canyons or certain mineral surfaces — that would be another very important next step. Looking for local sources that are also repeatable would help direct future missions, because we would go to that place and measure the heck out of it."

Rethink

THE LONGEST JOURNEY OF ALL

By RACHEL FELTMAN

Proxima b, our nearest neighboring exoplanet, is almost 25 trillion miles away. Even one of our fastest spaceships—the 31,600-mile-per-hour *New Horizons*—would take hundreds of thousands of years to get there. Assuming we can't figure out how to warp space-time (seems unlikely, but fingers crossed), we're still looking at a couple-hundred-year trip in the best-case scenario, which leads to the real problem: No human crew could survive the entire ride. Science-fiction writers have long floated so-called generation ships as a solution. Designers would outfit these interplanetary cruise vessels to support a community of adults and their children, and their children's children, and their children's children's children...until humanity finally reaches a new exoplanetary home. Here's our best guess for what it would take to sow the seeds of an extrasolar species.



CAREER PLANNING

Successive generations need to fill all the vital crew roles—such as medics and mechanics—which doesn't leave much room for freedom of choice. A version of modern career tests would assign occupations based on aptitude, passions, and available jobs.

PROPULSION

We're gonna need a mighty push. So far, no one's had any better ideas than Freeman Dyson: Slap A-bombs on the back of a ship and physically shove ourselves forward with constant nuclear explosions. It's not safe or healthy, but it's all we've got.

WASTE MANAGEMENT

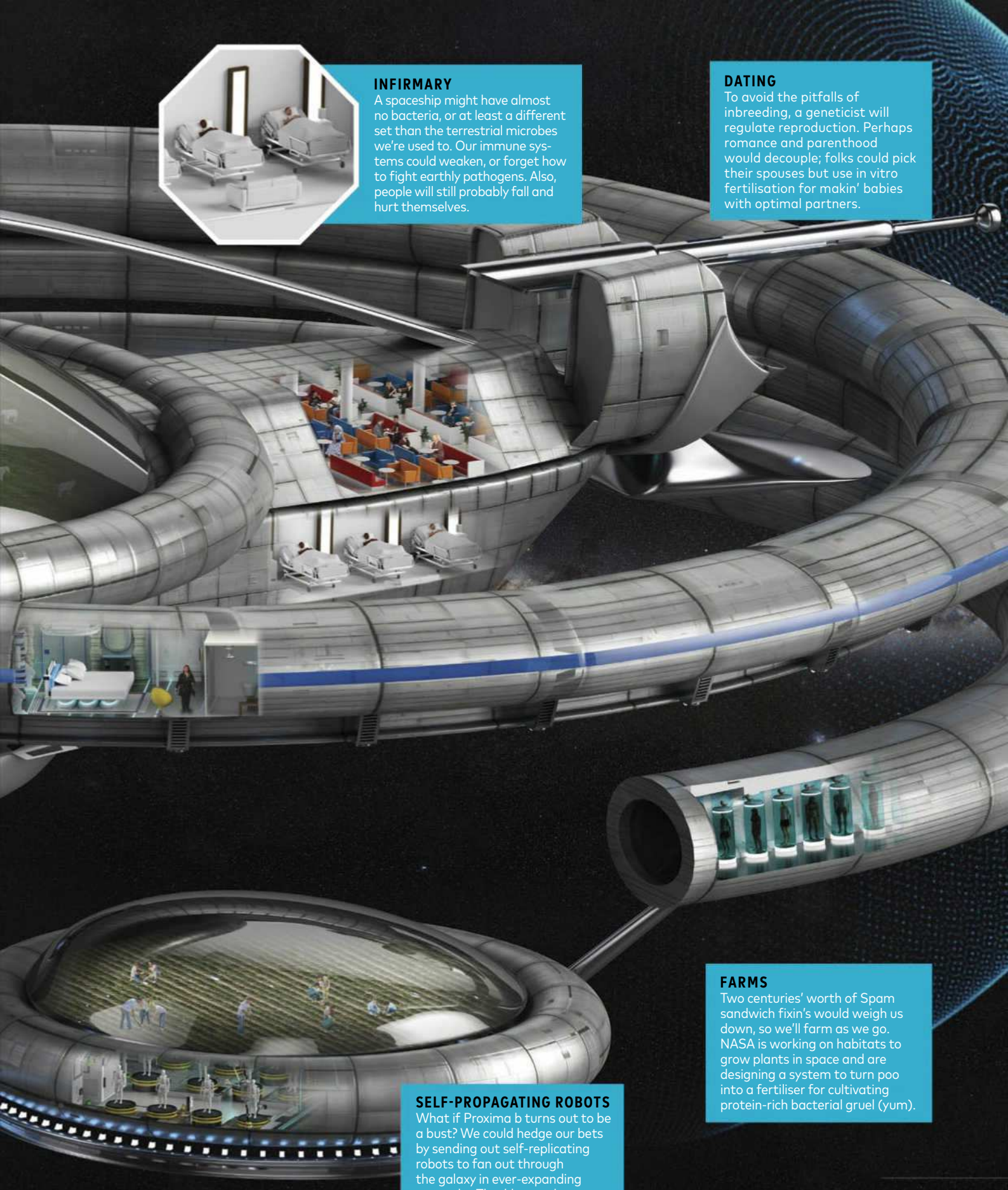
A healthy human needs over 1100 litres of water a year, and that's just for drinking. We'll need to reclaim every drop we use. The ISS already packs a system to recycle astronaut pee, which we'll scale up to avoid surges of raw sewage from the tap.

Illustration by Sinelab

PETTING ZOO
Fluffy and Fido are too great a luxury for space, but evidence suggests a small menagerie of animals could help our immune systems. Toddlers who roll around in pastoral dirt may develop fewer allergies. Besides, furry friends do wonders for mental health.

PEOPLE
One study estimated a starting crew of 160 could maintain a viable population for 200 years, provided they were a diverse bunch. Large gene pools provide crucial variety—we wouldn't want any two passengers closer than sixth or seventh cousins.

illustration by Sinelab



INFIRMARY
A spaceship might have almost no bacteria, or at least a different set than the terrestrial microbes we're used to. Our immune systems could weaken, or forget how to fight earthly pathogens. Also, people will still probably fall and hurt themselves.

DATING
To avoid the pitfalls of inbreeding, a geneticist will regulate reproduction. Perhaps romance and parenthood would decouple; folks could pick their spouses but use in vitro fertilisation for makin' babies with optimal partners.

FARMS
Two centuries' worth of Spam sandwich fixin's would weigh us down, so we'll farm as we go. NASA is working on habitats to grow plants in space and are designing a system to turn poo into a fertiliser for cultivating protein-rich bacterial gruel (yum).

SELF-PROPAGATING ROBOTS
What if Proxima b turns out to be a bust? We could hedge our bets by sending out self-replicating robots to fan out through the galaxy in ever-expanding networks. They'd spread on our behalf, eventually finding and preparing a home for us.

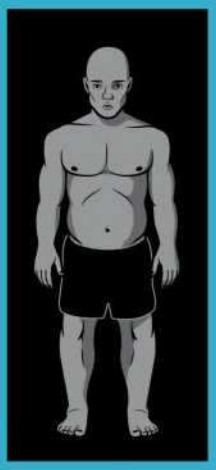
SHIELDING
Earth's magnetic field protects us from DNA-scrambling. Deep space is more radioactive than low-earth orbit, so we'll need stronger shields than our current ships have. A force field would be nice, but asteroid clay or even simple water ice could work.

ARRIVAL PLAN
We might not know much about Proxima b when we lift off. Our crew needs to be prepared, so we'd want a bit of everything: a full suite of equipment capable of extracting resources from - and building more stuff with - solids, liquids and gases alike.

FROZEN PEOPLE
The crew can manage in a closed system for a couple of centuries, but speculators say it'll take 20,000 souls to start a healthy population on a new world. One space-saving tip: Bring frozen embryos and people to diversify the gene pool upon arrival.

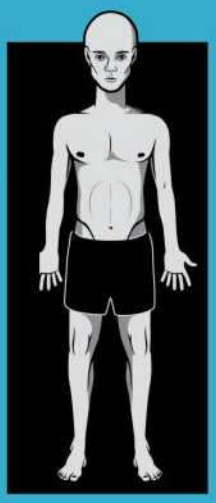
USS *YOUMANS*

ALIEN HUMANS



Fresh from a Martian Colony

By the time we're ready to leave the solar system, we might have Martian colonists to pick up along the way. Dark skin fares better against the UV radiation pummelling the Red Planet's paltry atmosphere, so pale settlers probably wouldn't thrive. Low gravity makes bones brittle, meaning evolution might select for those who can afford to lose bone mass—short, squat, sturdy folk.



Growing up on a space ship

Low Gs could also go the other way, making us tall, willowy, and brittle, thanks to spine stretching and bone loss. Ship dwellers en route longer than expected would have to opt for C-sections to avoid shattered pelvises, meaning massive noggins could flourish. Mutations might be more likely (thanks, space radiation) and a small gene pool means random changes could spread rapidly.

On our new home planet

Genetic engineering could help us survive on less food and water. Tiny tardigrades provide clues; they can persist for years dried up, so we might crib some of their genes (once we figure them out). Frail space explorers could also use exoskeletons to minimise their need for fuel. Meanwhile, larger eyes could help illuminate our new world: Rocky planets often orbit dim, little red dwarf stars.

illustrations by Todd Detwiler

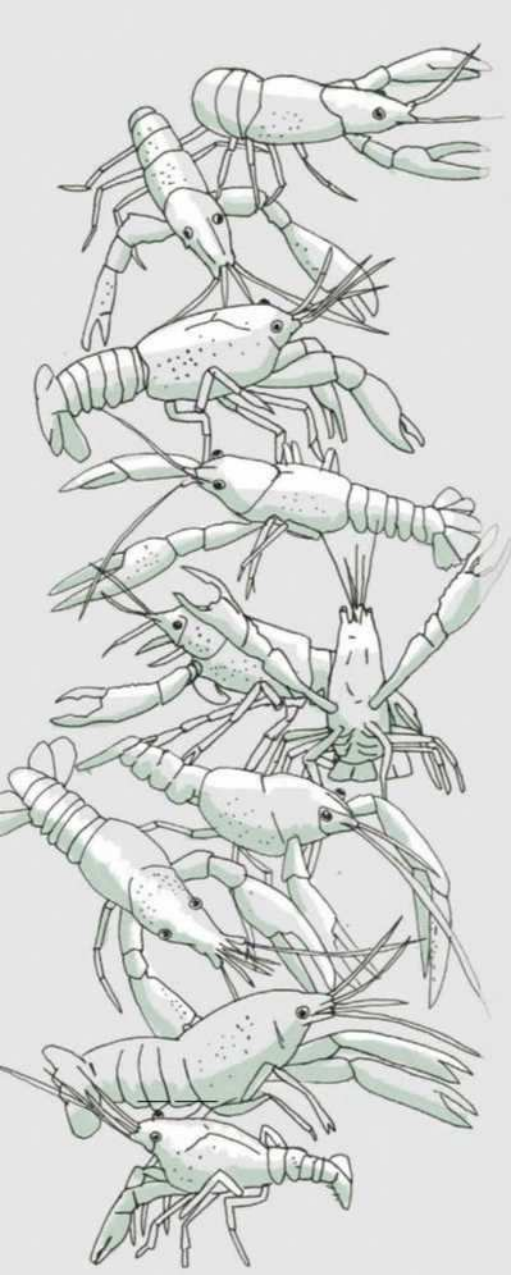
Rethink

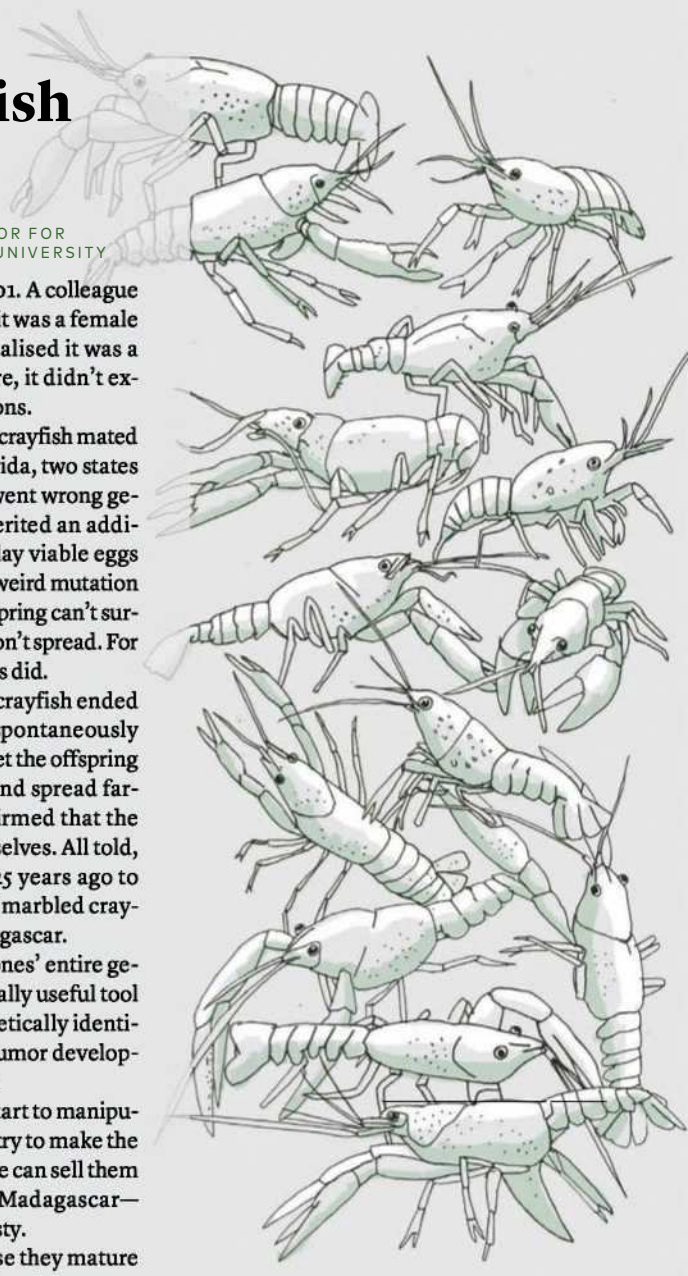
TALES FROM THE FIELD

SNAPPY

Invasive Self-Cloning Crayfish Aren't All Bad

WOLFGANG STEIN, ASSOCIATE PROFESSOR FOR NEUROPHYSIOLOGY AT ILLINOIS STATE UNIVERSITY





I first saw a marbled crayfish around 2001. A colleague brought one into the office and told me it was a female that was reproducing on its own. We realised it was a new species—only a decade or so before, it didn't exist—and it was cloning itself by the millions.

We think that in the 1990s, two slough crayfish mated either in a pet store or in Georgia or Florida, two states where they live in the wild. Something went wrong genetically, and one of the daughters inherited an additional set of chromosomes that let her lay viable eggs without any males. It's not unusual for a weird mutation like this to happen, but normally, the offspring can't survive or reproduce, and the new species won't spread. For some reason, this daughter and her clones did.

Somehow, many of the new marbled crayfish ended up in German pet stores. They would spontaneously multiply, and their owners would often set the offspring free, which let the animals reproduce and spread farther. In 2003, scientists officially confirmed that the crustaceans were, in fact, cloning themselves. All told, they've gone from that single female 25 years ago to millions, or maybe billions, of identical marbled crayfish found throughout Europe and Madagascar.

In 2018, we published a map of the clones' entire genetic code. The species is becoming a really useful tool for researchers like me: We can use genetically identical creatures to study everything from tumor development to the effects of drugs on the brain.

Now that we know this code, we can start to manipulate it in the lab. For example, we might try to make the crustaceans grow to larger sizes so people can sell them for food. This is already happening in Madagascar—turns out, marbled crayfish are pretty tasty.

It's easy to get lots of them too because they mature in about three months and lay hundreds of eggs. Just put one in a tank and wait.

AS TOLD TO NICOLE WETSMAN

SERVING FACE

Science Eye for the Neanderthal Guy

ÉLISABETH DAYNÈS, SCULPTOR AND FOUNDER OF ATELIER DAYNÈS, PARIS

Thirty years ago, I was sculpting hyper-realistic masks for theatrical productions. Then I met these scientists who asked me to create models of Paleolithic hunters for museum exhibits. When I visited their lab, I saw 20 ancient skulls on a shelf, and I was fascinated by all the different shapes early humans took. I wanted to get my hands on those skulls.

Since then, it's been my job to bring ancient people back to life, a field called paleoreconstruction. We convey science's best guess about how these human relatives looked.

I start with a plaster cast of the skull and lay clay "muscles" over it, building thin layers to mimic flesh. The tricky parts are the features.

Right now I'm working on a Homo naledi—a 300,000-year-old relative of ours that archaeologists discovered in 2013. Many hominids looked more like chimpanzees than today's humans, so I could make the nose chimplike or modern. But I'm waiting for the scientists to determine that, based on how much H. naledi's teeth or other remains resemble those of better-understood species.

Next, I make a silicone mould of the entire structure—this copy is what actually goes on display—and paint on a skinlike complexion. I add real hair, as well as resin teeth and glass eyes.

Some aesthetic decisions are mine, not the scientists'. With Neanderthals, I can take liberties because I've reconstructed so many of them. For one man, I shaved down his facial hair with a stone razor, one hair at a time, and gave him ear piercings made of shells.

My favorites are Neanderthals because people once thought they were stupid, ugly, and brutal. But we now know they made stone tools and were the first to bury their dead. I look at a man I reconstructed and I know he was compassionate, not stupid.

So I compose facial expressions to make my reconstructions look charismatic. Their eyes should sparkle with life and intelligence.

When people see my sculptures in a museum, they're often meeting these Neanderthal relatives of ours—whom we lived alongside for thousands of years—for the first time. If one in five people leave the exhibit with an emotional connection, then I'm happy.

AS TOLD TO RACHEL FELTMAN

1. Skull
I start with a plaster cast of the skull, in this case, a Neanderthal's.

2. Muscles
Based on the muscles of similar species, I flesh out the face with clay.

3. Skin
I make a silicone mould of the head. This copy is what ends up in a museum.

4. Personality
Finally, I paint on a complexion and add hair, clothing, and decoration.

illustrations by Julia Rothman

Rethink

HEAD TRIP

WAXING AND WANING

Our Brains, on Space

By AMAL AHMED

trip meter | real world | westworld

FROM HERE ON EARTH, WE COULD swear that the moon gets larger as it dips near the horizon. One thousand years ago, Arab astronomer Ibn al-Haytham offered an answer that still holds true today: The bloating of the lunar body is all in our heads.

Neuroscientists' running theory goes like this: Our brains perceive the sky around us as a kind of flattened dome. As such, the horizon seems much farther away than the sky that is directly above our heads. (It's not.) So, when the moon hits the horizon, our brains make an assumption: It must be huge in order for us to still see it at such a far distance. Our noggins adjust what we see accordingly. We tell our retina's snapshot, *Nah, can't be*, and reset it.

But why the moon and not objects on Earth itself? Toshiro Kubota, a computer scientist at Susquehanna University, says our brains instinctively calculate depth and distance among all objects. The problem with space is that it's really a translucent non-object that stretches forever. The moon is never "in front" of the sky, but we perceive it as such.

We don't yet grasp how our gray matter deals with this never-ending expanse. But we have plenty of time to figure it out. Our satellite isn't going anywhere anytime soon.

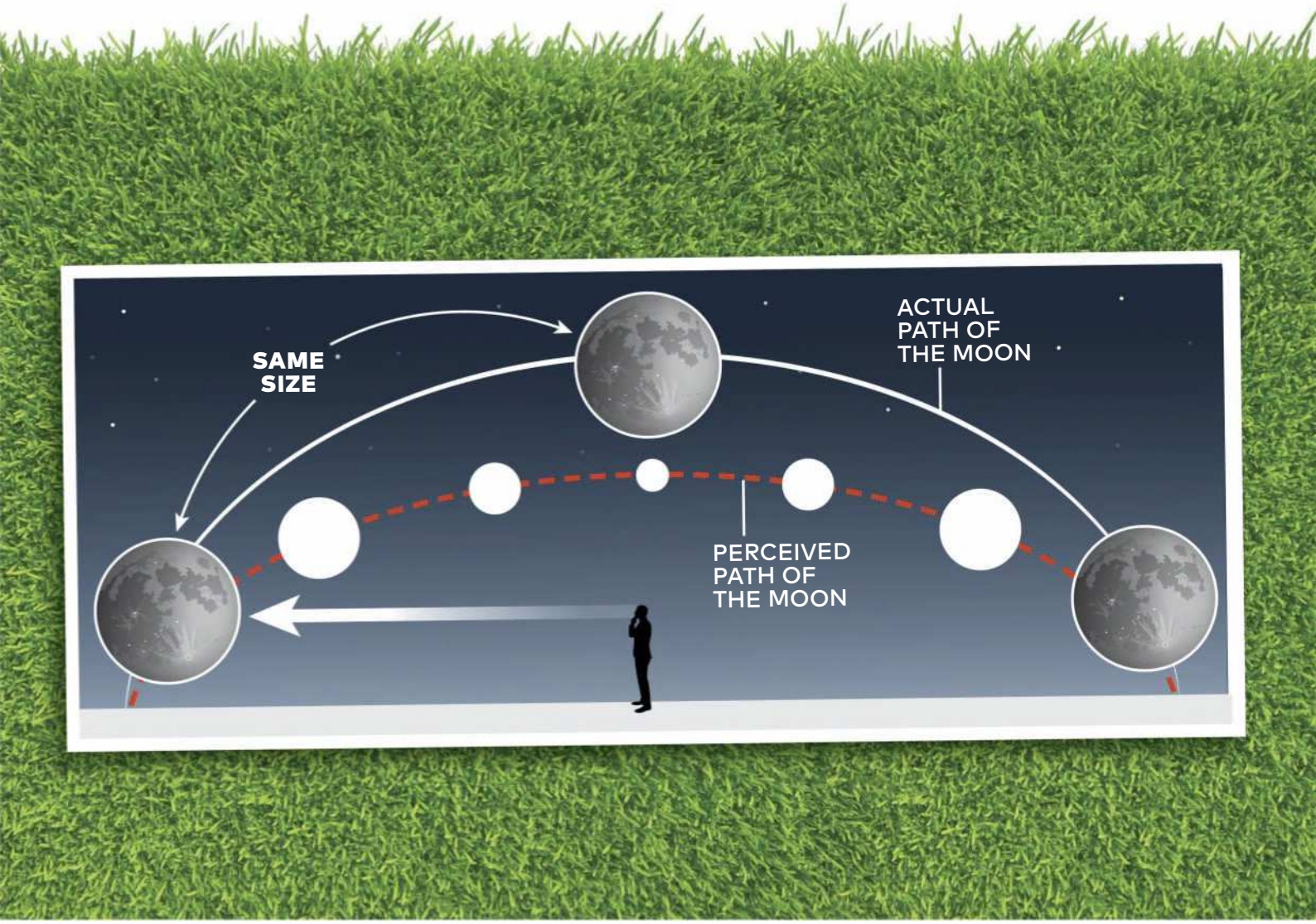
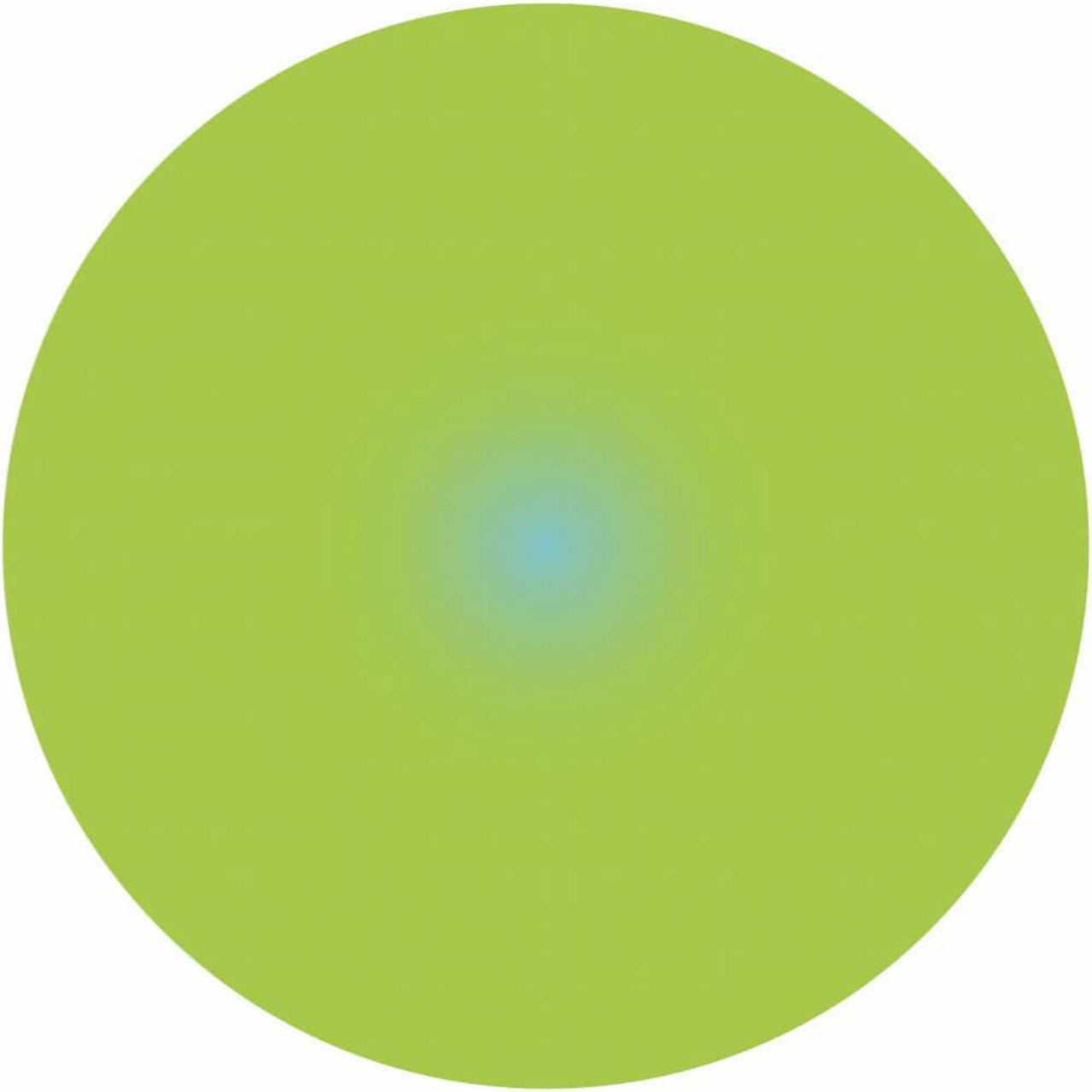


ILLUSTRATION BY PETE SUCHESKI / SHUTTERSTOCK.COM



THE GREAT DOT DISAPPEARANCE

Fill in the Blank

By JESSICA BODDY

CAN YOU FEEL YOUR SOCKS RIGHT now? Sensations—smells, sights, feelings—that stay constant for too long tend to fade away. The same goes for the blue dot in this circle. Stare it down for 15 seconds and it fades away. Blink or move your eyes, it comes back. (And especially weary readers may find their minds drifting enough that even the edges of the green circle start to lose definition against the white of the page.)

Why? Our brain conserves energy whenever possible, says Frans W. Cornelissen, a neuroscientist at the University of Groningen in the Netherlands. If something never changes, we stop registering it. To generate images, neurons constantly relay signals from our retinas to the brain. The longer we stare, the more the cells tire of sending along the same messages.

Eventually those signals decay in strength. Instead of working hard to analyse the intricacies of the image, after a while, the brain ignores details in favour of the big picture. It says: "Eh, that's mostly green."

Cornelissen also notes the blue dot's spotty boundary encourages the brain to annul it.

But your grey matter isn't slacking; it's still mostly correct. According to Cornelissen: To survive, we don't need to sweat the small stuff.

JUNE 1968

From The Archives

The Unfettered Space-Optimism of the 1960s

WHEN 2001: A SPACE ODYSSEY first hit theatres in 1968, plenty of people didn't get it. Especially the monkey parts. But the people who had at least half an idea of how space travel could actually work, they got incredibly (over) excited.

So naturally, Popular Science dedicated an entire cover feature to the film, breathlessly explicating on how all the tricky camera work was done, and how all the vehicles and locations were super-plausible and realistic and absolutely achievable within the next 33 years.

The late 1960s was of course the height of the space race, and June 1968 was almost exactly a year before Apollo 11. Fevers were running high, imaginations were running wilder, yet of all the things predicted in the movie, the phone call that Dr Heywood Floyd makes from orbit is the most unexpectedly realistic.

But probably not in the way Kubrick intended. Floyd's two-minute video call to his daughter cost him $1.70, a shocking price in 1968. But today of course, especially from orbit, it seems quite reasonable.

by ANTHONY FORDHAM

HOW THEY FILMED "2001: A Space

An astronaut lost in space . . . moon cities ... a voyage to Jupiter. And take a look, too, behind the scenes of the new movie

By HERBERT SHULDINER
PAINTINGS BY BOB McCALL

The future is here. That's the feeling you get when you leave the theater after seeing 2001: A Space Odyssey, the most realistic science-adventure movie ever filmed.

It uses an astonishing combination of camera tricks and scientific fact to give you the closest thing possible to the actual sensations of space travel.

2001 shows the boldness of a new breed of heroes who conquer space to colonize the moon — and the heartbreak of death when a rescue mission fails and an astronaut becomes a satellite around the sun.

Here's the fascinating scientific background for the scenes that the camera caught — plus some of the amazing things you don't see on the screen that made it possible.

The picture ranges from the dawn of man — which is shown with the aid of a revolutionary new projection technique —to the discovery of extraterrestrial intelligent beings in outer space. The existence of such life somewhere in the universe is the absolute conviction of Arthur C. Clarke, famous scientist and spinner of science-fiction tales, and producer-writer-director Stanley Kubrick, who co-au-

Not A Cliche in 1968!

JUNE 1968

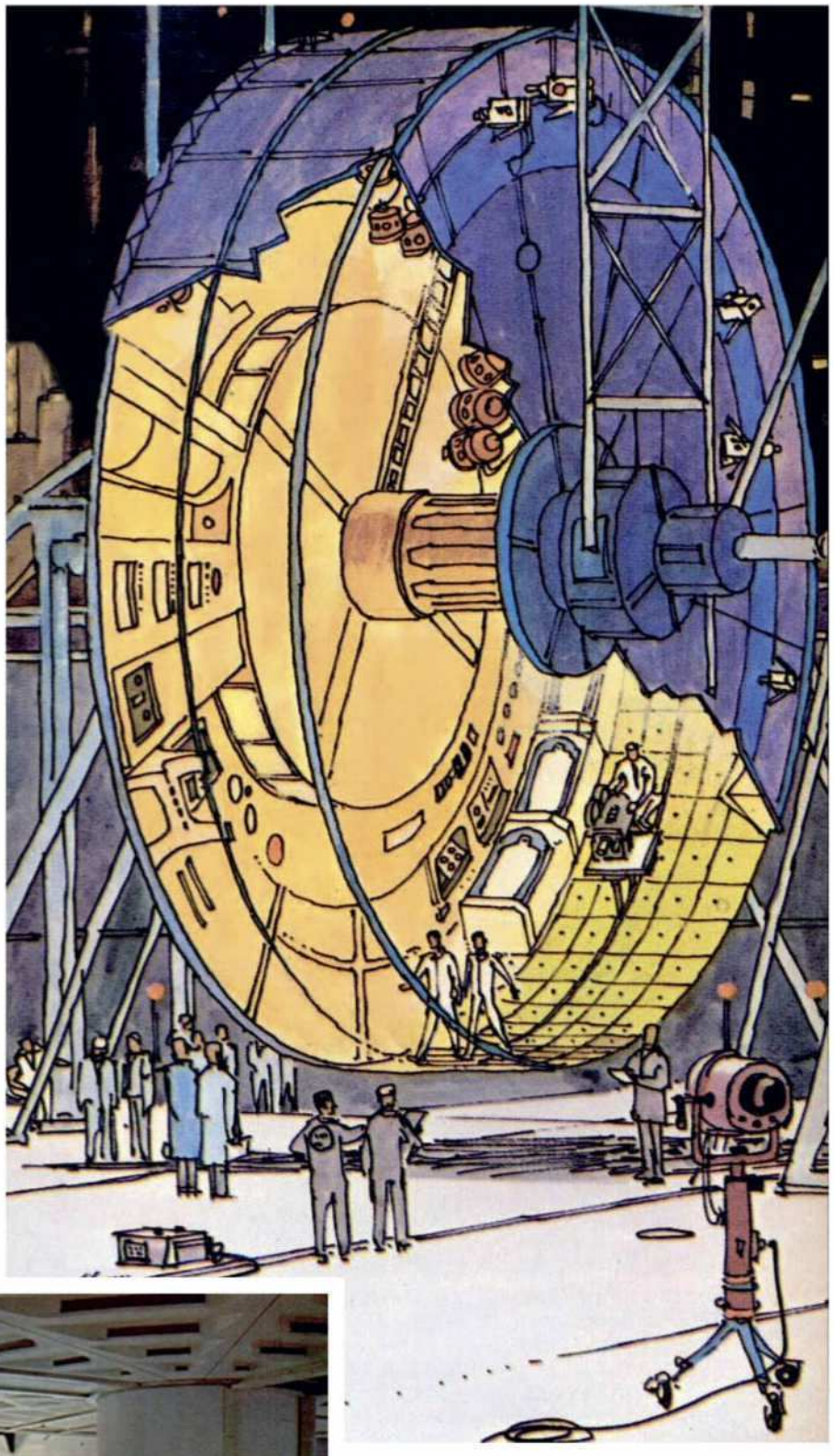
This picture of a hapless astronaut drifting in space being menaced by robot claws etc, might have already been a staple of the pulp SF mags, but on Popular Science it was radically new and innovative stuff. In 1968, space was happening! Also, the Vietnam War was happening but that's less fun to talk about. Note also the 16p special report on GAS, because even in 1968 the energy price shock of the early 1970s was already building...

Odyssey"

thored the screenplay. By the end of the movie, you may be convinced yourself.

Kubrick destroyed a mad, mad world with a nuclear-bomb orgy at the climax of his last film, Dr. Strangelove. Here he resurrects a far better world in which you find man routinely shuttling to the moon. The earth's natural satellite has been settled. Children have been born there and know no other home. Nuclear power and a highly developed, almost-human computerized technology make anything possible.

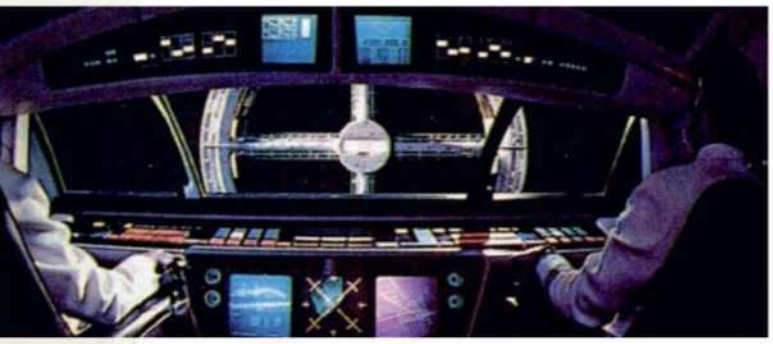
Why is it all believable? Kubrick and his staff did



Astronauts walk on the walls and ceilings in the fantastic sets of 2001. They exercise in the centrifuge (left) which is part of the Discovery, a giant space probe. The huge wheel (shown in drawing above) is 60 feet in diameter and weighs 32 tons. It actually turned during filming, but not enough to create centrifugal force. Specially mounted cameras were used to create the illusion on the screen. The wheel had to be sealed for shooting, and a special closed-circuit video system was set up to enable the director to monitor and direct the action, by radio, inside the centrifuge. Trained rescue guards stood by at all times, to help actors escape if a fire started inside the centrifuge.

Astronauts of 2001 start their journey into space aboard aerospace vehicle called Orion (above). Designed specifically to take man from earth for a short trip into space, it can take off like a conventional plane and boost itself into orbit with rockets, or it can be launched into space by a rocket instead.

Orion approaches orbiting space station turning slowly 200 miles above the earth. Space Station 5 is a transfer point for ferries to the moon. It also contains scientific and weather labs staffed by scientists. The huge wheel was constructed in space by assembling prefabricated parts sent up from earth.



Control deck of Orion is a realistic mockup designed by scientists to simulate controls of 21st-century spacecraft. Pilots must synchronize their course with rotation of the orbiting space station to make a proper landing in the core. Monitors give pilots readouts on proper approach.

painstaking research to make sure that everything they show in this incredible movie *will be achievable in 33 years. [Emphasis from the future - Ed]*

Recruiting scientists. Starting five years ago, they canvassed leading scientists from many nations to find out how far into space man would venture and how he'd get there. Consultants from the NASA Voyager program were hired to help create the spacecraft and sets. Their suggestions were given form by art director Tony Masters at MGM's British studios, where the movie was filmed. Masters had 35 set designers working under him for the job.

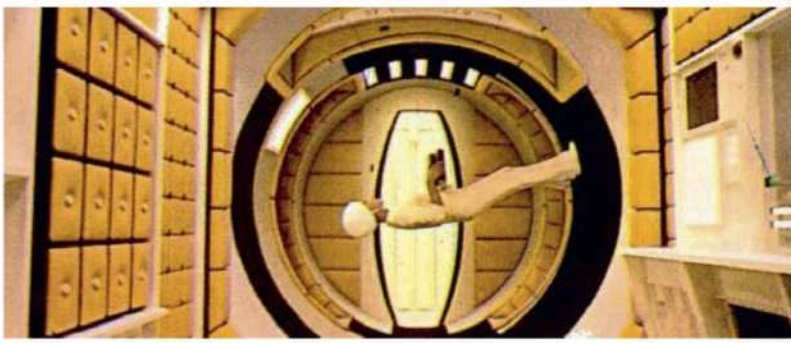
Scientists at the NASA Marshall Space Flight Center, Huntsville, Ala., helped set the designs for six types of spacecraft seen in 2001. These space vehicles, Clarke predicts, will influence designers of real ships for years to come.

Masters' team designed an entire system of craft, all with unique characteristics, to provide movie space travelers with all types of transportation. "It wouldn't do to have the wasteful kind of spacecraft that are used only once, like today's," says Frederick I. Ordway, a leading NASA consultant. So they created vehicles that, theoretically, could be used over and over.

[Article continues with a synopsis of the film and further assurances all these moon bases and manned missions to Jupiter will definitely happen within the next 33 years.]

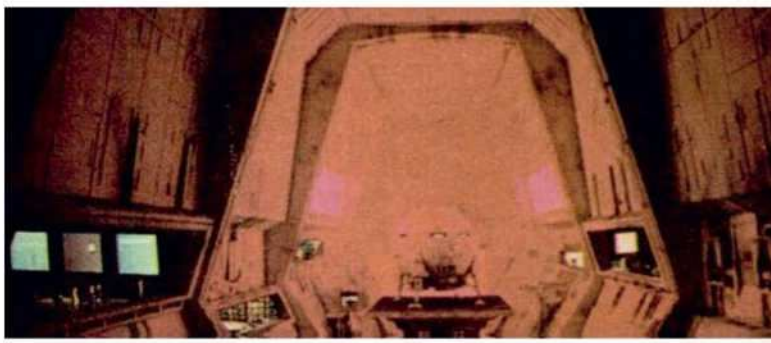
Astronauts plot a magnetic map of the moon (right), not far from busy Clavius Base where moon settlers work and live. Spherical ferries take off from star-shaped moonport to shuttle between moon and orbiting space station. Relatively few things have to be brought to the people who live or the moon. They even get their own water supply —by processing crushed rock and recovering Ovate from it. Crops are cultivated in pressurized green houses to furnish food and purify interior air

Space travelers to the moon catch regular ferries like Aries IB (above), which fly to the moon base from Space Station 5 on schedule. Aries IB is patterned after existing LM (lunar module) designs; these require relatively little propulsion thrust to journey through the vacuum of space.



Spaceship stewardesses serve passengers their meals, which are prepared in a futuristic kitchen designed by the Whirlpool Corp. The stewardess (above) is in a corridor transferring from the kitchen to the passenger compartment. In weightless condition, she can walk up the walls with ease.

Traveler to the moon enjoys a meal in space. Food is served in trays with sealed compartments for different "courses" — which are sucked in through straws. Design prevents crumbs and liquid droplets from flying around the interior of the spacecraft while it hurtles through space in weightless state.



Ferries land in huge moonport, which is one of 23 huge sets built for 2001 at MGM's British studios. Here the travelers debark after a journey from an intermediate stop. They will then transfer to short-range vehicles that will take them to their destinations at various places on the moon.

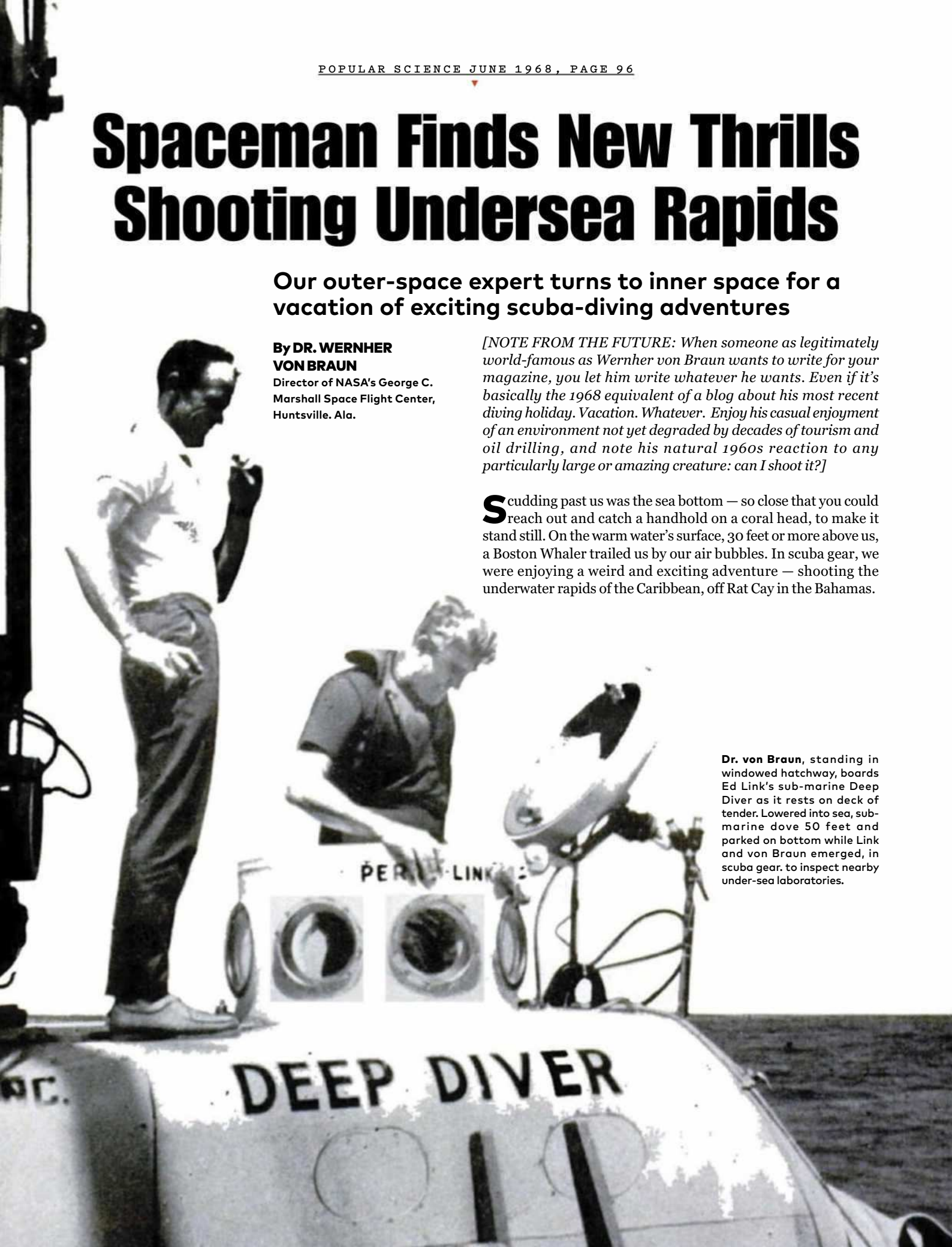
Spaceman Finds New Thrills Shooting Undersea Rapids

Our outer-space expert turns to inner space for a vacation of exciting scuba-diving adventures

By DR. WERNHER VON BRAUN
Director of NASA's George C. Marshall Space Flight Center, Huntsville. Ala.

[NOTE FROM THE FUTURE: When someone as legitimately world-famous as Wernher von Braun wants to write for your magazine, you let him write whatever he wants. Even if it's basically the 1968 equivalent of a blog about his most recent diving holiday. Vacation. Whatever. Enjoy his casual enjoyment of an environment not yet degraded by decades of tourism and oil drilling, and note his natural 1960s reaction to any particularly large or amazing creature: can I shoot it?]

Scudding past us was the sea bottom — so close that you could reach out and catch a handhold on a coral head, to make it stand still. On the warm water's surface, 30 feet or more above us, a Boston Whaler trailed us by our air bubbles. In scuba gear, we were enjoying a weird and exciting adventure — shooting the underwater rapids of the Caribbean, off Rat Cay in the Bahamas.



Dr. von Braun, standing in windowed hatchway, boards Ed Link's sub-marine Deep Diver as it rests on deck of tender. Lowered into sea, sub-marine dove 50 feet and parked on bottom while Link and von Braun emerged, in scuba gear. to inspect nearby under-sea laboratories.

Paying a visit beneath the sea, Dr. von Braun approaches entrance at bottom of cylindrical sea lab, made of rubberized fabric and inflated with air.

For a vacation from all those unglamorous but necessary activities that go into our spectacular space launches — design reviews, planning conferences, budget sessions — my taste is for fun in "inner space," like Caribbean scuba diving. And with the great good fortune of meeting the right people, as I did last year, it can include the thrills of undersea rapids-shooting and of diving from a submarine parked on the sea floor.

Rat Cay lies near the center of the 100-mile-long Exuma chain of several hundred islands in the Bahamas. This chain acts like a dam between the Atlantic to the east and the Caribbean to the west, and the narrow passages between the islands are like spillways of the dam. As tides rise and fall, tremendous amounts of blue water race through the passages — twice a day from east to west, twice a day from west to east.

Large quantities of small fish are swept along through the narrows. Bigger fish, knowing this, have only to keep their mouths open to be fed — nature's version of a true welfare state.

Human fish can enjoy a wild ride in the same subsea currents with an excellent chance of emerging intact. I was invited to try it by James P. Lewis, an upstate New York industrialist. After a short over-night cruise from Nassau aboard his 78-foot yacht Searcher, we dropped anchor off Rat Cay.

Shooting the Exuma rapids. A number of us donned scuba gear, and one of the yacht's two Boston Whalers dropped us off at a passage's upstream end when the tide was running fastest. Riding the underwater current was pure fun, and we did it over and over. When we reached bottom, 30 to 50 feet down, our speed became more obvious than in the boat.

We zoomed over the sea floor — sometimes grassy, sometimes sandy — without moving a flipper, at about the five-knot clip of a sailboat in a moderate breeze. Groupers headed for cover. Barracudas drifted past, looking for prey. We tried hanging on to a coral head, and maneuvering into the still water in the wake of one, for a shot at a game fish or lobster with an underwater spear gun. The Boston Whaler above us, drifting with the same current, kept nearby. Because reefs and coral heads slightly retarded the flow at the bottom, the current was faster at the surface, and so the boat tended to run away from us. But the fellows in the boat could see where our bubbles rose. Now and then they would rev up their outboard motor and turn back against the current, to enable us to keep pace with them.

A fantastic grotto. We went exploring, too. In one of the cays we found a fabulous cave. Its mouth, below the waterline, could be entered only by diving. Inside, you could surface and breathe normally. You found yourself within a nearly circular dome about 70 feet in diameter and 30 feet high. At the apex was a three-foot opening, as in the Pantheon in Rome. A soft blue light bathed the cathedral-like cave — the combined effect of the lighting from above, and the water-filtered light emerging from four or five connections with the ocean. Red corals and multicolored tropical fish added their hues to a scene of surpassing beauty.

For me, the climax of the thrilling three-day adventure was the sight of a huge leopard ray, easily the size of a grand piano. At first glimpse I was so excited, perhaps alarmed, that I came up fast. I pulled myself together and bravely asked an experienced diver in our group whether I should try to shoot the ray. He advised against it. We both went down and watched the beautiful creature winging through the water for at least a minute. My companion later explained that I never could have landed that leopard ray.

Awesome Ad of the Month!

While there's obviously something very Mad Men about describing your lawnmower as a "fun machine", what's especially interesting about the Gravely-424 is that it still has fans today. That's right, in 2018, people restore these and use them to mow lawns. You can even buy an "Ultimate Engine Rebuild Kit" for the mower's Kohler K241 10HP engine, for a mere US$239.99 from *isavetractors.com*. This is not satire.

Come see the great new GRAVELY-424

Love that power! You'll get real satisfaction when you take command of the finest compact tractor that ever mowed a lawn or plowed a furrow! It's Gravely . . . so you know it's a real working machine. Uphill. Sidehill. Over the rough spots. 10 HP engine in the rear gives you full power, ground-hugging traction that lets you have the fun while the tractor does the work.

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Retro Invention

Water of (Plant) Life

Growing plants with their roots suspended in a nutrient-rich liquid is a centuries-old technique. So why did hydroponics only become super-popular in the 1970s?

by ANTHONY FORDHAM

THE CONTROL OF FIRE MIGHT BE humanity's most fundamental technological achievement, but agriculture has to be number two. Forget going out and finding food: farming allowed us to make the food grow where we wanted it.

But the history of agriculture has, in part at least, been a history of a never-ending war against nature. For millennia, humans were the little guys, trying to help our pathetic little fields grow in the face of locust plagues and fungal rot and straight up harsh weather.

Defending against nature meant understanding how nature grew plants in the first place. And as early as 1627, science was was wondering if we could dispense with this annoyingly unpredictable and disease-ridden stuff called dirt. In fact, English philosopher Francis Bacon was one of the first to publish on the theory and technique of hydroponics.

DITCH THE DIRT

The idea is pretty simple. Dirt has nutrients, which are good, but also lots of other things from fungus to viruses to horrible munchy bugs, that are all bad. Plants definitely can't live without water, but can they live without soil? Is there some other way to deliver only the necessary nutrients to their roots?

At this end of history, of course we know the answer is yes. Hydroponics suspends plant roots systems either in liquid, or in an "inert" substrate which is then soaked in liquid. Nutrients are added in precise, controlled amounts.

Combine hydroponics with a greenhouse and you get crops growing in places where the mix of climate and soil-type would make it otherwise impossible.

For a long time though, hydroponics was considered as nothing more than a useful research tool. It wasn't something that could be used economically for actual agriculture, because crop yields were no better than what you could get from good-quality soil.

In other words: fertiliser was a cheaper and easier way to make big money from agriculture in the 19th and early 20th centuries. And we all know how that turned out.

But of course, nowadays we understand that there's more to boosting plant growth than just floating their roots in water and nutrients. You might think the secret is in providing quality light, but there's something more basic even than that: oxygen.

Commercial hydroponics systems today benefit from digital sensors and computer control. It's even economical to use artificial light.

THE AIR DOWN THERE

An aspect of plant biology often overlooked by non-botanists is that plants do, in fact, breathe oxygen. While photosynthesis uses carbon dioxide and sunlight to produce sugars, a plant's roots draw in oxygen and release CO_2, for more or less the same biological reasons that we do.

This is part of why it's possible to "drown" a plant. While roots can breathe in oxygen-saturated water, stagnant water and anoxic conditions kill them. Yet a plant also uses its roots to take up water. No wonder the balance can be tricky: it's like if we had to breathe and drink through our lungs, at the same time.

Hydroponics, with its constantly circulating water, eliminates the problem of over- or under-watering. But unlike animals which have a very, shall we say, obvious minimum oxygen intake level, plants can survive in low-oxygen environments. They just don't grow optimally.

So the secret to hydroponics, as a technology for agriculture, was in getting the water and oxygen balance just right. And in the 1970s, Allen Cooper at the Glasshouse Crops Research Institute in the UK, saw the potential of a technique developed by Dutch researchers a decade earlier.

In what he eventually termed the Nutrient Film Technique, Cooper arranged plants in channels, down which ran a very shallow stream of nutrient-rich water. The water was then pumped back to the top of the channel,

ideally agitated or oxygenated in some other way to ensure maximum O2 saturation.

In response to sitting in this shallow stream of water, plants would grow wide root "mats", and the tops of these root systems would be exposed to the air and thus a constant supply of oxygen.

PROBLEM SOLVED...?

As with almost everything in hydroponics, NFT isn't a simple solution. There are various different ways to apply it, and certain crops need it set up in certain ways. But all applications share a core idea: minimal root immersion, maximum oxygenation.

Most importantly for the subsequent explosion of (not always successful) commercial hydroponic operations in the wake of the development of NFT and the publication of Cooper's book The ABC of NFT, is that setting up such a system could be relatively cheap.

In Australia, hydroponics boomed in the 1980s among lettuce growers in particular. According to industry magazine Practical Hydroponics & Greenhouses, hydroponic lettuce could be grown on what were essentially raised tables, which made working the crop easier. Hydroponics didn't just boost crop yields and reduce losses to pests and disease, it even saved farmers' backs.

VERY HAPPY HERBS

By the 1990s, the kinds of people who respond to a shift in the Zeitgeist by opening a specialty shop, decided to offer urban enthusiasts access to compact versions of NFT-based equipment. Hydroponics retailers opened in Sydney and Melbourne and the response from the public was, by all reports, massive.

And why not? There's something simultaneously "space age" *and* "new age" about hydroponics, about growing veggies on your balcony without the mess of dirt. It's both high-tech and in tune with nature at the same time.

Of course, the technology was then appropriated by cannabis growers who combined it with innovations in artificial lighting and never had it so good. This put an unfortunate stigma on "home hydroponics", and this plus the discovery that actually maximising results from this technology requires in some ways more skill and dedication than just shoving seeds into the ground, saw the fad fade.

But commercially and industrially, development of hydroponics continues. Computerisation allows for very precise control of both nutrients and oxygen, and greenhouses have become almost like assembly lines, especially those where plant trays move around on automated tracks, depending on how old the crop is.

Francis Bacon's *Sylva Sylvarum* (1627) explored early ideas of how water and nutrients aided plant growth. Yet it took another 350 years for hydroponics to become a significant technology for agriculture.

The rise of vertical farming - where plants are grown stacked in warehouses - also owes (nearly) everything to hydroponics. Vertical farms allow complete control of all factors that affect plant growth, yet like so much of this soil-free philosophy, were conceived as early as 1915. They were considered uneconomical, because the energy cost of providing each plant with enough light would eat any possible profits.

Then we invented high-output LEDs. But that's another story.

HANGING IN THE WIND

Hydroponics not Biosphere 2.0 enough for you? Then check out *aeroponics*, where root systems dangle in a mist of water and nutrients. This technique almost (but not quite) totally eliminates pests and disease, but the downside is its mechanical complexity. Again, aeroponics first made it into a scientific journal in 1915, was investigated extensively in the 1940s, and made it big once the availability of cheap chip-based micro-controllers allowed a company called GTi to build the Genesis Machine in 1983. And yes, it was a Star Trek reference.

BEST OF: Kareer Kreator

Because nobody ever achieved anything all by themselves...

BY SUBJECT ZERO

[Due to a foolish decision to accept an invitation to "join the amazing new world of the NBN!" from a major ISP which shall remain nameless except to say that it was once wholly owned and operated by the Australian government, my computer exploded. As a result I missed my deadline but was able to get this note, and a reference to the folder in the archives where, as far as I knew anyway, a vaguely-relevant-to-the-NBN previous column was stored, to the magazine, before the editor sent like goons or whatever. Note that almost nothing about my personal situation has changed since I visited Skew Samplesize back in, oh gosh was it really 2014?]

THERE ARE THOSE IN MY CIRCLE WHO SAY my life is directionless and all but meaningless. But I disagree. I've turned a series of half-started science degrees into a career as an itinerate test subject, and that's a valuable role that society needs people like me to fulfil. Definitely it does. I join a proud cohort, that includes murderous chimps, rabbits with underactive thyroids, and cancerous puppies. All of us together, sometimes running around in the vents, but performing a valuable and essential role.

Still, I'd be lying if I said there weren't times when I found myself lying on a gurney watching yet another sample of my blood being sucked into a vial while some loon in a lab coat rubs his hands together and cackles... uh, what was I saying? There are times when I do wonder where all this is going. This life of being a test subject and not having achieved even the most basic or universal of adulthood-type milestones viz. partner, permanent home that isn't reliant on a medical-injury-compensation rental deal, bedclothes made of natural fibres, reliable income, credit rating etc.

So it is with some anticipation - the good kind - that I've signed up for this latest test. A system that uses a combination of biometric analysis and trawling the internet to, more or less, predict a person's future.

"Or at least his future role as an economic unit in our uncaring and essentially cruel society," says Kareer Kreator, uh, creator Skew Samplesize. We're standing in the middle of an unrenovated warehouse on the so-called "bad edge" of town. There's a huge pile of electronics in the middle of this vast open space, into which I've been variously strapped, plugged and sucker-cupped. The pile of electronics is connected to the world at large via one of those cool but increasingly rare fibre optic internet links the Government seems hell-bent on stamping out. [*The irony that one of these links will blow up my computer 4.5 years into the future of this, is not lost on me - SZ*]

"Hello?" says Skew. "Are you even paying attention?"

"You told me to clear my mind of all distractions," I reply, maybe a little defensively.

"Oh yes," says Skew. "Well done. Steve Placebo [*ex-agent eaten by flesh-eating bacteria in 2015 - SZ*] said you were good. He was here last week. Did I mention he was here last week?"

I pause to consider whether this is a trick question. "Y... yes?" I hazard. Skew makes a satisfied face and punches something into a mechanical keyboard.

"Okay," Skew punches some more keys. "Let's take a look here. This... apparatus basically analyses your physical sort of you know gestalt and then does a Google search on your name and runs all that through some kind of algorithm I cooked up when I was high and then it should spit out a result."

"Cool," I say, sucker-cups akimbo.

Skew presses a final button. The machine hums for a while, I fancy I hear the sound of ticker-tape clattering out from a dot-matrix printer but that must surely be my imagination, and then there's a loud, harsh, buzzing noise.

"What the hell is that?" I ask.

Skew frowns. "That," he says, "is a divide by zero error. Wait... do you even have a Twitter?"

"No," I say. "Hell no. Twitter is human interaction on a grand scale. Any moron can read what any other moron has said. Twitter is hell on Earth. Twitter is - "

"Yes, alright, I can correct for that." He goes tappy-tap for a bit and then the machine buzzes again. "Damnit. You don't have Facebook either?"

"It's not COMPULSORY!" I scream.

Skew gives me a dark look. "For now," he says. Then he sighs. "Bloody Steve Placebo, he told me you were good. But according to my machine you have no future. In fact, according to my machine you barely exist. It's even having trouble picking up electrical activity from your brain." He taps me on the forehead with one finger.

I consider this for a while. Quite a long while. Skew stares at me. Then he taps my forehead again.

"My point exactly," he says. "Geez man, don't you have ANYTHING going on in your life? Hopes, dreams, plans for a book or a sweet Kickstarter project? Anything at all?"

I lick my lips. "I have a cat?"

The machine buzzes loudly, then makes a popping noise. A small curl of black smoke escapes from where the fibre optic cable is connected. Skew puts his hand over his eyes. "Please leave," he says.

I slink away. Outside, I see a bunch of telecommunications engineers gathered around the NBN fibre optic splitter box, laughing and drinking beer. One of them is holding a pair of cutters. They flinch guiltily when they see me.

"Asbestos," says the one with the cutters, pointing into the signal box.

"Whatever," I say. "I don't even have a Twitter."

"Good on you," says another. "Have a beer instead."

So the afternoon isn't a total write off. Later on, they even let me have a turn with the cutters.

"But... according to my machine you have no future. In fact, according to my machine you barely exist. It's even having trouble picking up electrical activity from your brain."

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Nightmare in a puddle
POND MONSTERS

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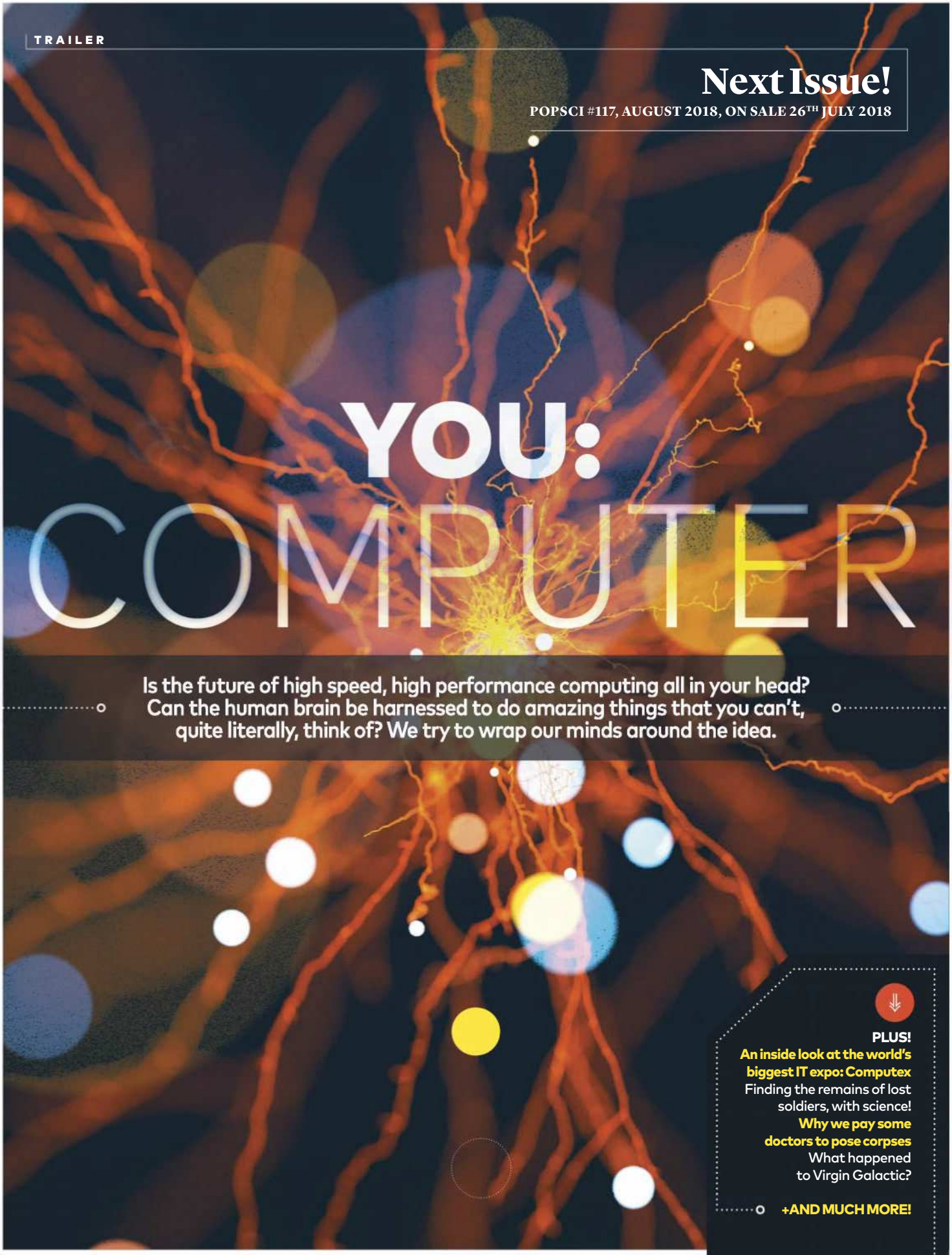

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