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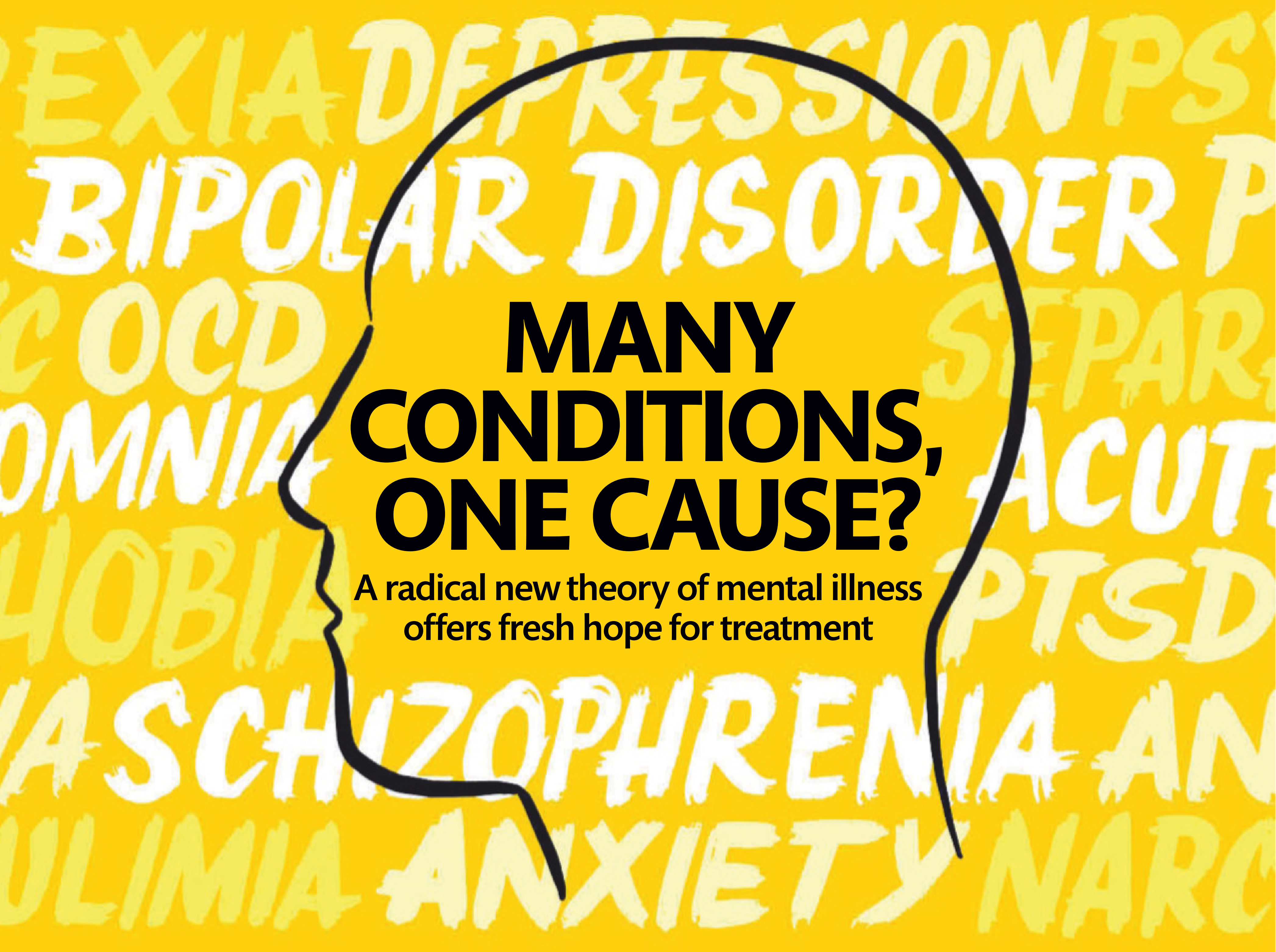
WEEKLY January 25–31, 2020



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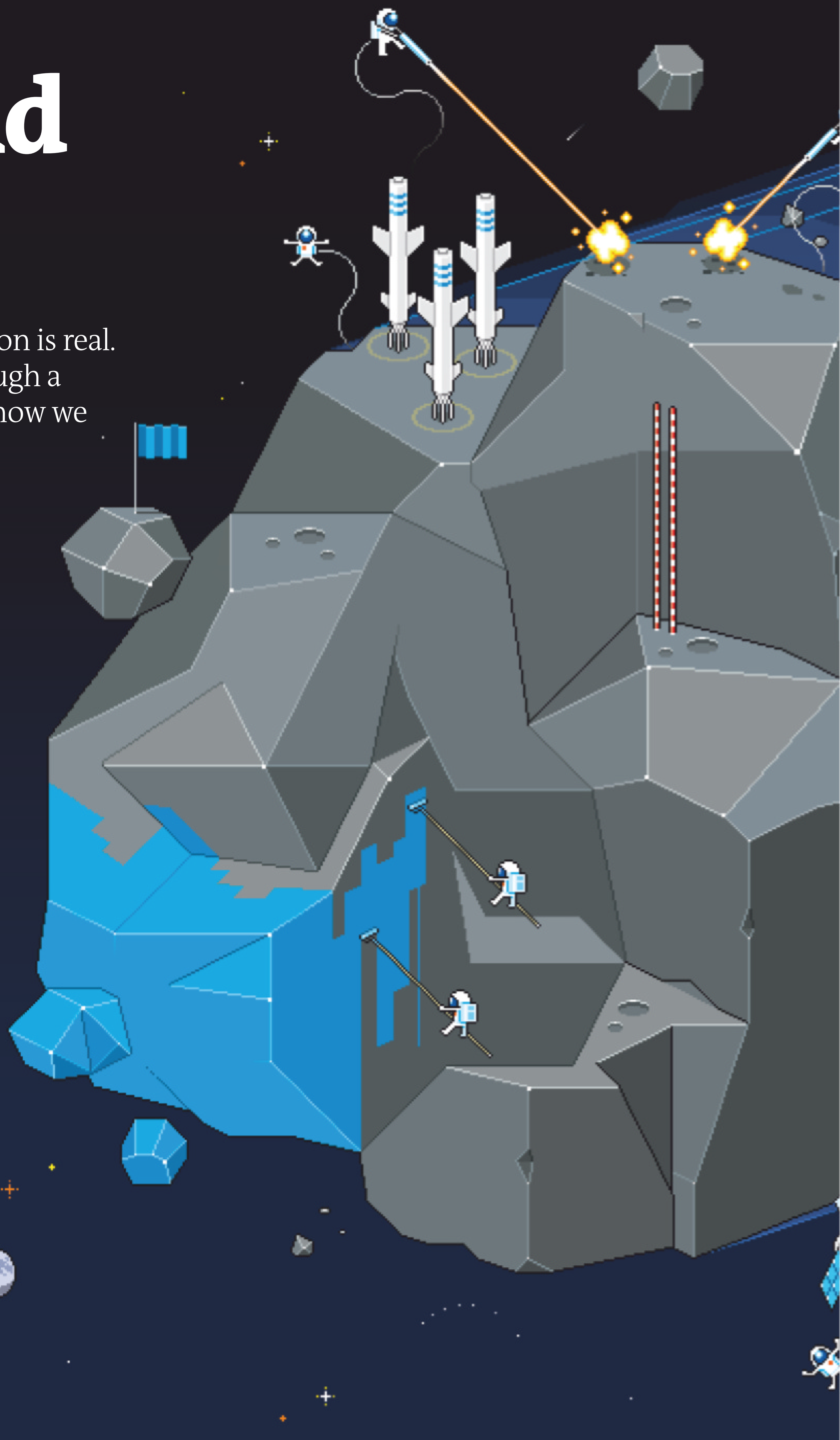
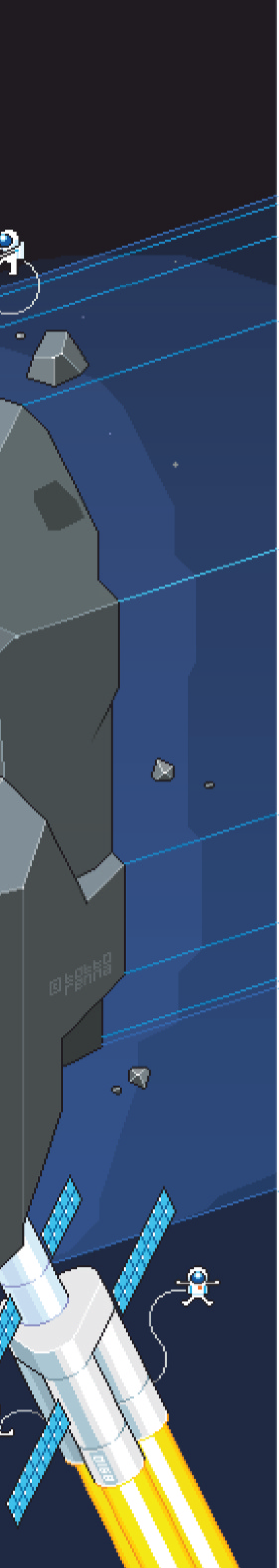
Asteroid alert!

The threat of a major collision is real. **Leah Crane** guides us through a step-by-step simulation of how we would save the planet





TOTTORENNA

IT IS just after midnight on 29 April 2027. The island of Manhattan in New York has been entirely evacuated. The lights in Times Square are off, the streets abandoned. An eerie silence hangs over the empty neighbourhoods. Overhead, a ball of rock the size of a large building is speeding towards the ground at 19 kilometres per second. In a little over a minute, if the calculations are right, it will explode in the sky over Central Park.

The city has had 60 days to prepare. Museums have been emptied of exhibits, nearby nuclear power stations shut down and fleets of buses requisitioned. Inhabitants of America's most populous urban area need to be rehoused. The matter-of-fact briefing notes for the evacuation state: "People will be leaving permanently. There will be nothing remaining."

At 00:01:38, the rock hits. A blast equivalent to 1000 Hiroshima atomic bombs turns much of New York to rubble. The economic and financial damage is incalculable. Ten million people have just lost their homes.

In a meeting hall in Washington DC, there is excited chatter as Paul Chodas declares the simulation over. His five-day exercise at the 2019 Planetary Defense Conference has played through the impact of an imaginary asteroid called 2019 PDC from detection to collision (follow the progress in italics on the following pages), to try to determine what would happen if – or when – the real thing happens.

"This is basically the worst-case scenario," says Chodas. "It all makes for a good movie plot line, of course, but they are realistic factors." Yet as the room full of astronomers, engineers and government decision-makers has just found out, happy endings aren't guaranteed.

The risk of an asteroid collision is the price we pay for living in our crowded bit of space. The sun's gravity attracts not only the moons and planets of our solar system, but also many rocky or icy loners and vagabonds that jostle for room. So far, astronomers have spotted more than 21,000 asteroids with orbits that are set to bring them close to our world. Every day, another one of these near-Earth objects is discovered.

For most of them, the chance of striking Earth is close to zero. As for the rest, the vast majority aren't worth worrying about. Tens of thousands of tonnes of material falls from space every year, most of it in the form of inconsequential particles of dust. Even an asteroid the size of a car would burn up in the atmosphere, putting on a light show but not causing any destruction on the ground.

At the other end of the spectrum, there are asteroids such as the one that hit Chicxulub in what is now Mexico about 66 million years ago, wiping out the dinosaurs. That one measured somewhere between 10 and 81 kilometres across. Thankfully, such monsters are both incredibly rare and big enough to see coming (see "Crater creators", page 45).

"We've found the vast majority of the 'dinosaur-killing' class of object, which is great, but when it comes to objects just below that size, there are a lot of them out there," says Amy Mainzer at the University of Arizona's Lunar and Planetary Laboratory. We have only found about one-third of the objects we think are capable of flattening a small country, and less than half of the asteroids that could destroy a city. Objects of this size pose a real risk, being both large enough to cause serious damage but small enough to avoid detection.

When the sky falls in

"An asteroid impact is one of the few natural disasters that we know how to prevent if we detect it far enough ahead of time," says Johnson. The majority of asteroid surveys are funded by NASA. In 2005, it set a goal to detect, track and characterise 90 per cent of the near-Earth objects that are 140 metres across or larger by the end of 2020. One way to tell how we are doing is to count how often our observatories rediscover the same objects. The fewer new objects we spot, the more confident we can be that we have spotted most of the asteroids out there. So far, we have found less than half of those that astronomical estimates suggest there should be. Even though none of the ones we have found has a significant chance of hitting Earth in the next 100 years, those are worrying statistics.

"With the telescope capabilities we have now, not seeing an incoming asteroid in time to prevent an impact is a distinct possibility," says Johnson. Part of the problem is that ground-based telescopes need Goldilocks conditions in which to work. "They can only operate at night, in clear weather, when the moon is not full so the sky isn't too bright," he says. We have failed to observe large asteroids making relatively close passes by Earth several times, including as recently as mid-2019, he says. Luckily, none of those has been on a collision course with us. That said, the more pressing danger is still likely to be from something we do see coming. ›

In Washington DC, Chodas begins to unveil the details of his meticulously planned exercise. It starts innocuously enough, with the observation of what appears to be a near-Earth object by the Pan-STARRS telescope project in Hawaii. The date within this fictional scenario is 26 March 2019. As per protocol, the observation is passed on to the Minor Planet Center (MPC), which is run by the International Astronomical Union. The MPC gives it the official designation 2019 PDC, and starts collating observations made by other astronomers. The Center for Near Earth Object Studies at NASA's Jet Propulsion Laboratory in California is notified. The researchers there alert Lindley Johnson at NASA's Planetary Defense Coordination Office, who sends the necessary details to NASA headquarters and the rest of the US government. For the moment, sustained tracking is the main priority. There is no reason for immediate concern.

Asteroid watchers make all their data public, so whenever a potentially dangerous object is spotted, astronomers in different countries simultaneously evaluate the risk. In 2013, the United Nations recommended that the global effort be more organised, so the International Asteroid Warning Network was formed with astronomers and space agencies from Europe, Asia and North and South America. Should they all agree that an impact really could be catastrophic, the network sends a message to the United Nations Office for Outer Space Affairs, which gathers member states together to discuss what they should do about any impending threat.

Their plan will depend significantly on what we know about the asteroid and where it is going to hit. In the best-case scenario – if it is a small object likely to burn up in the atmosphere or if it will only hit the middle of an ocean – we might choose to do nothing, or simply warn people in the affected area to stay away from windows that may be shattered by an explosion in the atmosphere. In the worst-case scenario, we may not have time for anything but evacuation, says Johnson.

Ideally, we would detect the asteroid decades, or at least years, before it is projected to hit Earth. At that point, we won't know exactly where it is going to hit, but we will be able to say with some certainty that it is headed towards us. The moment we know that, it is time to start planning.

For attendees of the Planetary Defense Conference, that time is now. The date is 29 April 2019, and we know that 2019 PDC is likely to cross our planet's orbit in eight years' time – around the end of April 2027. The probability of a direct impact remains low, near 1 per cent. Given the asteroid has a diameter of roughly 200 metres and could cause major damage, this is fortunate. On the Torino scale used to rank such objects from 0 up to 10 – the most dangerous – it is classified as a 2, which means it "merits special attention". As per UN General Assembly resolution 71/90, the International Asteroid Warning Network begins coordinating preparations.

"If there is a high probability of impact, and when I say high probability mean just about 10 per cent, we should not wait to be developing a mitigation-capable mission," says Johnson. Because such a mission to intercept an asteroid would take about three years, he adds, "if you wait until you know for sure where it's going to hit, it's going to be too late".

RANDY OLSON/NATIONAL GEOGRAPHIC

Australia's Wolfe Creek crater was formed by an impactor 15 metres across

Crater creators

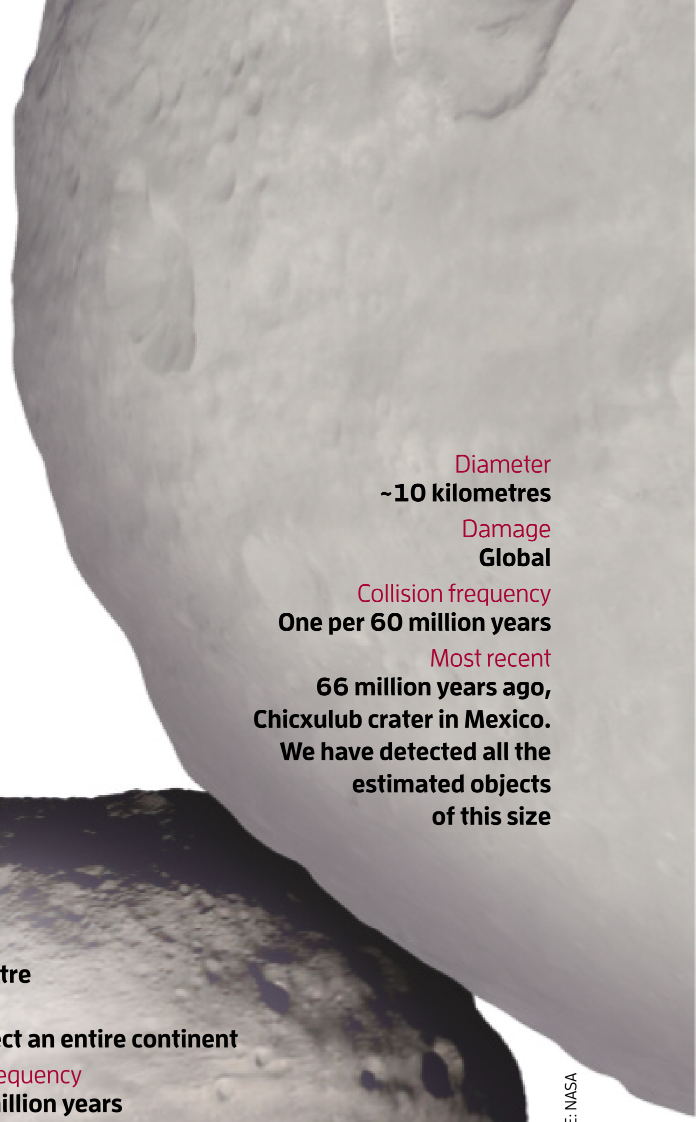
Our patch of the solar system is full of space rocks, many on a collision course with Earth. Most are too small to cause damage and those big enough to wipe us out are easy to see coming. Those in the middle, big enough to destroy a city, are the ones we need to watch out for

Diameter
<1 metre
Damage
None
Collision frequency
Thousands per year. Too many to track

Diameter
~1 metre
Damage
None
Collision frequency
30 per year. Too many to track

Diameter
~100 metres
Damage
Could destroy a city
Collision frequency
One per 2000 years
Most recent:
Tunguska event in Russia, 1908. We know of less than half of the objects this size that astronomers suspect are out there

Diameter
~1 kilometre
Damage
Could affect an entire continent
Collision frequency
One per million years
Most recent
About 900,000 years ago, Zhamanshin crater in Kazakhstan. We know of about 80 per cent of the estimated number of objects this size



Diameter
~10 kilometres
Damage
Global
Collision frequency
One per 60 million years
Most recent
66 million years ago, Chicxulub crater in Mexico. We have detected all the estimated objects of this size

SOURCE: NASA

NOT TO SCALE

Back in Chodas's simulation, it is 29 July 2019, and the chances of 2019 PDC colliding with Earth have just reached 10 per cent. Calculations indicate that the most likely points of impact are in two belts: one running from San Francisco to New York in the US, and the other across Africa from Nouakchott in Mauritania to Lilongwe in Malawi. At its newly calculated size of 185 metres, it has the potential to render entire cities uninhabitable. The advice to space agencies is to begin mitigation work immediately. The first priority: launch a reconnaissance mission to the asteroid. We have less than two years to do so.

Once we know an asteroid is on a collision course with Earth, there are two main options: blow it up or change its trajectory. Shattering it with a nuclear bomb, the course favoured in disaster movies such as *Armageddon* and *Deep Impact*, tends to be a non-starter for political reasons. "There is a problem with international treaties: you cannot really launch nuclear weapons into space," says Peter Vereš, an astronomer at the Minor Planet Center.

It is also an issue of practicality: when you blow up an asteroid, the shrapnel doesn't just disappear. They are probably still headed towards Earth, and they might not all be small enough to disintegrate in the atmosphere. "You're not going to eliminate it, so you're going to have, instead of a single object coming at you, essentially buckshot," says Johnson. "That could spread the devastation over a broader area of Earth." It also makes the danger less predictable.

So we are left with one good way of getting rid of an incoming asteroid: we will have to push it off course. For a long time, the most popular proposal was a gravity tractor, a large spacecraft that would fly close to an asteroid, slowly changing its trajectory via the craft's own gravitational attraction without ever actually touching it. This method would be slow, though, so most of the work in recent years has shifted to the use of kinetic impactors: spacecraft that simply slam into the approaching rock to change its course.

The Planetary Defense Conference is now in its third day. Within the world of the simulation, that is 30 December 2021, and Recon 1, a spacecraft sent to observe 2019 PDC, has vital new information. We now know, with near 100 per cent certainty, that the asteroid is on course to impact near Denver, Colorado. Deploying a nuclear missile to deflect the asteroid is deemed too controversial, and so all efforts are devoted to kinetic impactors. To give the asteroid the shove it needs, six rockets must be launched at the end of May 2023, scheduled to collide in August 2024. This will require the collaboration of multiple space agencies, each sending the heaviest rockets at their disposal on a one-way mission. The launch times of these rockets are all precisely fixed: the orbital dynamics gives us just one shot at getting this right.

Before we can do anything like that, we have to learn more about asteroids. "It's much easier to protect ourselves if we know our enemy," says Vereš. We already know that some asteroids are porous bundles of rock called rubble piles, whereas others are solid iron. There is probably a spectrum of different compositions in between. Knowing their composition matters, says Mainzer. "The physics of pushing something out of the way is dependent on its nature."

So, immediately after detecting a dangerous asteroid, the race to characterise it will begin. Earth-based telescopes will tell us its size and shape, as well as its reflectivity. We expect less-reflective asteroids to have lower densities because they are a porous mixture of rock and ice, whereas brighter asteroids are likely to be more solid. Radar data could also let us define the orbit more precisely and look for any big boulders or moons that might be orbiting the asteroid and making it even more dangerous.

There is a limit to how much we can find out about asteroids from the ground, though. That is why NASA's OSIRIS-REx and Japanese space agency JAXA's Hayabusa 2 missions to bring back samples from potentially hazardous asteroids are so important. "Studying meteorites is great, but with these missions, we can see what they look like without getting fried by flying through Earth's atmosphere at 20,000 miles per hour," says Mainzer.

So far, both of the asteroids being visited by NASA and JAXA – Bennu and Ryugu – are more porous than we expected, with Bennu being 40 per cent pores and caves, and Ryugu as much as 50 per cent empty on the inside.

That could present a problem for a potential kinetic impactor mission. "If an asteroid is a rubble pile, it has lots of holes inside, so if you punch it, it might change shape but not change its orbit," says Vereš. "It's like hitting a sponge with a baseball bat." If these rubble-pile ›

THEY JUST MIGHT WORK

Two methods are considered the most credible ways of helping us divert asteroids on a collision course with Earth (see main story), but other, wackier, ideas are also being taken seriously. The simplest would be to paint one side of an asteroid white or silver. The painted part would then reflect more sunlight and the energy imparted by the extra light bouncing off that surface could change the asteroid's trajectory. Alternatively, we could attach engines to an asteroid and turn it into a spacecraft, or use high-powered lasers that could vaporise rock. While demolishing an entire asteroid with a laser is unlikely to be possible, the puff of dust jetting off the surface could act like a thruster, allowing us to push it off course. Such ideas could work, but are untested and would probably take decades or require technology we don't yet have, so they aren't part of any official plan.

With the right preparation, apocalypse can be averted

ALAN POWDRILL/GETTY IMAGES

asteroids are common, which seems likely, we need to study and test the effects of a kinetic impactor more carefully.

NASA is on the job with the Double Asteroid Redirect Test (DART) probe. DART is due to launch next year to the asteroid Didymos, where it will deliberately crash into the asteroid's 150-metre moonlet, nicknamed Didymoon. That is expected to change Didymoon's orbit enough for the effects to be visible from Earth. Once we know how crashing into an asteroid (or, in this case, an asteroid moon) affects its motion, we will be much better equipped to build a kinetic impactor – and guarantee it works.

Chodas has good news and bad news. The good news is that the kinetic impactor missions have hit 2019 PDC, and the bulk of the asteroid is no longer on course to hit Earth. The bad news is that a fragment about 60 metres across remains on its original trajectory. That isn't all: contact has been lost with the Recon 1 spacecraft, probably owing to collision with debris. The resulting lack of information is compounded by the asteroid now being behind the sun, making it impossible to observe from Earth. Our options are limited. It is now 3 September 2024, and as the collision time approaches, the momentum needed to disrupt the fragment's trajectory sufficiently to avoid Earth rises. But given the asteroid's small size, any disruption is likely to break it apart, causing a repeat of today's scenario. A radical proposal is raised for a deliberately robust collision, shattering the rock into such small pieces that no damage to Earth's surface will result. That means a nuclear device is needed. The legality of such a launch sparks heated debates. Meanwhile, time ticks on.

Ultimately, a disastrous asteroid strike of this sort remains very unlikely. But we should still be prepared. That means working on more mission concepts (see "They just might work", above), building more telescopes to look for asteroids and maybe moving them into orbit so that they can operate 24/7. For Chodas, that also means running more "what if" scenarios, testing the limits of our contingency planning. "In each one of these exercises, we go a little deeper into interesting details and we are forced to think about issues that we haven't thought about before," he says.

This most recent scenario, for instance, brought home to him the scale of the disaster response required. "Evacuating a large metropolitan area, of course, would be a daunting task," he says. "What was eye-opening for me was how long that would take." As for how life resumes on the day after the sky falls in, that is beyond his remit. "That's something that FEMA [the US Federal Emergency Management Agency] would address after the fact, like they do for other disasters."

But thanks to planetary defence research, the chances of such a clean-up ever being necessary are pretty slim. "If we try hard enough," says Mainzer, "it's something that we can cross off our list of worries." An asteroid probably won't kill us all. But it would be good to know for sure.

A last-ditch nuclear strike on the asteroid remnant has been cancelled for lack of time. The collision has been inevitable for weeks. Last night, the Arecibo Observatory in Puerto Rico confirmed the space rock would explode above Central Park, New York, in 10 days' time, after approaching Manhattan at an angle of 29 degrees south of due east. By a quirk of fate, that matches the orientation of many of the island's streets, giving any life forms in the city an uninterrupted view of the incoming fireball. The 9/11 attacks damaged an area of around 16 acres; 2019 PDC is expected to render 20,480 acres uninhabitable. The evacuations begin immediately. ∎

Leah Crane is a reporter for *New Scientist* based in Chicago. She tweets @downhereonearth