RESULTS of Dutch scientific research

19

Abrupt wave of extinction after meteor impact

Towards – and beyond – hydrogen

The Yde Girl murder; Trial or sacrifice to the gods?

Patients with Parkinson's dance and sing

Nature-inspired technology

For the first time, researchers have measured the accuracy of 2-qubit operations in silicon: an important step towards quantum computing. ***www.nwo.nl/02***

IMAGE : BRAM SAEYS

Pushing the boundaries

We have every reason to be proud of the high quality of our scientific research

Cleaner fuel for aviation. Patients with Parkinson's learning to walk again. Understanding the life and death of the Yde Girl, 2,000 years after her death. And, it cannot have escaped you, the first photo of the shadow of a black hole.
Indeed, I could go on – these are only some of the stories in our new annual magazine Results. A rich anthology of ground-breaking, surprising and above all socially relevant scientific results from 2019.

Whether it concerns our progress towards a hydrogen economy, pushing the boundaries of artificial intelligence or making headway in health care, all of the examples in this magazine have one thing in common: Each and every one of them shows that fundamental and applied research makes society in the Netherlands – and far beyond – better and more sustainable.

As a funder of top-level research, NWO encourages cooperation and establishes links. Not only within the scientific community, between researchers from different knowledge institutions and disciplines. But also with businesses and society, such as the Dutch Research Agenda, which launched its first programmes this year.

We have every reason to be proud of the high quality of our scientific research – and our excellent researchers. It is partly thanks to them that for years now knowledge has been one of our most important export products. And it is partly thanks to them that on behalf of the Dutch scientific community we can present ground-breaking results year after year.

Stan Gielen
Chair NWO

Electrons were confined in a Sierpinski 3-angle but behaved as if they lived in 1.58 dimensions. This imitates fractal structures, common natural forms such as the lungs, which have a large surface area relative to their volume. ***www.nwo.nl/03***

Snapshot of a mass extinction

The devastating blow of a meteor impact 66 million years ago wiped just about all forms of life off the face of the earth. **It brought an abrupt end to the dinosaur age.** A spectacular fossil site reveals what actually happened.

What?

The meteorite impact in Yucatán 66 million years ago.

Why?

We want to know why waves of mass extinction took place in the history of earth and precisely how they transpired. This specific mass extinction opened the way for mammals and is therefore at the basis of the origin of humankind.

Who?

Jan Smit, professor emeritus of event stratigraphy at VU Amsterdam. Partnerships were established with Robert DePalma (curator of the Palm Beach Museum of Natural History) and Pete Larson (Black Hills Institute).

Where?

North Dakota (USA), Amsterdam (VU Amsterdam) and Brussels (Vrije Universiteit).

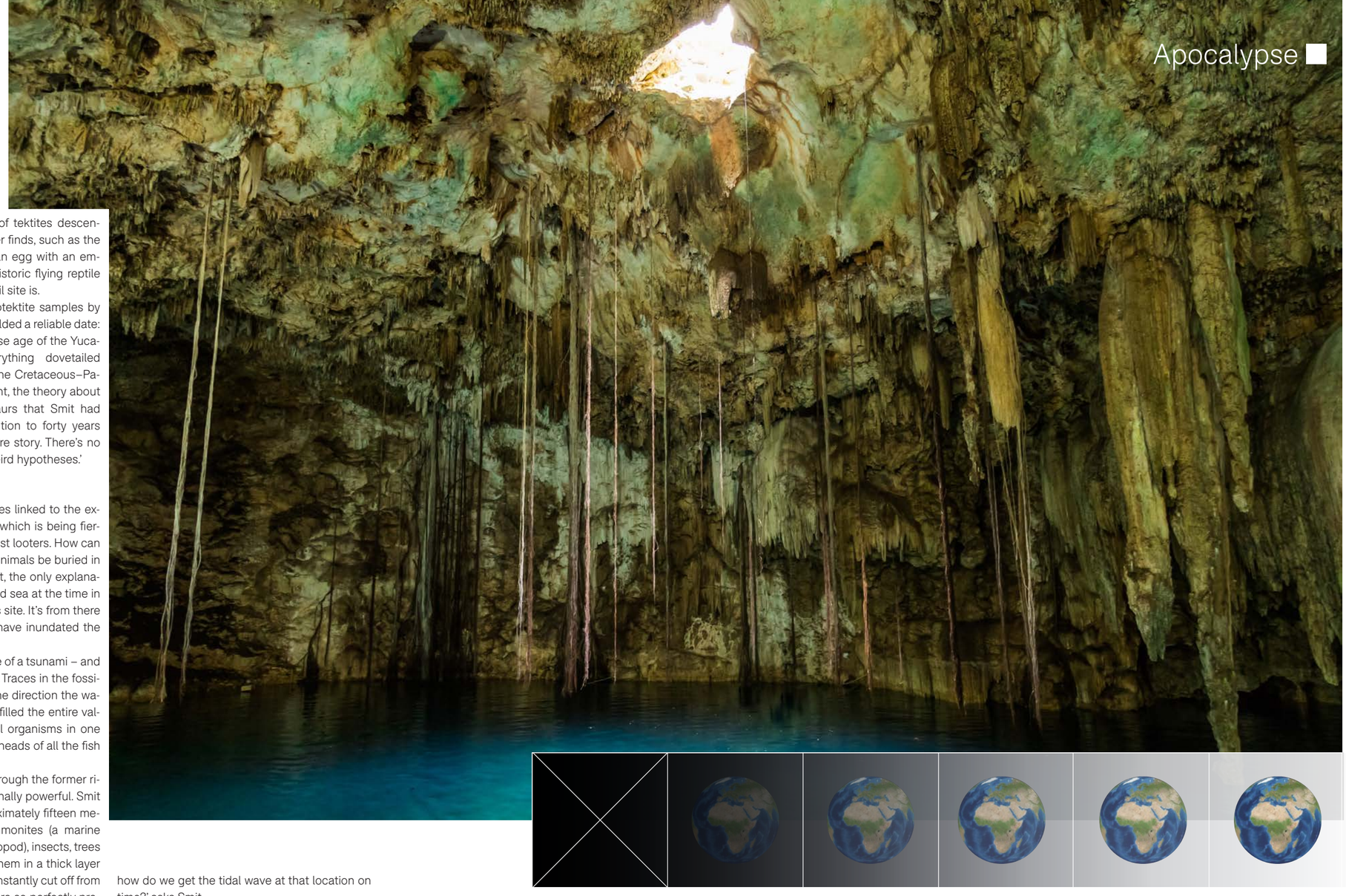
Result?

This research is hard evidence of the mass extinction 66 million years ago.

TEXT: EDO BEERDA

Adult ocean sunfish (Mola mola) can reach a length of 4 metres and weight up to two thousand kilos. One was found in the Wadden Sea now as well, even though that's not a place they usually frequent. ***www.nwo.***

In the second half of the 18th century, more than ***5*** *per cent of the gross domestic product was driven by slavery.* ***www.nwo.nl/05***



The unfolding of the apocalypse and the return of light and life

- **The impact in Yucatán created a massive crater which is hidden beneath sea level. Fabulous cenotes have formed along its perimeter: they're often underground caves with waterholes. The impact of the meteor 65.95 million years ago unleashed a catastrophe that would last thousands of years. It's estimated that ninety per cent of all species on earth eventually perished.**
- **At zero hour the meteor pounded a crater into the earth 180 kilometres wide. Remnants of it were discovered in 1991 near the Mexican town of Chicxulub. About ten million m^3 of rock was hurled into the atmosphere. The shockwave that followed must have completely wiped out an area with a radius of about 3,000 kilometres.**
- **The energy of an estimated 100 million megatons generated a mega-tsunami that destroyed entire coastal areas around America. According to the latest hypothesis, the impact probably led to a marked increase in volcanic activity worldwide.**
- **Fifteen to sixty minutes after the impact, the debris that was ejected into the sky returned to earth. Pieces of rock burned up as they re-entered the atmosphere and caused a meteor shower.**
- **That caused fires to break out worldwide. The rocks eventually landed on earth as solidified glass particles – microtektites. As a result of all the smoke and dust, it became pitch-dark. This may have lasted for months, killing trees, plants and algae as photosynthesis came to a grinding halt. Dinosaurs were unable to find food anymore, likewise small sea organisms. They died on a mass scale, and entire food chains collapsed.**
- **Most of the dust and soot particles fell to earth again, but for years white sulphur particles remained high in the atmosphere. They reflected the sunlight and caused temperatures to cool down dozens of degrees. Animals that had managed to survive perished after all.**
- **After the cold came the heat. CO_2 emissions and rotting organisms caused a rise in temperature that persisted for hundreds of years. This climate change was responsible for a final mass slaughter.**
- **The ten per cent of all animal and plant species that survived had the earth all to themselves for several thousands of years. They were responsible for the wholesale repopulation of earth. A slightly slower evolution took place in the millions of years that followed, resulting in the species that we're now so familiar with.**

Reports of new fossil sites rarely rattle professor emeritus Jan Smit (VU Amsterdam) these days.

But when he received photos of a fossilised quagmire in North Dakota in 2014 he found himself clutching the armrests on his chair. 'I saw perfectly preserved fossils of freshwater animals – sturgeon and paddlefish – and the mother-of-pearl shell of an ammonite, a marine animal. All in one block. That's only possible if a tsunami mixes saltwater and freshwater. Arrows on the photos indicated the abnormal amounts of iridium that had been found. Hold on, I thought, this is serious.'

Space debris

The presence in a single layer of earth of freshwater and marine animals is exceptional in itself. But the alarm bells really started to ring when iridium was discovered in the twenty by seventy metre large excavation area. Geologists had already established a link between this precious metal and the meteor that slammed into the Yucatán Peninsula in Mexico 65.95 million years ago with disastrous consequences. On that fatal day, a piece of space debris ten kilometres in size appears to have impacted our planet with unimaginable force. Scientists estimate that the projectile released an amount of energy equivalent to five thousand million atom bombs of the kind that wiped out Nagasaki. There was a much larger amount of iridium in the meteorite than in the earth's crust. It was spread across the earth in the form of a thin layer of dust after the huge impact.

Microtektites everywhere

It became even more of an adventure when the American excavation team led by palaeontologist Robert De Palma found microtektites everywhere during one of Smit's visits. These are miniscule glass beads that were formed by the heat of the explosion. After the impact, the particles must have been catapulted upward out of the impact crater, after which they fell back to earth like a shower of 'shooting stars'. They caused fires to break out all over the place.

'When we scraped clean the mouth of a paddlefish, we discovered impact glass in the gills. We made the same discovery in other fish fossils,' says Smit enthusiastically. 'That means they must have been alive when the impact occurred. Maybe they even suffocated in them. So what we're looking at here are the immediate victims of the meteorite impact.'

Some tektites were found embedded in fossilised resin – amber – on charred tree trunks. That suggests that the resin was still soft and that the tree was alive when the tektites were raining down. It's possible that the tree was burned by the radiation of the billions of tektites descending like shooting stars. Other finds, such as the footprints of dinosaurs and an egg with an embryo of a pterosaur – a prehistoric flying reptile – show just how rich the fossil site is.

Dating on a number of microtektite samples by the team from Amsterdam yielded a reliable date: 65.95 million years, the precise age of the Yucatán crater. In short, everything dovetailed perfectly with the theory of the Cretaceous–Paleogene mass extinction event, the theory about the extinction of the dinosaurs that Smit had made an important contribution to forty years earlier. 'The finds tell the entire story. There's no need for support from any weird hypotheses.'

Tsunami

Yet there were some mysteries linked to the excavation site, the location of which is being fiercely guarded to protect against looters. How can both freshwater and marine animals be buried in one place? According to Smit, the only explanation is that there was an inland sea at the time in North America, near the Tanis site. It's from there that a saltwater wave must have inundated the river bend.

The scientists found evidence of a tsunami – and a second wave that followed. Traces in the fossilised deathbed even reveal the direction the water flowed in. 'The tidal wave filled the entire valley,' says Smit, 'and buried all organisms in one go. There's a reason why the heads of all the fish are pointed in one direction.'

The tidal wave that flowed through the former river must have been exceptionally powerful. Smit estimates its height at approximately fifteen metres. It swept away fish, ammonites (a marine mollusc resembling a cephalopod), insects, trees and branches, and covered them in a thick layer of mud. The organisms were instantly cut off from oxygen, which is why they were so perfectly preserved. Indeed, the excavation produced a kind of snapshot of the immediate consequences of the Yucatan impact.

Sognefjord

And yet one thing remains a conundrum: how can a meteor impact three thousand kilometres away have caused a tsunami in an inland sea? And an even tougher nut to crack: how did this tidal wave arrive at the location of the excavation in North Dakota at the right time? The way the animals, glass particles, charred tree trunks and branches were stacked and the layer of iridium suggest that the whole shebang must have been submerged within about an hour of the meteor's impact. Microtektites take no more than an hour to land back on earth. A tsunami starting in Yucatán would only have reached Texas by that point, whereas North Dakota is about a thousand kilometres to the north. 'The big question for us was: how do we get the tidal wave at that location on time?' asks Smit.

The solution to the conundrum presented itself when he learned of a phenomenon that took place following the devastating earthquake in Japan in 2011. At the time, one and a half metre high tsunami waves were witnessed and filmed thirty minutes after the earthquake in the largest fjord in Norway, the Sognefjord. 'That's over eight thousand kilometres away,' says Smit. 'That means those shockwaves travelled right through the earth's crust in half an hour! The same thing must have happened during the meteor impact in Mexico, but then much stronger. What we're dealing with here is an indirectly controlled tidal wave.'

The excavation in North Dakota is a definite highlight for Smit, and ironically it followed his retirement. 'I never thought that I'd get to see such a perfect picture of the direct consequences of the Yucatan. And there's still a wealth of material for our PhD students to sink their teeth into!'

Inspired by nature

What can engineers learn from a parasitoid wasp or an octopus tentacle? A great deal, as the Bio-Inspired Technology Group (BITE group) at TU Delft illustrates. Together with biologists at Wageningen University & Research, the researchers have developed medical instruments inspired by nature. 'If you combine smart human technology with what evolution has given us, then you come up with solutions that no one else could conceive,' says professor Paul Breedveld. Cooperation is crucial: 'This can only be done if you put an engineer and a biologist in a room together.'

TEXT: DIRK-JAN ZOM IMAGES: BOB ESHUIS

Octopus

During keyhole surgery, medical instruments only a few millimetres thick often need to be able to move in narrow spaces. Developing a hinge at this scale is difficult, however. The researchers studied an octopus tentacle, which has layers of muscle on top of each other in different directions. They used this idea in an instrument containing parallel cables surrounded by spiral-shaped cables. As a result, the tip of the instrument can move in all directions and look around corners. The worldwide patented idea has led to the creation of the thinnest medical instruments in the world that can be steered in every direction.

Parasitoid wasp

Ultra-thin medical instruments are needed to treat areas that are difficult to reach, such as the brain. Inspired by the parasitoid wasp, the researchers developed the thinnest (0.4 mm), self-propelled, steerable needle in the world. The parasitoid wasp's ovipositor is so long that the insect is actually too small to push the tube into anything externally. The secret is that the ovipositor can pull itself forward because it consists of three individually moving parts, connected to each other by grooves. The researchers used this principle and connected a wreath of individual wires with miniscule rings. The wires can be pushed forward one by one, allowing the needle to penetrate tissue step by step.

Sea urchin

Sometimes, during a biopsy, surgeons push back tissue with their surgical knives. This is no longer a problem, thanks to the sea urchin. This animal has an advanced jaw apparatus consisting of various muscles and five teeth in a circular arrangement. The researchers designed a crown-shaped biopsy tool with knives in the shape of a crown. The tips of the knives drill into the tissue and move towards each other; the crown then closes in order to take a sample. Thanks to the spring mechanism, taking biopsies occurs at high speed. As a result the tissue doesn't deform as much, enabling surgeons to work with more precision.

Caffeine makes water molecules fall asleep. One caffeine molecule slows down the movement of as many as 10 water molecules in its immediate vicinity. ***www.nwo.nl/10***

Mantis shrimp

It is often difficult to puncture the arteries of patients suffering from chronic total occlusion (CTO).The required force cannot be applied because the clot is calcified and the catheters and guidewires buckle because they're too weak. Researchers developed a catheter that is able to give the calcified clot a powerful hit. One of the models for this was the mantis shrimp. This marine creature can unfold a kind of claw at high speed to give prey a massive punch. The first prototype immediately had sufficient power and speed to 'puncture' a blocked artery. This technology has now been built into hydraulic catheters.

The gravitational wave detectors LIGO in the US and Virgo in Italy detected signals from ***11*** *gravitational waves between 2015 and 2018.* ***www.nwo.nl/11***

Walking again by singing or skating

Many Parkinson's patients have great difficulty walking, **but they often make good progress** to the rhythm of a metronome or by 'ice-skating'.

What?
Walking therapy for people with Parkinson's.

Why?
Coming to a standstill or freezing while walking is a symptom of Parkinson's. Not only is this annoying, but it can also cause people to fall.

Who?
Jorik Nonnekes.

Where?
Radboudumc, Nijmegen, Donders Institute for Brain, Cognition and Behaviour.

Result?
An overview of 59 strategies conceived by patients themselves to somehow enable them to walk again.

TEXT: EDO BEERDA

Until recently, the patient doing her exercises in the Movement Lab at Radboudumc this morning was able to walk reasonably well. But early this year, Resi Godwaldt (62) was increasingly inconvenienced by 'freezing'. It's a common symptom of Parkinson's disease: the patient seems to suddenly come to a complete standstill while walking. Which is dangerous, because when muscles suddenly don't do their job anymore, it can suddenly cause people to fall. 'I'm not bothered by that at all anymore,' says Godwaldt, while she walks on a red strip in the shape of a question mark that the researchers have laid out across the blue floor. 'When I concentrate on the strip, I have something to hold on to. That helps me.' An exercise involving lifting the legs up high stimulates walking too, whereas walking with a tray of cups in the hand makes it more difficult. When the researchers ask her to name a series of towns, her right leg begins to drag.

The red strips on the floor are clearly the right remedy for Godwaldt. But why? 'Because the patient consciously transfers her attention to a very specific way of moving forward,' explains researcher and specialist in rehabilitation medicine Jorik Nonnekes.

Glued

Parkinson's is caused by the loss of dopamine neurons in areas of the brain that control voluntary motor behaviour, such as walking and cycling. It starts with stiffness and trembling, which is usually soon followed by walking problems. A confident stride makes way for a shuffling gait. When patients 'freeze', they feel that they're literally glued to the floor. It usually goes wrong at moments that require more coordination. If the patient wants to make a turn in the kitchen, has to step inside through a door somewhere or experiences stress, then suddenly these movements don't come voluntarily anymore. 'The whole network that controls walking from the brain collapses like a house of cards,' Nonnekes explains.

Some Parkinson's patients have remarkable tricks that help them to keep going, however. This had already been documented in practice and in the literature, but the researchers in Nijmegen decided it was time to catalogue them all. They received help from colleague specialists from all over the world. They described strategies that they had encountered in practice and sent in videos. After four years of research, these efforts resulted in a catalogue with as many as 59 different compensation methods.

Bypass brain areas

There are some bizarre solutions among them. People who shuffle around completely helplessly can suddenly move fine when they dance, sing, ice-skate, play basketball, fence or move like a bullfighter. For others, walking on stairs is a piece of cake, even though they can't move a step forward on the street. Nonnekes enthusiastically shows spectacular videos: a patient who can barely take a single step is capable of running like the wind. Another hops onto a bike and wastes no time disappearing in the distance. A third neutralises the freeze by pointing to his temples. 'The problem is in the brain, in the basal nuclei that control voluntary motor movements,' says Nonnekes. 'Compensation strategies help people to switch from voluntary to conscious walking. They enable you to bypass the damaged brain areas.'

The examples of compensation methods that the researchers collected in recent years provide patients with an option menu. That's important, because different things work for different people. There's no one-size-fits-all solution. An enthusiastic Parkinson's patient who had read about the research, even made a poster with illustrations of all the strategies. It also provides patients with alternatives for tricks they're already familiar with, which is handy because if you 'freeze' in the supermarket it can be uncomfortable to have to sing or bullfight your way to movement again.

Categorising tricks

Nonnekes divided the methods into six categories. The first is the use of what he describes as 'external cues'. Laying down strips on the floor or moving to the rhythm of music are examples of that. Counting while walking is an example of a strategy with 'internal cues'. 'Changing balance' is a trick to transfer weight more easily from one leg to the other – for example by walking like a tightrope walker.

'Visualising' is another trick: by imagining how to make a movement, you can circumvent freezing. An alternative is to simply watch how someone else does it. This will activate our 'mirror neurons'. The 'new walking pattern' strategy circumvents voluntary motor movements, for example by walking sideways, climbing stairs, jumping or making a cross step. The patient can also go a step further by seeking alternatives for normal walking. Think of cycling or scootering.

Mechanical aids were used in the research as well, such as lasers on shoes and a wheeled walker. They appear to improve 'walking confidence', even if the lasers aren't turned on. Patients seem to feel surer of themselves if they know that they have the option of turning on the laser.

Looking for the best fit

Nonnekes is currently working on a survey involving thousands of Parkinson's patients. He thinks the large majority of them won't even know that compensation strategies exist. Subsequently, he will test various methods in the Movement Lab on patients with walking difficulties. By linking the results to personal characteristics, he hopes to soon understand which method is the best fit for a specific kind of patient. Monitoring brain activity, moreover, should give an idea of exactly how the brain's control mechanism works during these compensation strategies. 'The ultimate aim is to design a tailor-made rehabilitation treatment for each individual patient. I think we're going to succeed. Thanks to the ingenuity of all those people with Parkinson's.'

IMAGES: RIËS VAN WENDEL DE JOODE

'I follow the seams of the pavement tiles'

About nine years ago, Resi Godwaldt (62) started suffering from stiff muscles and loss of strength. 'Menopause,' she thought. Yoga and Tai Chi made no difference. When she was examined by the doctor, it turned out to be something more serious: Parkinson's disease. She managed to keep working at the art academy in Utrecht until three years ago, when the complaints became too severe. 'It stressed me out,' says Godwaldt. That luckily improved when she was declared unfit to work. Lately she's been using walking sticks because now she also suffers from dystonia. It causes sustained muscle contractions. 'It gives me cramps in my toes. I can't wear regular shoes anymore.' She also suffers from freezing episodes while walking.

Treatment with botulinum toxin, a muscle relaxant, was initially effective, but in the past six months, walking has become increasingly difficult. That's why she ended up at Jorik Nonnekes' walking polyclinic. During the exercises with compensation strategies, she quickly discovered that strips on the floor were helpful. 'It somewhat resembled what I already do when I walk on the street: I follow the seams of the pavement tiles,' Godwaldt explains. Ice-skating movements also make walking easier. 'At a certain point you start thinking: how is this going to end? That feeling has passed now.'

*Thanks to genetic analyses, wood can be traced to within **14** kilometres of its origin. This will help combat the illegal timber trade.* ***www.nwo.nl/14***

*The number of organ transplants increased by **15** per cent in 2018, in part thanks to Organ Assist, a new technology to wash and test organs.* ***www.nwo.nl/15***

What?
Sustainable and efficient production and use of hydrogen as an energy carrier.

Why?
Switching to an affordable, reliable and sustainable energy system is one of the cornerstones of the climate agreement and the main goal of the top consortiums united in the Energy Top Sector.

Who?
Everyone. It's one of the most pressing issues occupying physicists, technicians, chemists and other scientists.

Where?
Essentially everywhere, at almost every scientific institution. In the Netherlands, for example, at the NWO research institute DIFFER.

Result?
New ways of improving the production and storage of sustainable energy.

TEXT: HARM IKINK IMAGES: FLORIAN BRAAKMAN

Towards – and beyond – a hydrogen economy

Hydrogen is on its way. Thanks to a variety of new ways to produce and use 'green' hydrogen, researchers are paving the way to a more sustainable economy. But we're not there yet. What's more, we need to start thinking 'beyond hydrogen'. **Five questions to Richard van de Sanden,** director of DIFFER, the Dutch Institute for Fundamental Energy Research.

Professor and sustainability strategist
Prof.dr.ir. M.C.M. (Richard) van de Sanden is scientific director of DIFFER, the Dutch Institute for Fundamental Energy Research in Eindhoven. The institute carries out research on generating sustainable energy through nuclear fusion and storing sustainable energy in the form of synthetic fuels and chemicals. Van de Sanden is one of the figureheads of the Energy Transition route of the Dutch Research Agenda and chairman of the advisory committee for Electrochemical Conversion and Materials. This committee advises the government on what is needed to produce sustainable fuels and chemical products through the use of renewable electricity, based on CO_2 and/or biomass.

*The ALMA telescope in the Atacama Desert in Chili consists of sixty-six antennas spread over a distance of **16** km from each other. Computers reconstruct images from the heavens based on differences between the signals that all the antennas detect.* ***www.nwo.nl/16***

*A new separation technique for plastic waste can render **17** thousand tons of plastic waste suitable for reuse thanks to a technique invented at TU Delft.* ***www.nwo.nl/17***

What is hydrogen actually?
'When we talk about a hydrogen economy, then we mean hydrogen gas, H_2. It's colourless and odourless and hardly occurs naturally on earth. You can make it, however, by getting hydrogen atoms from other molecules, such as water, to form a hydrogen molecule together. Then you have usable gas. But it takes a lot of energy to make that happen.'

What's green and sustainable about hydrogen?
'Hydrogen is essentially an energy carrier. The sustainable, green variety is made from water using electricity. That occurs by means of a chemical reaction in which the hydrogen atoms of the water molecules form hydrogen gas together. If you do this using green electricity from wind turbines and solar panels, then you're essentially storing sustainable energy in hydrogen. The nice thing is that you could potentially transport that energy, for example in a tank truck or through pipelines, and use it again somewhere else or at some other time. That's also possible with batteries, but they're relatively heavy and still have limited capacity.'

What are its applications?
'When the wind is blowing hard and the sun is shining, the production of renewable energy can exceed the demand for electricity. You can store the surplus in hydrogen and make electricity out of it again later. In the evening, for example, when we all want to turn our lights on but there's no longer any solar power. Or you can make hydrogen in the summer, which can be used in the winter.
A fuel cell can be used to make electricity again from hydrogen, for example for cars. Hydrogen cars are essentially electric cars, not with batteries but with a fuel cell. They're not as heavy and it takes less time to fill up on hydrogen than it does to recharge a battery. The more you drive per day, and the more important it is to save on weight, the greater the benefit of hydrogen. That's why hydrogen is an excellent option for making buses and lorries more sustainable. Germany even uses hydrogen trains.
Hydrogen can also be used to produce heat. You can use it to heat homes in a sustainable way and also provide industry with heat. The chemical industry, incidentally, also uses hydrogen as a raw material, for example during the production of chemical fertiliser. So green hydrogen can make advances in sustainability there as well.'

So why are we seeing so little of it?
'Large-scale innovation is always difficult, but there are justified doubts about several aspects. For example, a lot of energy is lost when electricity is converted to hydrogen and back to electricity. Moreover, it requires energy to put hydrogen under pressure so it can be transported efficiently. As a result, it's often not possible to make the application of hydrogen economically viable. That's one of the reasons why hydrogen cars are having difficulty competing with today's electric vehicles. And that's why it's still challenging to apply it on a large scale.

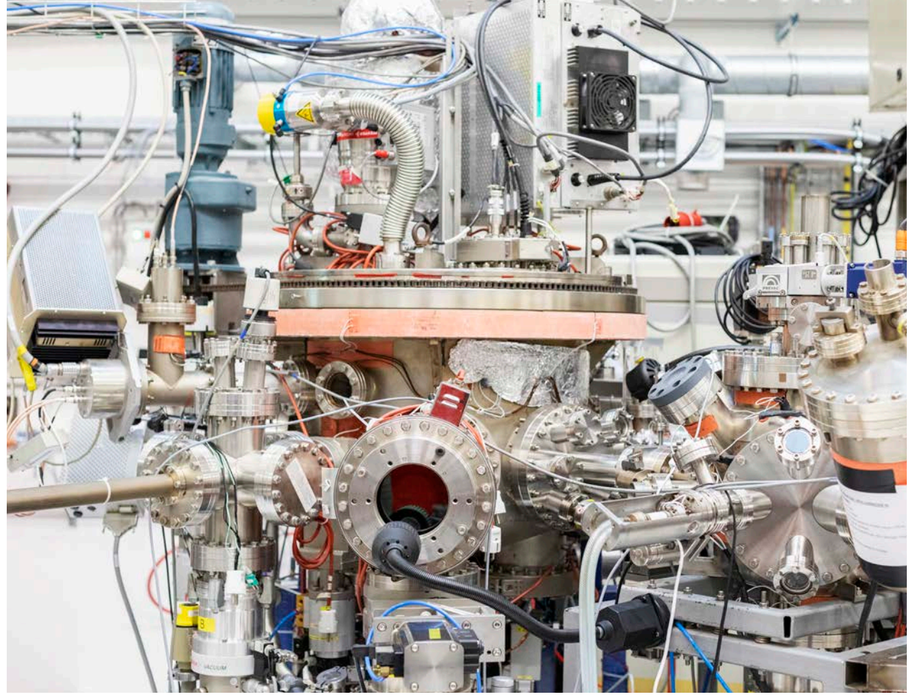
The smallest element
The hydrogen atom is the smallest known atom. It's part of various molecules: natural gas, petrol, sugars, proteins, DNA – hydrogen atoms are basically found almost everywhere. On the scale of the universe, hydrogen makes up more than ninety per cent of all atoms.

Green, grey, blue and turquoise hydrogen
'Green' hydrogen is produced from renewable energy, such as wind and solar. The chemical industry has been producing hydrogen from natural gas and water for many years now. We call this hydrogen 'grey hydrogen' because it releases CO_2. There are plans to store this CO_2 underground, which would then give us 'blue hydrogen'. And finally it has recently become possible to produce hydrogen from natural gas without emitting CO_2. That's often referred to as 'turquoise' hydrogen.

More than technology
We are in desperate need of new technologies for a sustainable economy. 'But technology alone won't solve anything,' says Richard van de Sanden. 'The transition is primarily a societal issue. How we manage innovation processes, how we ensure that people change their behaviour, what the government's role should be – these are not issues that technology can solve. Luckily there are an increasing number of results from the social sciences and humanities that can help us in that respect. The research being conducted in these fields is definitely just as relevant as developing new electrolysers.'

Essentially, much of hydrogen technology is still too expensive, too small scale or insufficiently reliable. That's why scientists are currently working hard on ways of improving hydrogen production with electrolysers and integrating these into a major hydrogen plant. There's great potential for development in underground storage in salt domes and creating an infrastructure of hydrogen pipelines. What's also standing in the way of large-scale implementation is the expected amount of sustainably produced electricity. The overall energy need of the Dutch economy is a continuous supply of over 100 gigawatts. The Dutch economy will also need a higher overall supply of energy in 2050 than will be available through sustainably generated electricity – especially wind energy from the North Sea. So it remains to be seen whether it's wise to start producing a huge amount of hydrogen with the relatively scarce electricity that we have, because a great deal is lost during conversion. Then it makes much more sense to use this energy directly, for example in electric cars and heat pumps in the built environment and in industry.'

Is there going to be a hydrogen economy at all?
'I think there's definitely a place for hydrogen on the road to a sustainable future society. It has many useful applications and can become one of the cornerstones of a sustainable economy. But hydrogen is not the panacea that will make everything sustainable – we'll be far off our target with hydrogen alone. That's why we already have to start thinking 'beyond hydrogen'. To give you an example: you can't fly an aeroplane on hydrogen. But you can with green, synthetic kerosene. That has much higher energy input per kilo. In addition to hydrogen atoms, you also need carbon atoms to make kerosene. You can extract them from O_2, for example. Using ambient CO_2 is the next key step on the road to a sustainable future. In addition to fuels, you can actually produce all substances that chemists call 'hydrocarbons' and which are largely made of petroleum at the moment. That would enable us to simultaneously pave the way for sustainable materials, from plastics to medicines.
Incidentally, in addition to synthetic kerosene, you can also produce other sustainable fuels from O_2. We call them solar fuels. Think, for example, of synthetic methane, essentially natural gas. You could produce that in regions with a lot of sun, such as Morocco or the Middle East, from water and carbon dioxide, with sustainable electricity. We could bring it here on tankers intended for liquefied natural gas – the infrastructure for it is already in place. That's another reason why I think it's premature to say that we have to get rid of gas. Synthetic 'solar gas' could potentially be an excellent sustainable alternative in the future.'



Working on the hydrogen economy: four results

1 Hydrogen without electricity
Energy research institute DIFFER is working on a new way of making hydrogen: without electricity and without water. Well, yes with water, but then from water vapour. The group for Catalytic and Electrochemical Processes for Energy Applications, supervised by Mihalis Tsampas, developed a device that can extract these vapours from air. Then all you need is to let the sun shine on them and they'll produce hydrogen, thanks to porous photoelectrodes and electrolyte membranes. The water doesn't need to be purified in this simple and effective concept – water vapour is fairly clean. And you can produce hydrogen from it in places that lack liquid water. In deserts, for example, where there is more than enough sun. An initial prototype was an instant success, and the researchers plan to improve that now with new materials and a better design. After that, it's a question of upscaling.

2 Green kerosene from CO_2 and water
Producing a new, clean synthetic fuel for aviation, that's the aim of the European consortium KEROGREEN. Capturing CO_2 from the air creates a closed aviation carbon cycle: the burning of kerosene releases CO_2 and KEROGREEN, in turn, uses it to produce new kerosene again. And all of that is driven by renewable energy. Researchers in Eindhoven developed efficient plasma technology to convert the CO_2 captured from the air into carbon monoxide (CO) with wind or solar energy. The oxygen that is produced in this process is removed with separation technology developed by Belgian, Norwegian and Dutch partners. Thanks to German technologists, reactors can subsequently convert the CO with hydrogen into kerosene. That occurs according to well-established chemical principles, but on a relatively small scale. 'All of the technology is now available. The next goal is to build a unit the size of a sea container that's economical and energy efficient,' says project coordinator Adelbert Goede from DIFFER. 'It will enable us to produce decentralised sustainable kerosene, with turbines or solar panels.'

3 Innovative membrane reactor
Professor Fausto Gallucci from the Eindhoven University of Technology developed a 'fluidised bed membrane reactor' that produces hydrogen from natural gas (or biogas) in a highly efficient manner. Thanks to the membranes, the CO_2 that's produced is immediately captured. The relatively small-scale reactor is suitable for the production of hydrogen in hydrogen stations or industrial ovens, for example. 'It's pure enough to use immediately,' says Gallucci. 'And because the reactor is small, and the process temperature low, both the investments and the operational costs stay within limits.' During his research, Gallucci already built a small functioning reactor. Now he's partnering with companies to build a version that can produce twenty m^3 of hydrogen per hour. In the meantime, he's also working in a European project to further scale up the concept into an industrial-sized pilot plant.

4 Battery and hydrogen production in one
Is it a battery? Is it an electrolyser? The Battolyser is two devices in one. You can use it to store renewable electricity. First in the battery, and when that's full, then you make hydrogen. Professor Fokko Mulder from Delft based the device on an old, robust type of battery that dates from before Thomas Edison. It has iron and nickel electrodes that change chemically so they can efficiently produce hydrogen from water. 'The battery stores energy for the short term,' Mulder explains, 'while hydrogen can absorb the seasonal variations in renewable electricity generation. Moreover, hydrogen is valuable as a raw material for the chemical industry.' The Battolyser is efficient, stable and relatively inexpensive as a result of the 2-in-1 principle. The start-up Battolyser BV is now working on a trial in Eemshaven, together with the energy company Vattenfall (previously Nuon), Yara, a player in industrial hydrogen, and the Waddenfonds. 'After that we're going to further scale up the Battolyser,' Mulder says. 'Think of units the size of a sea container, which we will place at sites of industrial partners or at locations where a great deal of electricity from offshore turbine parks is brought ashore.'

■ The coast of Oman

Mudflat in the desert

TEXT: MARIETTE HUISJES

IMAGES: JAN VAN DE KAM, AZIZA SAUD AL ADHUBI (AERIAL PHOTO)

On the south-east coast of the Arabian Peninsula, bordering the desert, is a virgin mudflat landscape. Just like our mudflats in the Netherlands, **it's a stopover for migratory birds and a nursery for fish, crabs and shrimp.** But these mudflats are still unspoiled. Knowledge of this faraway area can help us to make our own mudflats more natural again as well.

*The development of a joint energy network by North Sea countries will generate a lot more money than it costs: preventing a ten year's delay in construction will boost prosperity by **20** per cent in a quarter of a century.* ***www.nwo.nl/20***

*The tower with solar panels and wind turbines that supplies festivals such as Pukkelpop with sustainable energy is **21** metres high.* ***www.nwo.nl/21***

Until recently, little was known about Barr al Hikman, a remote tidal area on the south-east coast of Oman. Its nutrient-rich mud, gentle winters and sparse human habitation make this place a paradise for migratory birds, and it supplies the Indian Ocean with countless fish and other sea creatures that started their lives here. Marine biologist Roeland Bom from the Royal Netherlands Institute for Sea Research (NIOZ) was the first scientist to make an inventory of the animals that live in Barr al Hikman and the structure of the food web. That's providing inspiration on how to manage the Dutch Wadden Sea. As the largest mudflat area in the world, it also plays a pivotal ecological role as a temporary home for about eleven million migratory birds. As a result of human activity, the diversity of species in the Dutch mudflats has dramatically decreased. For example, seagrass already disappeared from the Wadden Sea in the 1930s. 'In Oman,' says Bom, 'we noticed that the fields of seagrass serve as an important habitat for many fish and invertebrates, which many birds, in turn, rely on for food. It would be great if we could restore these fields in the Wadden Sea as well.' Bom's research not only shows how we can help the mudflats in the Netherlands to recover, but it can also contribute to the conservation of the Arabian mudflats.

An evolutionary arms race is taking place on the Arabian mudflats. Sea snails protect themselves with extra-thick shells, crabs develop extra-strong claws so they can crack them open anyway, and crab plovers tear the dangerous claws off the crustaceans with their strong dagger-like bills before eating them.

Soil samples reveal that an unprecedented number of invertebrates live in the fertile mud, such as worms and molluscs.

Barr Al Hikman, an unspoiled mudflat landscape with a large variety of species, an absence of dikes and the presence of large fields of seagrass.

*In twenty**22**, breakwaters should prevent saltwater from flowing into the Hedwige Polder. The resulting silt will be an important nesting and migration site for animals.* ***www.nwo.nl/22***

*Genetic information from more than **23** x 10,000 mothers has enabled researchers to discover 190 links between their genetic code and the weight of their baby at birth.* ***www.nwo.nl/23***

Cold case solved after 2,000 years

A cadaver with a half-shaved head, strangled and dumped in a pond. Presumably the Yde Girl, the Netherlands' most famous bog body, was killed by her own fellow villagers. These are the findings of a new environmental analysis of the scene of the crime, more than 2,000 years after the deed was committed.

She was barely sixteen when she was strangled and thrown into a pond.

Two thousand years later the Yde Girl was found again. The girl, who was approximately 1.40 metres tall, was wearing a worn-out woollen cape, had a braided, woollen strangulation band around her neck and a stab wound near her left collarbone. Half of her long, reddish-blond hair had been shaved off. Wageningen archaeologist and raised bog expert Roy van Beek and his colleagues reconstructed the Yde Girl's living environment and suspects that the perpetrators were people from her own village.

Close to home

Contrary to what you may expect, the murder didn't take place in a vast, inhospitable, remote peat bog marsh, where the spirits of wise women roam in the mist at ungodly hours. In fact, it probably happened close to home, about a kilometre away, in a half-open cultural landscape that the then inhabitants had already tamed and put to intensive use. 'Members of the public were probably present, but not many, because there simply wasn't enough room in this place,' concludes Van Beek.

Broader picture

Hundreds of bog bodies have been found in northwestern Europe, usually during peat extraction, 48 of which were discovered in the Netherlands. Some were given a posthumous burial after being discovered and some simply vanished. Others are now on exhibition at the Drents Museum in Assen. 'You could fill your bookcase with works about bog bodies,' says Van Beek. 'They describe their clothing, their diseases, their last suppers, the ritual artefacts that were found with them in the marshes. But no one has ever painted a broader picture. How did these people live, what kind of a society was it? A good landscape analysis can provide answers to some of these questions.'

Peat cutters

Van Beek and his colleagues' reconstruction reveals that the bog in Drenthe where two peat cutters, to their dismay, discovered the Yde Girl in 1897 was about sixty meters in diameter and no more than a metre or two deep. When the land was reparcelled in the 20th century, it shifted and filled with sand, but this area is still visibly damp in the fields. An analysis of the ancient pollens in the soil has revealed that the bog was surrounded by spots of fairly open deciduous forest with oak, beech, hornbeam and linden, interspersed with heath and grassland, raised bogs and streams.

Diverse landscape

The closest farm could not have been more than a kilometre from the site. Every couple of kilometres, there were small hamlets in the landscape with no more than twenty to thirty inhabitants. There were burial grounds near most villages. On the higher sand ridges were networks of fields separated by earthen walls (referred to as Celtic fields). Cows and sheep grazed in the damp stream valleys. Three enclosed 'strongholds' were also found around the site, but they're so small that their purpose is more likely to have been spiritual than military. 'We weren't able to identify any differences in status at the houses and the burial sites,' says Van Beek. 'Presumably this concerned an egalitarian society. There was probably some cooperation between the villages, because it must have taken great effort to build all those Celtic fields and other fortifications.'

Sacrifice to the gods

So the key question remains: Why was the Yde Girl killed. 'We still don't know for certain,' says Van Beek. 'Presumably the decision was made at the local level, by several villages in unison. She may have been tried for adultery or another crime. Or perhaps she was a sacrifice to the gods, which was most common in times of unrest, war and disease. The one doesn't preclude the other, by the way, because criminals were sometimes offered to the gods as well and thrown into the bog after being killed.' It's striking that there are no other known archaeological finds from this bog. Nor can we say with any certainty that the Yde Girl really did live in the Yde area. 'Prehistoric people were more mobile than was previously thought. For example, it turns out that an archer found near Stonehenge was actually from the Alps,' says Van Beek.

What?

Reconstruction of the living environment of the Yde Girl in the raised bog of Drenthe.

Why?

There was a time when more than half of the Netherlands was covered in raised bogs. At most, five per cent of that remains today. Researchers are examining how these raised bogs were used for centuries and how we can conserve the last of the raised bogs, an important part of the country's heritage.

Who?

Roy van Beek, Wageningen University & Research in collaboration with the Faculty of Geosciences at Utrecht University and the ADC, an archaeological research and cultural heritage centre.

Where?

The vicinity of Yde in North Drenthe.

Result?

The Yde Girl was probably killed close to her home near a bog about sixty metres in diameter and no more than a metre or two deep. She was probably tried for a crime or offered as a sacrifice to the gods.

TEXT: MARION DE BOO IMAGE: DRENTS MUSEUM

The bog body of the Yde Girl as it was found by two peat cutters in 1897. Researcher Roy van Beek became fascinated by these kinds of finds at a young age. 'I already wanted to be an archaeologist as a small boy in Salland,' says Van Beek, now an expert in raised bogs. 'I was always looking for fragments. When I was about fourteen, there was a fantastic European exhibition about bog bodies in the Drents Museum in Assen. They're so appealing because the acidic peat preserves them so well. People from thousands of years ago! I was completely fascinated. My parents thought it was a bit strange.'

What?
The search for that one elusive image.

Why?
The gravitational force around a black hole is so strong that it distorts time and space: even light cannot escape. Demonstrating the existence of black holes confirms the theories Einstein developed on gravity in physics.

Who?
Heino Falcke, professor of radio astronomy and astroparticle physics at the Radboud University Nijmegen, together with colleagues from Radboud University, the University of Amsterdam, Leiden University and the University of Groningen, as well as an international team of astronomers.

Where?
Eight telescopes spread across the globe that together form the Event Horizon Telescope (EHT).

Result?
The first image of the shadow of a black hole.

TEXT: MARION DE BOO IMAGES : HOLLANDSE HOOGTE

The shadow of the black hole

Finally we know what a black hole looks like. In April, an international team of astronomers presented the very first image of the shadow of a black hole.‘

‘I felt like Christopher Columbus. We saw things that none of us had ever seen before,’ says Heino Falcke. On 10 April 2019, the radio astronomer working in Nijmegen presented the very first image of the light bending around the black hole in M87 galaxy. Black holes are places in the universe where the gravitational force is so immensely powerful that it even devours light. But black holes are small or very far away, which is why we didn’t have any pictures of them yet.

Fundamental

Why is Falcke so fascinated by this matter that he is making it his life’s work? ‘It’s about the limits of our knowledge, in a very fundamental way,’ says the originally German researcher. ‘The entire history of life and the universe unfold in the theatre of time and space. You can see as far as the Big Bang, but not further back than that. You can also study everything up to the edges of a black hole, but not further than that, because as soon as you’re inside a black hole, you won’t be around to tell the story. That’s a fundamental boundary that we come up against.’

Super telescope

It was Falcke’s idea to use a global network of telescopes, linked together to form a super telescope, in order to see the shadow of a black hole. It took 17 years to develop this super telescope. In 2017, an international team observed two black holes for four nights. It concerned Sagittarius A*, an enormous black hole in the centre of our Milky Way, and Messier 87, a monster with an overwhelming mass of 6.5 billion suns. The weather conditions were perfect all around the globe. After studying the measurement results for year, the observations of M87 seemed to be the most promising ones. That’s why they were the first to be optimised, which resulted in the famous image two years later.

Testing Einstein

The shadow around the black hole arises because rays emitted from around the black hole are devoured by the powerful gravitational forces. Around the shadow we see a halo of rays that are bent by the strong gravity near the black hole. These observations have made it possible to test Einstein’s theories of gravity, very close to the objects in the universe that possess the absolute strongest gravity. In black holes, a weight the equivalent of the Earth is compressed until it’s the size of a thimble, and that causes this massive gravitational force.

Big dreams

Did he ever doubt this wild plan? ‘I often have big dreams, it’s in my DNA. And then I’ll do everything in my power to make them come true,’ Falcke says. ‘But until that moment arrives, you’re never sure if it’s really going to succeed.’ In 1994 he obtained his PhD summa cum laude at the University of Bonn. He developed a theoretical model in his dissertation that explained the radio emissions of a large black hole in the centre of our Milky Way. He was surprised by the conclusion that this radiation seemed to be coming directly from the edge of the black hole. During this same period, colleagues were developing a technology that would make it possible to create extremely sharp images of this radiation. The idea, however, was that a black hole was in fact too small to capture in an image, even with a telescope as large as the entire planet Earth. ‘It’s like trying to read a copy of the New York Times in New York from Nijmegen,’ Falcke says. But luckily black holes function as their own magnifying glass and thus Falcke predicted that it would be feasible after all.

Global network

To make better measurements, Falcke did his best to encourage colleagues all over the world and secure funding. Winning the prestigious NWO Spinoza Prize in 2011, worth 2.5 million euros, gave him a massive boost. ‘That meant we could compete again, because in the meantime the United States had taken over the initiative to set up a global network. It’s one thing to be inspiring, but you have to be able to participate in experiments. Money talks.’ With the Spinoza Prize in his back pocket, the astronomer had sufficient self-confidence to submit a request for a grant from the European Research Council (ERC). The odds of getting one were only two per cent. Nonetheless, Falcke and his German colleagues Luciano Rezzolla and Michael Kramer landed an ERC Grant worth 15 million euros. ‘Expensive research? On the contrary, it’s actually inexpensive. The discovery of the Higgs particle cost billions, whereas here we’re talking about tens of millions. A major project such as this requires a large group of smart and driven scientists – and of course top-level PhD candidates in the Netherlands. Working with them is a privilege.’

Secret service
To capture an image of a black hole, the scientists observed two of these space monsters in 2017. In 2018 the measurements were repeated. This time everything went wrong. The weather conditions were much worse. In Spain, where radio astronomer Heino Falcke worked, there was only one night with favourable weather. Two other telescopes weren’t ready on time to participate. In Mexico, a staff member was mugged by six heavily armed, masked men. ‘Afterwards we learned that the secret service was behind it. They had no idea who they were dealing with,’ Falcke says. ‘We stopped, but there might be a bit of good data left over that we can use.’

*In 2026, the PLATO telescope will be launched into space. PLATO has **26** cameras on board which the telescope will use to search for exoplanets. **www.nwo.nl/26***

*From nineteen**27** onwards, Amsterdam dumped waste into Europe’s biggest toxic waste belt, the Vogelmeer Polder. Clay, reedmace and water soldiers ensured that the toxins were broken down naturally. **www.nwo.nl/27***

Every year, NWO invests almost a billion euros in scientific research. That comes down to more than seven thousand research projects at universities and knowledge institutions. A great deal of research also takes place at the nine NWO institutes, AMOLF, ARCNL, ASTRON, CWI, DIFFER, Nikhef, NIOZ, NSCR and SRON.

Deep-sea mining

In many places, the ocean floor is littered with manganese nodules that are chock full of valuable metals. Mining these at an industrial level is an attractive prospect, especially now that there are economically viable methods for doing so, but according to researcher Tanja Stratmann it would cause irrevocable environmental damage. Mining would cause the corals and sponges that attach themselves to the manganese nodules, which took millions of years to form, to perish forever. In 1989, German researchers churned up a seabed in the Pacific Ocean at a depth of four thousand metres. Stratmann demonstrated that even after thirty years, the average fauna activity is still 54 per cent lower than in a control area that was not churned up. 'The destruction caused by industrial mining will be far greater, because that would concern thousands of square kilometres of deep-sea floor,' Stratmann says. For the deep-sea research, the Royal Netherlands Institute for Sea Research (NIOZ) developed special deep-sea boxes to catch organisms. This enabled Stratmann to measure their metabolism and scientifically demonstrate the disruption. 'We aren't even close to knowing all deep-sea organisms, let alone what the effect will be if they vanish from the ecosystem,' Stratmann explains.

Bystanders in action

The bystander effect has been a valid theory in psychology for more than fifty years: when a larger number of people witness an incident, they wait for someone else to intervene. But this theory is based on hypothetical situations. Thanks to video footage from security cameras we can now see what really happens. Marie Rosenkrantz Lindegaard, anthropologist at the Netherlands Institute for the Study of Crime and Law Enforcement (NSCR), examined 219 videos of disputes in Amsterdam, Cape Town and Lancaster. To her surprise, she discovered that bystanders do take action: in nine out of ten cases, regardless of the city. 'Offering help turns out to be a universal human response in situations with a high level of stress,' says Lindegaard. That's an uplifting message, which was reported in news media all over the world. And that's just the beginning, according to Lindegaard. 'Footage from security cameras are a goldmine for social research.' She will now study what kind of help from bystanders works out best in which situations. The police can tailor their advice based on the findings, for example.

Bowel cancer

Micro-organisms can contribute to the development of cancer. A one-off, violent bout of food poisoning with the *Salmonella enteritidis* bacterium, for example, which sometimes infects raw chicken meat and eggs, can significantly increase a person's odds of getting bowel cancer. This has been demonstrated by a group of researchers, who have conducted a major epidemiological study led by Sjaak Neefjes (LUMC). *Salmonella typhimurium*, a bacterium that ends up in vegetables via mouse faeces, can also cause bowel cancer.

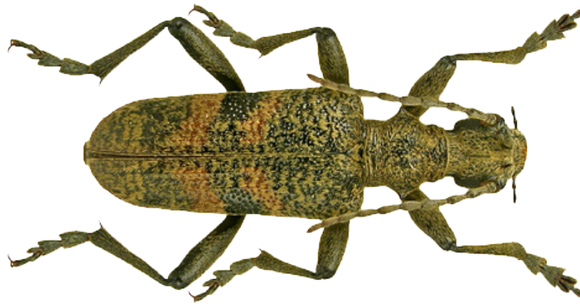
As a next step, Neefjes' group and the RIVM will examine whether repeated, mild salmonella infections that have mild symptoms can contribute to the development of bowel cancer. 'Moreover, we will investigate whether intestinal tumours caused by bacteria are different than other intestinal tumours and whether you need to treat them differently as well,' Neefjes says. 'If that turns out to be the case, then you could invite people who have just been infected with *Salmonella enteritidis*, for example, to a population screening for bowel cancer more quickly. Incidentally, the danger of infection can be dramatically reduced by eradicating salmonella from the poultry stock. There's a lot to be gained there!'

Techno fashion

A 'goosebump' shirt with coloured and luminous bubbles, which inflate when biosensors register more rapid breathing and higher heart rate. This piece of clothing by design firm Sensoree is an example of so-called techno fashion: fashionable clothing into which technology has been incorporated. For her PhD research at Radboud University, Lianne Toussaint spoke to the designers and wearers of this clothing. She examined the impact techno fashion has on the way in which we view ourselves and our environment. 'It can help the wearer to perform better or feel more confident, but it can also lead to uncomfortable situations.' Indeed, not everyone will feel comfortable in a goosebump shirt. But techno fashion can also be subtle and functional. Such as a jacket that signals air pollution or work clothing for healthcare providers that monitor whether wearers are straining their backs. 'Technology is thus being used to reveal what's under the skin. That makes it a promising but also exciting development,' Toussaint believes.

Anti-freeze

Researchers at AMOLF have unravelled how the black-spotted longhorn beetle (*Rhagium mordax*) manages to brave the icy Scandinavian winters. With molecular precision, they examined the protein with which the beetle protects itself from freezing. 'It's one of the most effective anti-freeze proteins in the world,' says researcher Konrad Meister. 'It blocks the growth of microscopic ice crystallites and therefore prevents the beetle's cells from freezing to pieces. What we didn't know yet was precisely how the protein achieves this.' Meister used advanced laser spectroscopy with professor Huib Bakker's group and thus discovered that the protein has such an impact on the surrounding water molecules that the ice crystallite can no longer absorb them. 'Now that we know the details, we may have better luck developing synthetic anti-freeze,' Meister says. 'To keep aeroplanes free of ice, protect transplant organs or keep ice cream smooth.' In the meantime, he has his own group for 'Environmentally Relevant Interfaces' at the Max Planck Institute for Polymer Research in Mainz (Germany).



Limburgish

All babies are sensitive to pitch in language, but if they're not continuously exposed to it, the sensitivity will eventually disappear. Babies in the Dutch province of Limburg, however, who grow up with a tonal language, retain their sensitivity. In Limburgish, the tone used while uttering a word determines its meaning. For example, the word 'bie' can refer to an insect or a preposition. Babies in Limburg recognise that difference in pitch. And they can still distinguish between these subtle variations in intonation as adults as well, while other adults can no longer hear the difference. These were the findings of PhD research conducted by Stefanie Ramachers (Radboud University). She compared babies from Limburg with babies from other regions, and adults from Limburg who speak the tonal language with other adults. Ramachers grew up speaking Limburgish herself and still speaks it at home. She's glad that her research is able to demonstrate the linguistic richness in the Netherlands. 'That's something to be proud of, not something that should be restricted.' The fact the Limburgish is a tonal language (one of a few in Europe), explains why people from Limburg speak Dutch so 'melodiously'.

Conspiracy theory

Are vaccines unsafe? Are humans causing climate change? How reliable is the official story of 9/11, or the Bijlmer disaster? And what about crop circles? 'Depending on the way you pose the question, as much as twenty to forty per cent of the population believes in conspiracies,' concludes sociologist Jaron Harambam (Erasmus University Rotterdam). He interviewed dozens of 'conspiracy theorists' from all segments of society and from different age groups. 'The media, science, the church and politics all have it within their power to determine what the "official truth" is,' says Harambam. 'However, globalisation, secularisation and wider access to knowledge has created more room for alternative "truths". People have less to hold on to and are being inundated with information from all kinds of sources. Moreover, revelations about government failure, conflicts of interest and bank scandals have damaged confidence in institutions. Conspiracies thrive in that kind of a climate.' According to Harambam, we have to take this unease seriously instead of hitting people over the head with facts that don't sink in anyway.

What?
Computer systems that imitate the human brain and attempt to solve problems independently.

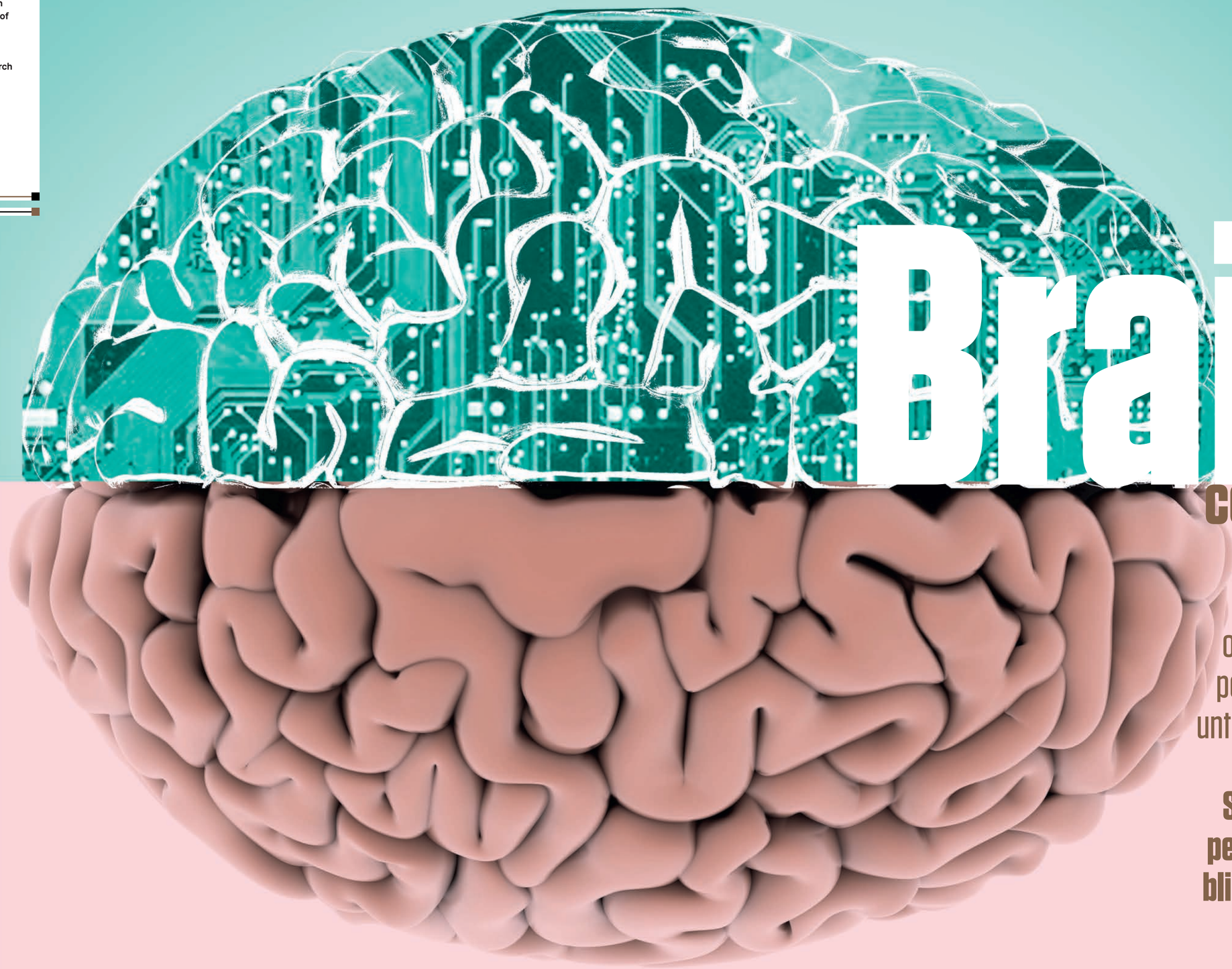
Why?
We can build faster, more efficient and above all more complex computer systems with artificial intelligence that make all sorts of innovations possible.

Who?
Sander Bohté at CWI, the national research institute for mathematics and computer science in the Netherlands.

Where?
Amsterdam.

Result?
A small step towards computer systems based on how the human brain works.

TEXT: AMANDA VERDONK



Brain computer

Artificial intelligence offers a range of possibilities that until recently were unimaginable. **Soon, will deaf people hear and blind people see again?**

These are some of the major issues of our time: how to age in good health and reduce the energy we consume. To solve these issues, we need new technologies that have greater thinking capacity than humans or current computers. The time for artificial intelligence has therefore arrived: computer systems that imitate the human brain and have the ability to solve problems independently. That can't be achieved overnight, but needs to be done gradually. And each step of the way will be accompanied by a great deal of pondering and head-scratching.

Networks are hot

'Biologically inspired neural networks are hot in artificial intelligence studies,' says Sander Bohté, researcher at CWI, the national research institute for mathematics and computer science in the Netherlands. These are computer programs that mimic the functions of real neurons in our brain by exchanging electrical signals. Highly promising results have been achieved already with this technique. Deaf people can hear things with it, you can control arm and leg prostheses with it, and eventually perhaps even allow the blind to see again. 'Research with monkeys has already shown it to work,' Bohté says. What's more, neural networks make chips operate more energy efficiently. And these chips are found in an increasing number of devices, from smartphones to cars and refrigerators. That explains why billions of euros are being poured into this field. Major tech companies have research programmes in this area, and the United States, China and Europe consider it one of their key scientific areas.

Allowing the deaf to hear

Since the beginning of last century, neuroscientists and computer scientists have already been working on a so-called cochlear implant, which would give deaf people, after several weeks of training, moderate hearing ability (again). It's a small device that's implanted into the skull and which converts electronic impulses via a thin coil in the cochlear and transmits them to nerve cells, or neurons, in the brain. Unfortunately, the sound transmitted by today's implants is often too loud or too soft; the devices aren't able to adapt to the noise level as well as human neurons. For example, if you walk into a noisy bar on a quiet evening, then the neurons in someone who can hear will adapt immediately so the bar noise isn't perceived as an explosion. And vice versa, your neurons respond extremely quickly as soon as you leave the noisy bar and walk into the quiet night. This process doesn't work as well in people with a hearing implant. Bohté has developed a computer simulation model together with the Leiden University Medical Center which, in contrast to the current models, does take into account the adjustments neurons make to the volume of noise. Ultimately, that should result in a better computer chip in the implant.

Impulse technique

Neural networks are improving all the time, according to Bohté, but they're still nowhere near as effective as the human brain. 'Our brain is more flexible – for instance, it can easily learn new tasks by establishing new connections. It also needs fewer examples to learn and operates more energy efficiently. Neurons transmit an average of one impulse per second, but in some places they can send a few hundred per second. It takes a computer much longer to do that, and as a result they use more energy.' Bohté has come up with a method to make artificial neural networks more energy efficient. 'Although the chips in our products use artificial neurons, they don't transmit impulses the way our brain does. These neurons have no concept of time – they're stacked images that are played in sequence, like a video. That process uses up a lot of energy.' Bohté therefore developed spiking neural networks that can transmit impulses. 'We want them to be able to communicate with each other with as few impulses as possible.' Because fewer impulses means less energy consumption: one chip with this special impulse technique only uses a few milliwatts. By comparison, a current image recognition chip in a smartphone uses 1 to 2 watts, which is about a thousand times more. Bohté expects his technique to be used in smartphones eventually as well.

No cloud

Because they're so energy efficient, these chips don't need the cloud either: simply a central computer server in a data centre, where data is sent via an internet connection. If you want to use a voice assistant, such as Apple's Siri or Google Assistant, you are constantly connecting to the cloud. There, the assistant can look for the requested information. For that, you always need an internet connection and it uses up quite a lot of electricity, because the assistant is always 'listening in', in order to hear your command. If a chip can do more calculations itself, then it can rely less on the cloud. That's also useful in locations with poor range. 'You can put sensors in a forest, for example,' says Bohté, 'to see which animals live there, or you can capture animal sounds in the sea. You can leave a chip with a thousand neurons in a location like that for months. Nor do we want the chips in self-driving cars to always depend on an internet connection.'

Science fiction

Ultimately, Bohté expects this technique to also end up in chips for biomedical applications, such as hearing aids and prostheses. The chips can already be used to improve text and voice recognition, but also for augmented reality: projecting images on top of reality, with the aid of special glasses. A computer has to be able to recognise and produce moving images at lightning speed, and that uses up a lot of electricity. Glasses aren't the ultimate vision of the future, however. Rather, it's an invisible implant that gives even healthy people additional functions. Such as a speech implant that allows you to speak Chinese on the spot. But that's still only science fiction, according to Bohté. 'You can't simply "load" another language. We wouldn't know where to start. You would have to change tens of billions of synapses in different parts of the brain. That remains something for a faraway future.'

Identify the Ferrari

Computers are often better at image recognition than humans these days, but when it comes to photos that are grainy, badly lit or distorted, even the best image recognition software still falters regularly. Take cars. A frequently used method for classifying images mistakes a Volvo for a Ferrari. As a human, you don't need to know much about cars to do a better job. Sander Bohté conceived a method, with the aid of neural networks, that is good at distinguishing between images. 'We trained the algorithm to focus mainly on contrasts. As a result, it became more efficient in poor conditions. 'The programming code is available as an open access publication and can now be used by any tech company wanting to improve its image recognition software. This code can help software not only to distinguish more accurately between cars, but also between other objects, and that can be useful in self-driving cars, anti-burglary cameras or nature watching, for example.

Chat competition

In the 1930s, British mathematician Alan Turing devised an experiment in which man and machine chatted with each other: the Turing Test. The machine wins the test if the human doesn't realise that he's chatting with a machine. But no computer has succeeded in doing that yet. Computers can do all kinds of things, however. Particularly in mental exercises and games that call upon knowledge at one's fingertips and logical reasoning. In 1997, IBM's chess computer Deep Blue beat Garry Kasparov, the best chess player in the world. But an interesting conversation with Deep Blue wasn't in the cards. Supercomputer Watson, also developed by IBM, is another specialist in understanding spoken language. In 2011, it won the television game show Jeopardy!, which poses questions in the form of answers, so candidates have to guess the correct accompanying question. To do that, Watson had to understand irony and riddles, something that computers are generally not very good at. And in 2015, AlphaGo, a supercomputer developed by Alphabet (the parent company of Google) was the first to beat a professional human player at the extremely complex Chinese board game Go. But you can't have a normal conversation with AlphaGo either.

*Data analysis among more than **32** thousand children revealed that children of older parents often have fewer behavioural problems than their peers with younger parents. **www.nwo.nl/32***

*The Dutch NICO expedition examined the opportunities and threats presented by a changing Atlantic Ocean. During the second stage, researchers filtered a whopping **33** million litres of seawater. **www.nwo.nl/33***

What?
Religious divorce.

Why?
Women who divorce are often unable to annul their religious marriage; these marital prisons violate human rights.

Who?
Susan Rutten, Maastricht University, in cooperation with Atria, knowledge institute on gender equality and women's history, the national working group Mudawwanah, the Clara Wichmann Test Case Fund, and refugee organisations.

Where?
Maastricht.

Result?
Legal solutions to prevent marital imprisonment; they've been partially taken over by the government.

TEXT: MARIETTE HUISJES

Married, divorced, but still imprisoned

Being divorced, but still not managing to detach yourself from your ex because the religious marriage lives on. This is spoiling the lives of women worldwide. Maastricht researchers are coming up with solutions but aren't satisfied yet with the steps being taken by the minister in the Netherlands.

What's marital imprisonment?
Marital imprisonment is when someone (usually a woman) is kept in a religious marriage against her will, because she cannot manage to annul it. It has been a familiar phenomenon for a long time in Orthodox Jewish circles, where a woman who wants to divorce requires a declaration of consent or 'get' from her husband. But women from other religious communities suffer from this phenomenon as well, according to associate professor of private international law Susan Rutten. Think of Muslims, for example, Orthodox Protestants and Catholics. There are countries where civil marriage is simultaneously a religious union. If people are married there and then divorce under Dutch law, that doesn't automatically mean that the religious marriage is annulled as well.
Being imprisoned in a religious matrimonial alliance can have a series of different consequences: from feeling hindered from divorcing as a result of moral pressure from the religious community to death threats by the ex-husband and ex-family in law, who don't recognise the divorce and feel their family honour has been violated. Some women cannot renew their passports without their ex's permission, cannot travel independently or start a new romantic relationship, because that's still considered adultery. Marital imprisonment violates fundamental human rights, argue the researchers.

What are the solutions?
The researchers are proposing a variety of solutions, based on good experiences abroad and many conversations with victims, social organisations, lawyers, healthcare providers and religious leaders. First, prevention works best, so people need to know what they're getting into, and if necessary make agreements about a potential divorce when marrying. Moreover, the researchers provide texts for legislative amendments that make it easier to back out of a religious marriage. But they also recommend that existing laws are implemented more effectively. Indeed, an ex-partner's unwillingness to cooperate in a religious divorce can be viewed as an illegal act. The researchers provide victims and their lawyers with tools to build a successful court case against this kind of refusal. Finally, this is a global problem. The researchers believe that it has to be put on the international agenda and be explicitly mentioned in human rights treatises.

What is the Netherlands doing about it?
In April 2018, Rutten's research led to a discussion in Dutch Parliament. Sander Dekker, minister for legal protection, expressed his great admiration for it, took over part of the recommendations and is preparing a legislative amendment. It proposes that from now on when there is a request for divorce in a civil marriage, the judge can also be asked to order the partner to cooperate in ending the religious marriage. According to research leader Rutten, this proposed legislation doesn't go far enough yet. 'It leaves a group of people unprotected, namely those who have only entered into a religious and not a civil marriage.' Rutten would prefer to see legislation that states that if one of the partners wants to end a religious union, the other partner is obligated to provide his or her 'unconditional and full cooperation'. The minister, however, is reluctant because of freedom of religion. 'That's too easy,' Rutten says. 'This is a social problem, which requires a good solution.' Other members of parliament share this opinion, from GroenLinks, D66, the SP and VVD. Dekker's proposed legislation is now with the Council of State. Rutten is optimistic that if it's dealt with in parliament, then this will lead to more extensive legislation, one that will free everyone from a union that's over.

In the dusty and vast Australian desert, a telescope of Christmas tree antennas is being erected **that will give us a glimpse of the genesis of the universe.** It's an enormous and expensive project, which got off the ground thanks to close international cooperation.

Searching for stars in the desert

What?
Telescope construction.

Why?
This telescope will enable us to look at gravitational waves, the origin of life and the universe after the Big Bang, among other things.

Who?
SKA (Square Kilometre Array) is an international partnership with thirteen countries currently participating.

Where?
SKA is in South Africa and Australia.

Result?
The largest radio telescope in the world.

TEXT: AMANDA VERDONK IMAGES: ICRAR/CURTIN

*In the Dutch climate, a modern trombe wall with phase-changing materials in buildings generates energy savings of about **36** per cent on heating.* ***www.nwo.nl/36***

*The lion's mane jellyfish, or Cyanea capillata, has tentacles measuring **37** metres in length, probably making it the longest animal on Earth.* ***www.nwo.nl/37***

About 380,000 years after the Big Bang, the universe consisted of a kind of mist of neutral hydrogen particles. Astronomers sometimes call this period the Dark Ages. Subsequently, the first stars emerged, which blew away the mist, as it were. How did the process that led from a thick misty soup to (presumably) 1 billion galaxies take place? 'That moment, following the Big Bang, is the holy grail for scientists. If we could measure that, then I guarantee you that there are people who would literally fall of their chairs,' says Pieter Benthem from ASTRON, the Netherlands Institute for Radio Astronomy. He's involved in the design of a gigantic radio telescope in Western Australia. It's not designed as a classic round satellite dish, but a field full of 'Christmas tree antennas': pines 2 metres high enclosed by a round tube. Currently, there's a test field of 512 antennas. The target is to have as many as 130,000. If you link them all together, then they operate as one large telescope.

SKA

Together with the satellite dishes in South Africa, all of these telescopes create the Square Kilometre Array (SKA). The African antennas are responsible for the middle frequencies, while the low frequencies will be detected in Australia. Astronomers are hoping to use this telescope to make a video of the origin of the universe after the Big Bang. The telescopes can detect radio frequencies that were transmitted three billion years ago, and they shed light on the origins of galaxies, black holes and gravitational waves.

More, better, bigger

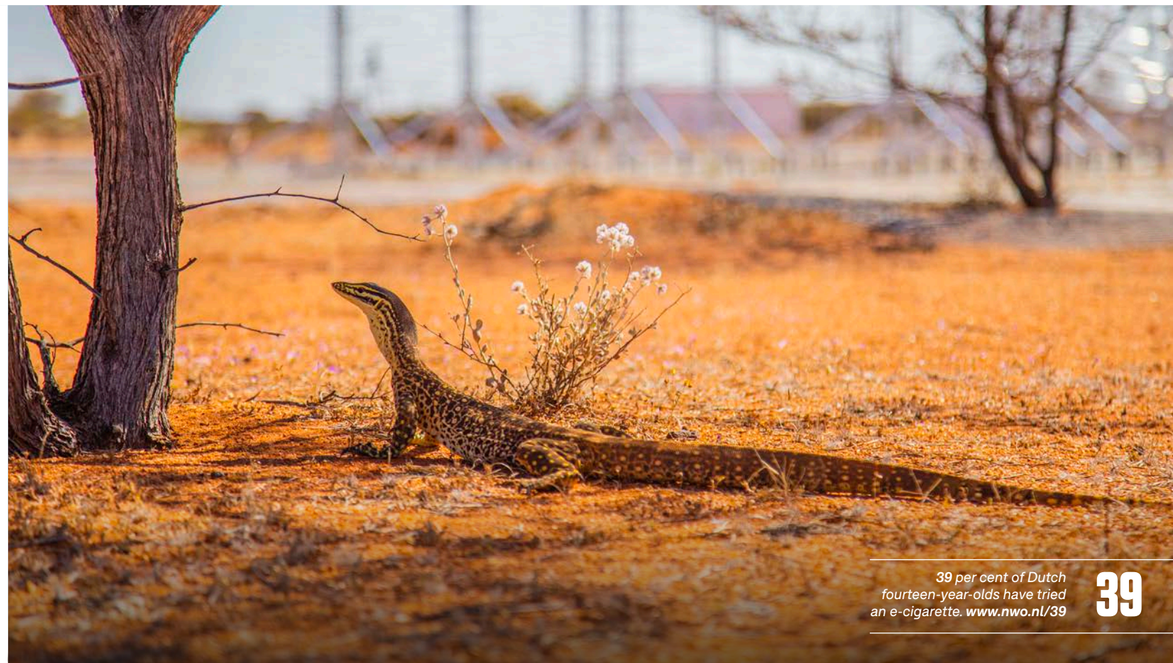
The Netherlands is closely involved in SKA and already has extensive experience with this type of antenna. Indeed, the design is based on ASTRON's Low Frequency Array (LOFAR) telescope, which is situated in the heart of Drenthe. However, more precise measurements can be made at the remote Australian location because there's more space there and barely any frequency interference from radio stations, aeroplanes or telephones, for example. 'In other words: more, better, bigger,' says Benthem. As technical project manager, he directs the international development team that designs the antennas and builds the prototypes. The third prototype is now ready. 'I think we'll need one more round of designing before the antennas are mature enough to be produced in large numbers.' Time is of the essence at this point for Benthem and his team, as construction is set to begin in two years, and the first scientific results are expected a year after that.

Heat sink for supercomputer

In addition to making the radio antennas, ASTRON is also co-developer of a supercomputer that can make specific calculations based on the data derived from the antennas. Eventually the 130,000 antennas will produce as much as a petabyte (1,000 terabytes) of data. Consequently, the computers that have to process these data will have to run full throttle. What's more, they'll generate a great deal of heat and need to be cooled. The technicians have therefore also developed a heat sink which can dissipate more than 95 per cent of the generated heat.

Cold hydrogen clouds

The Christmas tree antennas are in good company: on the SKA site in Australia, there's also a field with 256 spider-shaped antennas. They use the same prototype technology as SKA, and are thus laying down the groundwork, as it were. ASTRON has already had the opportunity to conduct research with it on cold hydrogen clouds near the centre of our Milky Way galaxy. The telescope observed hydrogen clouds at the lowest ever frequency, which are cold and ionised. The extremely cold hydrogen clouds had never been discovered previously. It could be that they delayed the development of stars, in which case that process took longer than you would actually expect. 'A nice result, which simultaneously shows that the technique we've developed seems to be working well,' says Benthem.



Water level

With a quarter of our country beneath the sea level, 'water' is an ultra-Dutch research topic.

Flood disasters

The history of the Netherlands is inextricably linked to disastrous flooding. There was the St Elizabeth's Flood of 1421, the Christmas Flood of 1717 and of course the North Sea Flood of 1953. A team of historians and literary experts studied how these disasters were portrayed by the media through the centuries. The battle against water is considered an important part of Dutch identity. 'The stories and images emphasise the solidarity and resilience in difficult times,' says research leader Lotte Jensen. 'That says a great deal about how Dutch people perceive themselves.'

Water also plays an important role in the climate. The Netherlands is a global expert in both areas.

Meltwater

The ice in Greenland is melting faster now than at any other point in the past 350 years, according to a group of researchers form the US, Belgium and the Netherlands. The melting of the icecaps began to pick up pace at the start of industrialisation in the mid-nineteenth century and has now reached the fastest rate in the past three centuries. The melting process accelerated in the 21st century in particular, and as a result Greenland's meltwater is now a major contributor to the global rise in the sea level.

IMAGE: WWW.NOAA.GOV/

ASTRON's Aperitif receiver can map a part of the skies that's 40 times the size of a full moon in a single observation. ***www.nwo.nl/40***

An experiment with 40 mothers and 41 fathers reveals that when fathers display fear, their babies become more scared than when their mothers display fearful behaviour. ***www.nwo.nl/41***

Water channel

Researchers at Deltares built a wave flume three hundred metres long, 9.5 metres deep and five metres wide. They planted willows in it and subsequently had extremely powerful waves of water flow through it. That allowed them to measure how well trees can break waves. In 2001, research in the Noordwaard Polder in the province of Brabant had already demonstrated that strategically placed willows had helped to reduce the size of waves by at least sixty per cent. As a result, a dike didn't need to be raised as much as originally planned. The researchers are now examining whether these results are more widely applicable. Incidentally, scientists from all over the world can use the wave flume for their experiments.

IMAGE: MARCO DE SWART

Water protection

A natural way of protecting the coast, that's the idea behind the Sand Motor. Waves, winds and currents are gradually spreading the sand of the peninsula built near Ter Heijde in 2011 to the coast to protect it from the water. The Dutch concept has now been repeated in Norfolk in Britain, where rapid coastal erosion was threatening two villages and a gas terminal. This summer, a small version of the Sand Motor was built there, using 1.8 m^3 of sand (in terms of size, comparable to the football stadium De Kuip in Rotterdam). It's expected to provide protection to the coastal area for fifteen to twenty years.

IMAGE: RIJKSWATERSTAAT / JOOP VAN HOUDT

42 per cent of the microplastics that end up in European seas through sewers consist of car tires. ***www.nwo.nl/42***

*Every year, about **43** thousand people suffer from a stroke. Of the people that survive a stroke, one third will have another stroke and die within five years.* ***www.nwo.nl/43***

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CONCEPT AND DESIGN: Studio Room / Durk.com

PHOTOGRAPHY: Sander van den Bosch, Florian Braakman, Bob Eshuis,
Joop van Houdt, ICRAR/Curtin, Jan van de Kam, Aziza Saud al Adhubi,
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This is a publication of the Dutch Research Council
ISSN: 2666-5840