On two continents, scientists are racing to crack one of the universe’s unsolved mysteries.

Their goal: to prove whether DARK MATTER exists.

By Hazel Muir. Photography: Andrew Hetherington
Dark matter. You can’t see it, but hypothetically it’s everywhere. It passes through coffee cups, walls and your body. The consensus among cosmologists is that dark matter is a by-product of the big bang, and comprises 85 per cent of the matter of the universe. Yet no one knows what it’s made of – and there’s no proof that it even exists. Now rival research teams are racing to find evidence of the uncapturable. WIRED joins the cosmic detectives at work on both sides of the Atlantic.

It’s 7:30am on a cold April morning in northern Minnesota, the state’s vast frozen lakes just starting to melt. A small crowd is gathering at the head-frame above a mineshaft. We put on hard hats then squeeze into the rust-coloured “cage”, an old lift that once carried iron-ore miners half a mile underground to hammer away at the seams. Then we descend into the underworld.

The rickety cage rattles downward, the electric hoist screeching and whining overhead. It’s pitch black, the darkness broken just occasionally by the fleeting glow of a passing light in the shaft. After nearly three claustrophobic minutes it’s a relief to hear the engine’s roar subside. The lift comes to a halt and we emerge into a tunnel, where a sign tells us we’re on the Soudan mine’s 27th level, 2,341 feet below the surface.

More than a century ago, men earned their trade down here by candlelight, mining the iron ore that fuelled an industrial revolution. But they abandoned this maze of tunnels in the 1960s. Today it’s physicists who journey down here each day to look for an elusive quarry of their own – invisible particles new to science. These modern miners are looking for “dark matter”, clouds of invisible particles left over from the big bang that created the universe.

A scientific consensus has emerged that dark matter makes up more than 80 per cent of all the matter in the entire universe. What it’s actually made of, nobody knows. But dark matter might not keep its identity secret much longer. In mines around the world and deep within mountains, teams are now racing to snare the beast in strange traps built from vats of liquid xenon, ultrapure germanium crystals and lead from medieval roofs (it’s less radioactive, so is better for screening out background particles).

Two of these experiments are the clear front-runners: the Cryogenic Dark Matter Search (CDMS) here in the Soudan mine, and XENON100, tucked under a mountain in central Italy. This year, both projects have scaled up their experiments to make them more sensitive to dark matter, which both hope to nail within 12 months. “Next year will be an exciting one,” says Elena Aprile, team leader for XENON100. “Hopefully we’ll have a first result by early 2010 – there’s a lot of expectation as to what will happen.”

There’s a big prize at stake. Whoever wins the race will crack one of nature’s most exasperating cryptic codes and plug some gaping holes in our grasp of how the universe evolved.

The dark matter problem has an embarrassingly long history that dates back to the 1930s. The first person to mention it was Fritz Zwicky, a brilliant and eccentric Swiss-American astronomer working at the California Institute of Technology. Zwicky noticed something very odd in 1933 when he measured the speeds of galaxies milling around in the Coma cluster, a group of hundreds of galaxies close together in the northern sky.

The galaxies were all moving under the influence of each other’s gravitational pull. But Zwicky found that they were moving unexpectedly fast – as though being pulled by the gravity of something huge and invisible. His observations seemed to make sense only if vast amounts of unseen “cold dark matter” were holding the galaxy cluster together.
Around the same time, Horace Babcock at the University of California noticed the problem too. He measured star speeds in the Andromeda galaxy – the nearest giant galaxy to our own Milky Way – and found that too, it should fly apart were it not glued together by the gravity of invisible matter telescopes can’t see. But these new observations failed to gain ground, perhaps partly because few astronomers warmed to Zwicky. He came up with many wild ideas – such as using fusion power to rearrange the solar system’s planets – and was notoriously abrasive, referring to his colleagues in print as “scatterbrains” and “sycophants”. In his 2002 book The Extravagant Universe, Harvard astronomer Robert Kirshner recalls Zwicky’s fastness for calling his adversaries “spherical bastards” – because they resembled bastards from every angle.

Zwicky’s provocative idea gathered dust until Jeremiah Ostriker and Jim Peebles at Princeton University came to the same conclusion. In 1974, they published a report highlighting a startling conundrum – there was evidence that many galaxies, perhaps all of them, are much heavier than their visible stars would imply. “That produced quite a stir – everyone thought it was crazy,” says Ostriker. But as precise observations of galaxies rolled in, gradually more and more astronomers became convinced. Theory backed the idea, too. Calculations showed that dark matter must have existed from the dawn of time, its gravity choreographing the collapse of normal matter into galaxies of stars. Without it, our galaxy the Milky Way, the Sun, planet Earth – none would exist.

There are some dissenters, however. In 1981, physicist Mordabhi Milgrom from the Weizmann Institute in Rehovot, Israel, suggested an alternative to dark matter which he called modified Newtonian dynamics (MOND). Perhaps the force of gravity in the outskirts of galaxies becomes stronger than Isaac Newton’s theory suggests; that would explain why the stars there orbit faster, without any need for exotic dark matter.

The trouble is that no one has come up with a one-size-fits-all MOND theory that explains all astronomical observations simultaneously. “It’s tremendous to have a competing theory because the best scientific work takes place when it’s driven by competition,” says Rick Gaitskell, from Brown University in Providence, Rhode Island, who has worked on dark matter experiments for two decades. “Unfortunately for MOND, it’s not panning out well. It has huge difficulty explaining some astrophysical data.”

Today the vast majority of scientists believe in dark matter, says Ostriker: “There are now so many completely independent arguments that all point to dark matter – it’s just overwhelming.”

Observations of the motions of stars and galaxies, together with theories about how the universe evolved from its origins in the big bang, all point to the same picture. Around 15 per cent of matter is “normal” – the atoms that make up everything familiar such as stars, planets, ants of baked beans. The rest is dark matter. It forms a vast invisible web throughout space in which galaxies of shining stars are embedded, like lights on a Christmas tree.

Our own galaxy hypothetically sits in a huge cloud of dark matter that extends well beyond the Milky Way’s visible stars. Estimates suggest that locally, a cube of space as wide as our solar system contains something like 900,000 billion tonnes of it.

It’s deeply enigmatic stuff. Dark matter isn’t dark in the sense that a forest is dark on a moonless night. Shine a torch on a tree, and you’ll see the leaves glow green in reflected light. The trees are also emitting plenty of light – a warm infrared glow that you can’t see. But no torches or night-vision goggles could reveal dark matter. It’s profoundly invisible and neither emits nor reflects light.

So what is it? Frankly, nobody knows. “There are multiple theories about what it might be, but theory is a slippery beast,” says Dan Bauer from Fermilab, a US government physics lab near Chicago, and project manager for the CDMS experiment. One popular bet, though, is that dark matter is made of “weakly interacting massive particles” or WIMPs.

WIMPs are beguiling because they could solve another problem at the same time. Physicists are keen to marry theories of quantum mechanics and gravity into one neat single theory, and one possible way of doing this is via so-called supersymmetry. This theory doubles the number of possible particles in the universe by giving every familiar particle in nature, like the electron or a photon of light, an as-yet-undiscovered partner. One of them – the lightest “neutralino” – is a WIMP that’s heavy and stable just like all the dark matter. Could they be the same thing?

Favoured mass estimates for this neutralino are 50 to 1,000 times as heavy as the proton found in an atomic nucleus. Experiments at accelerator laboratories such as CERN on the French-Swiss border should already have manufactured them if they were lighter than 50 protons.

If the neutralino is more than about 1,000 times as heavy as a proton, supersymmetry theories stop working.

So far there’s not a shred of experimental evidence for neutralinos or any other supersparticles. “What we would dearly like is some indication that the theory is right by actually detecting some of this family of supersymmetric particles,” says Gaitskell. “We’ve been wanting this as a Christmas present for decades now, but we’re yet to see one.”

The trouble is that WIMPs are too devilish to catch. They don’t carry any electric charge, which means they don’t “feel” normal matter and breeze straight through it without stopping. A gale of dark matter constantly blows right through the Earth. It floods through everything – your house, your sock drawer and your body.

So how on earth can you trap something as slippery as a WIMP?

Back in the 1980s, Bernard Sadoulet at the University of California, Berkeley, came up with a cunning plan. He reasoned that scientists might be able to sense a WIMP passing through chilled ultrapure wafers of the element germanium, already developed for the semiconductor industry. Most WIMPs would fly straight through a germanium crystal. But occasionally, though sheer luck, a WIMP might bump a germanium nucleus, making it rattle around. This would liberate a tiny amount of heat that cutting-edge sensors could pick up on the germanium’s surface.

From 1996, Sadoulet’s team tested this technology in a tunnel under Stanford University in an experiment called the Cryogenic Dark Matter Search. The trouble was that the detectors also registered cosmic rays, particles from space that constantly bombard the Earth’s atmosphere. Sadoulet’s detector was never going to sense a WIMP amid this cacophony of background noise.

The logical solution was to relocate the entire experiment deep underground, where everyting rock would block most cosmic rays but let the slippery WIMPs pass through. So in 2003, the CDMS experiment moved to a laboratory in the Soudan mine in Minnesota, whose deepest level is nearly half a mile underground.

The mine employed around 1,800 miners during its heyday in the 1890s but closed in 1962, when it became cheaper to extract iron from poorer ores closer to the surface.

Scientists saw the mine as an opportunity. Down at its 27th level, the cosmic rays raining down from space are slashed by a factor of 100,000. So around 1980, the University of Minnesota established a laboratory there to house all kinds of experiments that need to hide from cosmic-ray interference.

Nearly 100,000 tonnes of rock were excavated to build the lab, a pair of huge caverns more than 70 metres long. Hauling the rock}

‘It’s considerably more difficult than finding a particular grain of sand in the Sahara’

Top: Elena Aprile and XENON100’s cooling system. Middle: A tunnel in Gran Sasso. Bottom: the door to the cavern housing Soudan’s CDMS experiment

Dan Bauer in the airlock, where citizen clothes are covered with white “bunny suits” before anyone can enter the detector room.

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It would be easy to forget you’re underground, until you see the cavern’s concrete–sprayed walls dotted with little brown lumps. They’re bats, mostly dead. Thousands of them inhabit the upper levels of the mine, but down here they seem to dehydrate and die before they can find a way out.

The CDMS experiment sits in the lab’s second cavern, housed inside a “clean room” that aims to keep the detector dust-free as possible. Although the rock above the lab screens out most cosmic rays, the experiment must be kept as dust-free as possible. If a particle bumps inside the detector, that would be bad.”

We’ll find them within five years’ time if these critical particles escape. It will be enormously surprising if these normal background particles as possible. If a particle bumps through a xenon nucleus, it can emit a brief flash of light and liberate electrons. Sensitive detectors measure these signals in both xenon liquid and gas.

Sensitive detectors on the crystal surfaces measure tiny vibrations when a particle comes in and bumps a nucleus. They also measure any electric charge liberated by any particle that disturbs electron clouds around the nuclei. Computers analyse the signals to distinguish an exotic WIMP from run-of-the-mill background particles, which include ordinary, mundane particles like an electron.

From 2006, Aprilie’s team ran a smaller dark matter detector here with 1.1lbs of target xenon, but detected no unambiguous footprints of a WIMP. They’ve scaled the target mass up to 143lbs to improve their chances – the bigger the detector, the more likely it is that a passing WIMP will leave its mark.

Aprilie hopes to start gathering data with the upgraded experiment before the end of this year and analyse the first results early next year. Catching a WIMP would be the highlight of a lifetime, she says. “I would feel like it was worth all the pain, giving up time with my daughters, living such a screwed-up life and not sleeping,” she says. “You have to be a bit crazy to do this because it really takes 200 per cent.”
The man was Raymond Davis, a physicist at Brookhaven National Laboratory in New York State. His work formed part of a long-run effort to detect neutrinos: a tiny amount of energy just went missing. “You have to show that you can put together detectors and making them do that things that haven’t been done before - that’s the fascinating part. Do think about the problems of dark matter on a daily basis? Not necessarily.”

There is certainly no financial incentive. True, the technologies used to hunt dark matter might eventually have useful spin-offs for medical scanners or suchlike. But no one can think of any direct benefit of dark matter itself. Its innate slipperiness makes it untraceable. Even if some by miracle you could build some amazing consumer product using dark matter, it would immediately ruin the fun of the whole game, for the centre of the Earth is the most challenging place to build. None-the-less, they plan to upgrade from 11lbs of target to 220lbs.

But he was proved right. In 1968, his team announced that they’d detected solar neutrinos for the first time. Davis won a share of the Nobel prize for physics in 2002. The Nobel Foundation described his experiments as “considerably more difficult than finding a pin in a haystack.” And though scientists now understand the cosmos will have been written in its entirety.

Not everyone is quite so optimistic. Asked when he thinks dark matter will be detected, Ostriker is agnostic: “I have no idea,” he says, pointing to a sobering list of limitations. “I have no idea.”

He was the right start last year after an electrical fault, but it should be up and running again by next month. To Block cosmic-ray interference, Davis would have to find.

Most scientists say it’s about curiosity, the thrill of the chase - and healthy competition.

But the theory of the big bang, combined with astronomical observations, suggested that neutrinos are far too lightweight to account for all the dark matter. And they move too fast ever to interact, their properties are similar to those of dark matter. So much so, that some scientists suspected up until the 1990s that neutrinos were dark matter.

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The frustrating thing about that group and the reason why the community gets a little bit upset with them is that they don’t show all of their data,” says Bauer. “If they’re going to make a claim that what they’re seeing is WIMPs, they have a responsibility to show us everything, warts and all. They don’t. We would love to be able to prove once and for all whether DAMA is right, but we can’t without their data.”

To many scientists, the DAMA team seems isolated and lacks the community of other dark matter experiments such as CDMSII should also have detected the WIMP signal. Nobody disputes that DAMA is measuring a real seasonal change in the number of particles triggering their detector. But they could be from some mundane effect below Gran Sasso mountain.

F WIMPs are still a no-show, however, her team plans to scale the experiment up again to a tonne of xenon. This could make her the first person to detect a WIMP.”

In the US, their CDMSII collaborations will unite the as well as. They can only dream of one-tonne-scale crystal detectors, because each detector would take months to build. None-the-less, they plan to upgrade from 11lbs of target to 220lbs. For this “super CDMS” experiment they hope to up-sticks to a lab in Sudbury mine in Canada, an active nickel mine more than a mile underground - so deep that the Earth’s internal heat warms the air to 30°C.

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