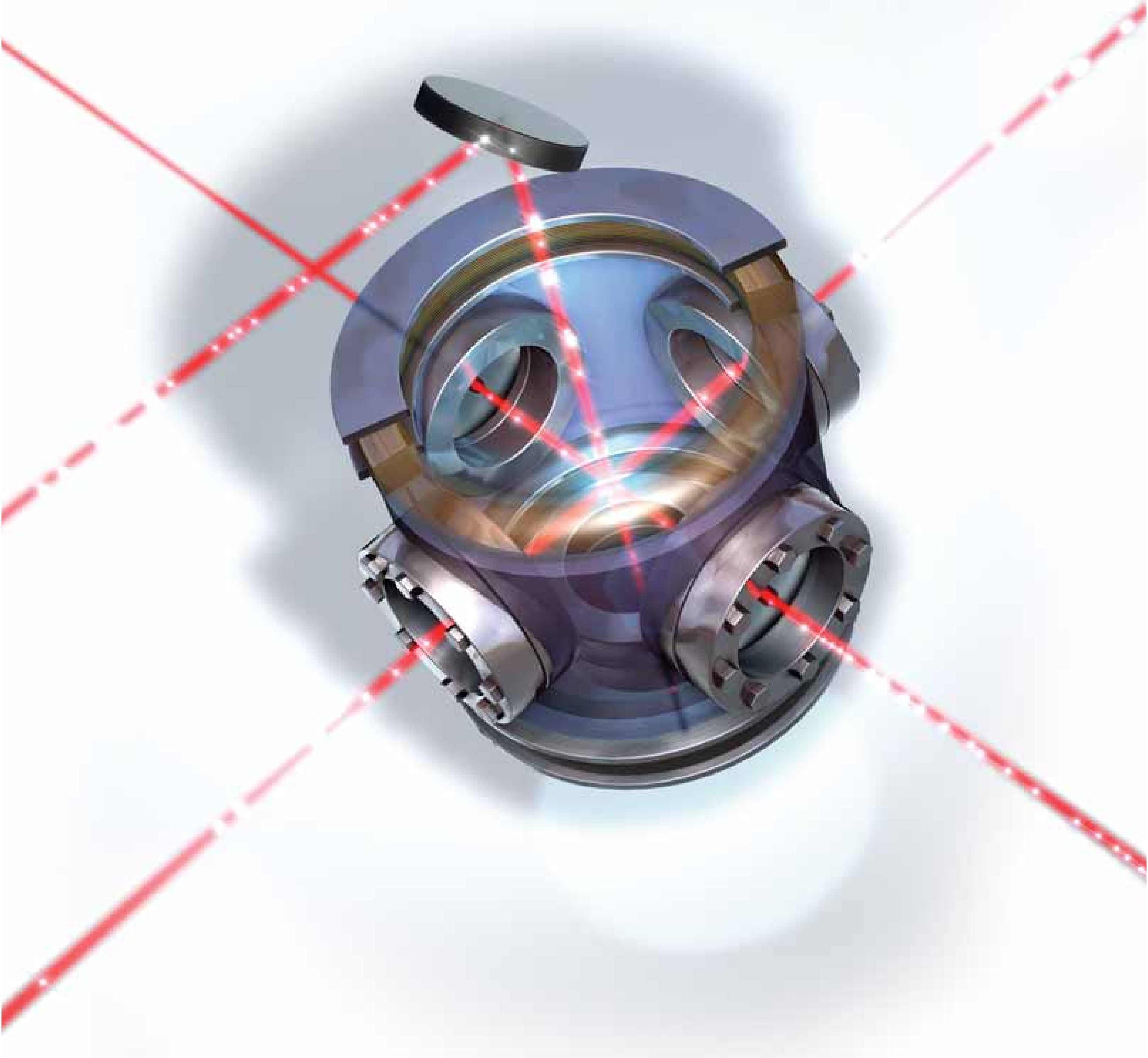
SUPERCOOL



The University of Otago's Ultra-Cold Atoms Group is making waves at the cutting edge of quantum science, a field in which the potential applications defy the imagination.

IN THE SPRING OF 2005, NOBEL LAUREATE PROFESSOR Carl Wieman, of JILA, University of Colorado, spoke to a packed house in the University of Otago's largest lecture theatre. His subject? The Bose-Einstein condensate (BEC), a new state of matter that he created in 1995 in a massive breakthrough that has taken him to the pinnacle of scientific recognition.

After almost a decade of painstaking work, he and his team, including Professor Eric Cornell, had cracked one of science's teasing totems. It had been 70 years since Albert Einstein had predicted that at temperatures just infinitesimally above absolute zero, the laws of quantum mechanics could force matter to take the form of a single quantum wave. Scientists had tried for decades to prove him right – or wrong. Against extremely long odds and working at temperatures of about a millionth of a degree above absolute zero (-273 degrees C), Wieman succeeded in producing a Bose-Einstein condensate. In this new state of matter the counter-intuitive behaviour of the quantum world is magnified a million-fold, enough to be viewed through a microscope.

It was no accident that Wieman was visiting Otago. He was here to work with the University's Ultra-Cold Atoms Group, which has been committed to the field for the last decade. In his lecture Wieman referred to the prominence of the group and the important theorists working in it.

The experimental team, working in a laboratory on the third floor of the University's Physics Building, had been one of the first in the world to duplicate Wieman's achievement. Coming just three years after Wieman's initial discovery, this was a moment of triumph and vindication for head of the Otago Ultra-Cold Atoms Group Professor Rob Ballagh and his colleagues who, three years earlier, had taken a calculated risk.

In 1995 when the Colorado experiment succeeded, Ballagh was on sabbatical and on his way to Oxford University in England. Once there he and experimental physicist Dr Andrew Wilson, an Otago graduate on a postdoctoral fellowship, put their heads together and explored the idea of Bose-Einstein work in Dunedin.

"We could see that it would be a huge challenge. A very high level of technical sophistication was required, and our lab would need a major increase of resources … but it was something we were both hugely excited by.

"We were committed to trying to get some serious world-class physics going in Otago, to doing something that would put us on the map."

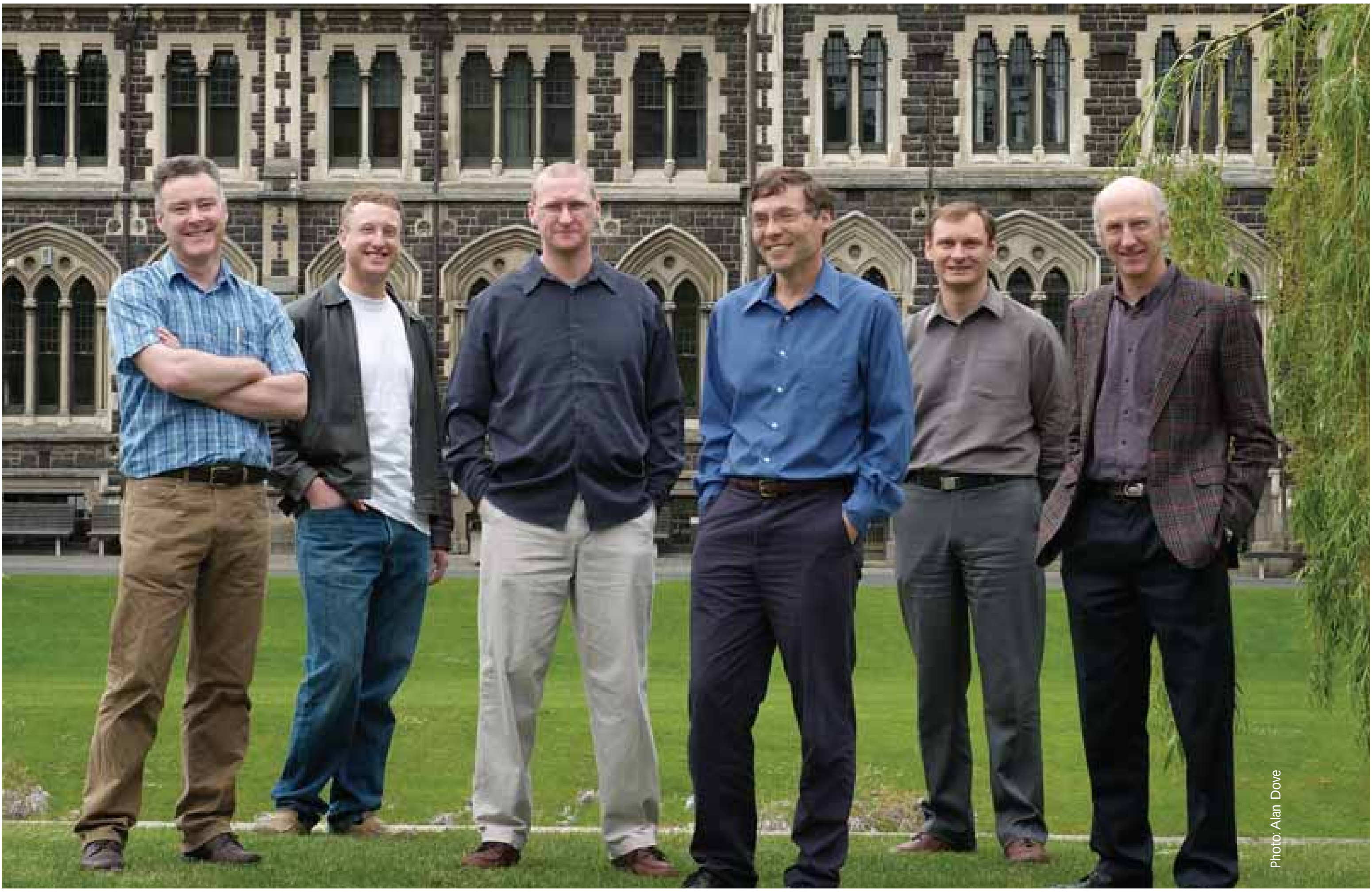
The pair spent six months scheming, writing research grant applications, and treading a path well travelled to the funding agencies.

"There were several factors that came together that were critical to our success," says Ballagh. "The Marsden Fund was established that year with the explicit goal of supporting just this sort of fundamental science. We were awarded our first grants from it in 1996, and our group has now won a total of 12 grants, which has been absolutely crucial."

The then head of department, Wes Sandle, immediately saw the significance of the proposal and put his weight behind it; and the University's research committee was very supportive in the early days when prospects were far from certain.

"They backed us financially at critical times when we would otherwise have fallen over," adds Ballagh.

By the beginning of 1997 Wilson arrived and hit the deck running. "He welded his team together and knew exactly what he had to do, and of course there were ups and downs, but there was also tremendous excitement.



Nobel laureate Professor Carl Wieman visited Otago's Ultra-Cold Atoms Group in October. From left: Associate Professor Andrew Wilson, Dr Warwick Bowen, Dr Murray Barrett, Wieman, Dr Blair Blakie and Professor Rob Ballagh. Absent: Professor Crispin Gardiner, Dr David Hutchinson.

"The theory team was already making an international impact, and the development of the experiment gave a real focus to everything. Every morning tea there would be this huge buzz of enthusiasm."

Ballagh was heading the theory effort, working in collaboration with distinguished theoretical physicist Crispin Gardiner – now Research Professor at Otago, but who at the time was based at Victoria University. "Crispin and I had been publishing work that was at the forefront of the theory and the field was just exploding … it was just a total revolution in atomic physics – a revolution comparable to the invention of the laser."

Ballagh draws on the laser to tease out some of the implications of BEC. "One way to describe ordinary lasers is to say they can provide the most precise control over an optical field that nature is going to allow.

"Now we had this BEC, a very special state of matter, a near-perfect wave, so the question was, could we develop something comparable to the optical laser? Could we do the same with matter as the laser allows us to do with light?"

The Ultra-Cold Atoms Group was entering the exotic new area of coherent atom optics – the counterpart of the usual optics with light. "Matter is a wave and light is a wave, so we should be able to do similar things with them. However, we need to understand how to manipulate matter waves with the equivalent of lenses, mirrors, beam splitters, diffraction gratings, prisms etc. What we are trying to do is achieve coherent control of matter."

What is BEC good for and where might it lead? The prospect of the coherent control of matter throws open possibilities that extend the imagination. One sure bet is super-sensitive gravity interferometers for use in geological/geochemical exploration. It should also lead to vastly improved atomic clocks, a technology that underpins increasingly ubiquitous and sophisticated global-positioning-system navigational aids.

Moving further into the realms of the speculative, atom lasers might be used to revolutionise "nanofabrication", laying down single atom layers in the most intricate of circuits.

Or the science could find practical expression in the development of quantum computing or teleportation, areas that Dr Murray Barrett, a recent appointee in the Ultra-Cold Atoms Group, is working on.

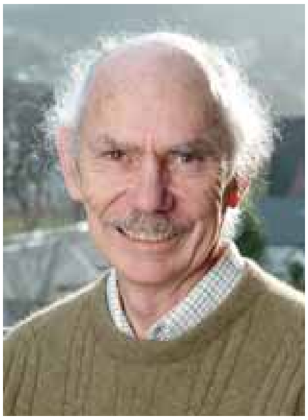
Says Ballagh, sounding a note of caution: "We learnt how to control light coherently 40 years ago. Now we're starting on matter and it could be a much longer path. It could be 30 years, or 50, before anything comes of it."

But that doesn't deter him, nor his colleague Professor Crispin Gardiner.

“You have this new material you can deal with,” Gardiner says. “You may not make a motor car out of it, but you may well make a number of subtle devices that involve things like very sensitive sensors. It’s a whole new field whose practical application is still not clear.”

What is clear is that the rest of the atomic physics world will retain an interest in what’s going on at Otago.

“We are very well known round the world,” says Ballagh. “We were among the first dozen or so establishments to get a condensate. People take a very serious interest in what we are doing. We have had several Nobel prizewinners visit, two in 2005 alone. Our students work in their labs, we work in their labs, they visit us. We work with them on planning international conferences.”



Professor Crispin Gardiner: “It’s a whole new field whose practical application is still not clear.”

In fact, in terms of putting New Zealand science on the map, the University of Otago’s Ultra-Cold Atoms Group would appear to have taken something of a quantum leap.

Useful websites

Ultra-Cold Atoms Group: http://www.physics.otago.ac.nz/research/uca/index.html

BEC Homepage: http://www.colorado.edu/physics/2000/bec/index.html

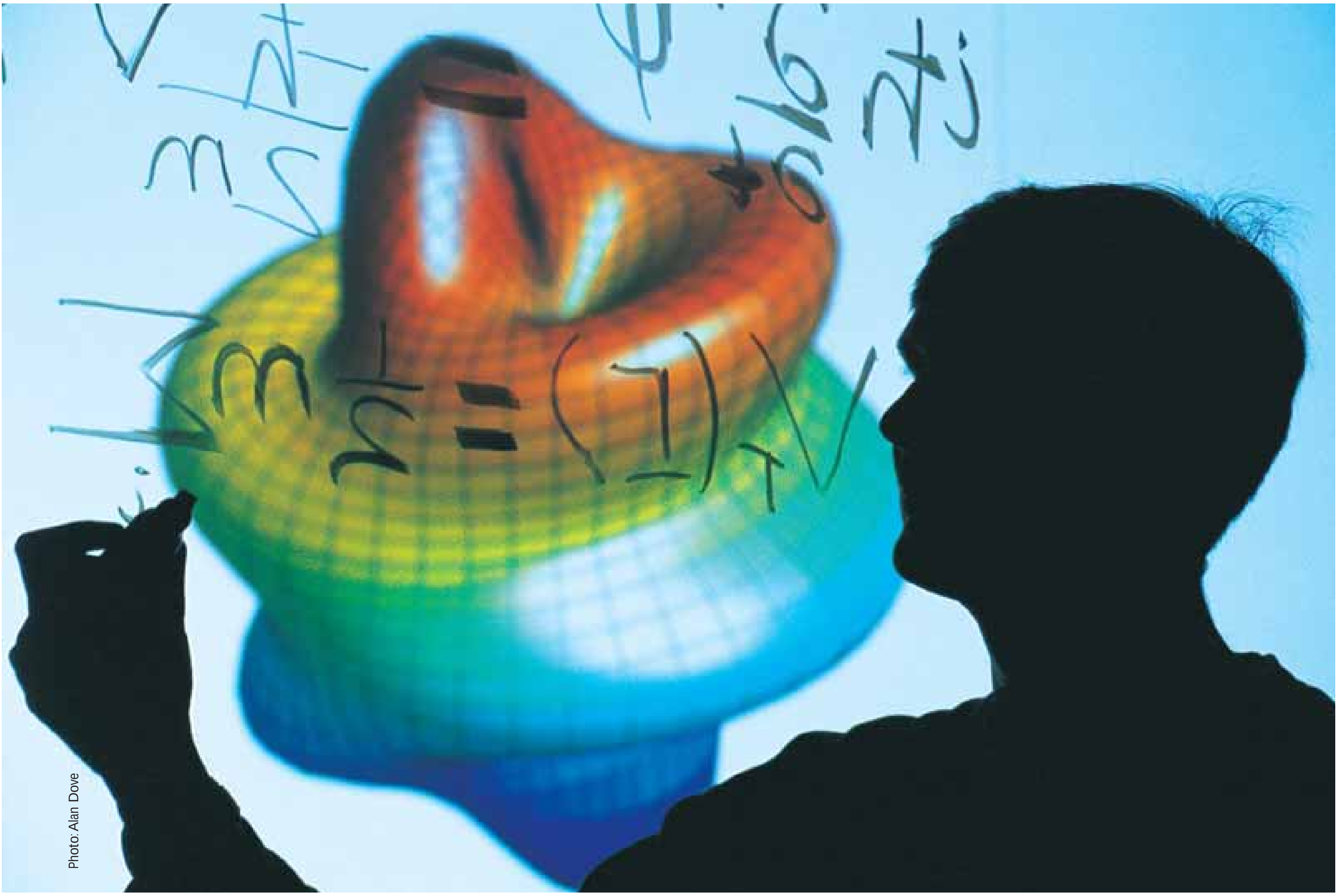


Photo: Alan Dove

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BEC for dummies

WHAT IS IT?

Bose-Einstein condensate (BEC) is a state of matter formed at ultra-cold temperatures when atoms take on quantum properties and form matter waves.

WHEN WAS IT DISCOVERED?

It was predicted by Einstein in 1924 and first produced at JILA in Colorado in 1995 by Professors Carl Wieman and Eric Cornell.

WHEN WAS IT FIRST CREATED IN OTAGO?

August 1998.

WHO WAS BOSE?

Bose was a young Indian physicist who used the new ideas of quantum physics to explain certain behaviours of light. Einstein then postulated what would happen if atoms behaved according to Bose's equations.

HOW IS IT MADE?

With great difficulty! Atoms are held in a vacuum and cooled with laser technology and evaporative cooling to temperatures of less than a millionth of a degree above absolute zero (-273 deg C). Magnetic fields, radiowaves and imaging technology add to the complex array of equipment and techniques required.

HOW SIGNIFICANT IS BEC?

In theoretical terms, very. It confirms yet again the validity of quantum mechanics as a theory.

IN PRACTICAL TERMS?

The jury is still out and it may be some decades before the full implications are worked through. In the meantime, the development of "atom lasers" may give rise to instruments for high precision gravitational and inertial measurements; to improved nanofabrication techniques; to better atomic clocks; and even, possibly, to super-powerful "quantum computers".

WHERE TO NOW?

The vibrant worldwide BEC community is making strides in many directions. One is the drive to produce a condensate of molecules. If successful this could lead to a new field of "superchemisty", where both the reactants and products are coherent quantum fields.

EUREKA!

AUGUST 1998. IT'S A DATE ETCHED INTO ASSOCIATE Professor Andrew Wilson's goal-oriented brain.

"I only remember it because my daughter was born a month or so beforehand and I had a little note up on the fridge that said: 'Get Bose-Einstein condensate' and 'Have family'. Have family came afterwards on the list because I knew things were going to be a bit grim in the lab until we got things to work. Unfortunately the timing didn't quite work."

The baby came first, followed six weeks later by the eureka moment most skeptics had written off as an impossible dream. So even for an experimental physicist described by colleagues as a brilliant organiser, the mistiming was understandable.

Producing Bose-Einstein condensate (BEC), for several decades the holy grail of quantum physics and first achieved a mere three years earlier in the United States, certainly put Otago in the international frame.

Says Wilson: "I had people email me and say: 'Look, we're trying to find the University of Otago, but we can't find the Otago on the New Zealand map. Where the hell is your lab?' "

Anybody who is anybody in the slightly arcane world of cold atoms now knows exactly where the University of Otago is and several leading lights have come to visit.

For all the surprise that such a stunning achievement be realised in a tiny laboratory at the bottom end of the world, there was a certain logic to what Wilson admits was a pretty big gamble.

"I had said to Rob [Professor Rob Ballagh], well, to be honest, I don't think the BEC experiments look all that hard. Well, not hard exactly – they *are* all technically extremely difficult, no doubt about that – but they're the sort of experiments well suited to the New Zealand research environment. You don't need a $3 million machine to make it work and you don't need a team of 50 dedicated full-time salaries …"

Ballagh himself calls the achievement "a triumph of optimism and youth over common sense".

"When you look back, most people would have thought we were absolutely crazy to do this. We just refused to accept that it wasn't going to happen."

"We did our homework," says Wilson. "We didn't presume that we knew how to do this. We presumed it was difficult and we asked lots of questions and looked carefully at what had gone on in Colorado where they had been successful. I think

Making Bose-Einstein condensate at Otago

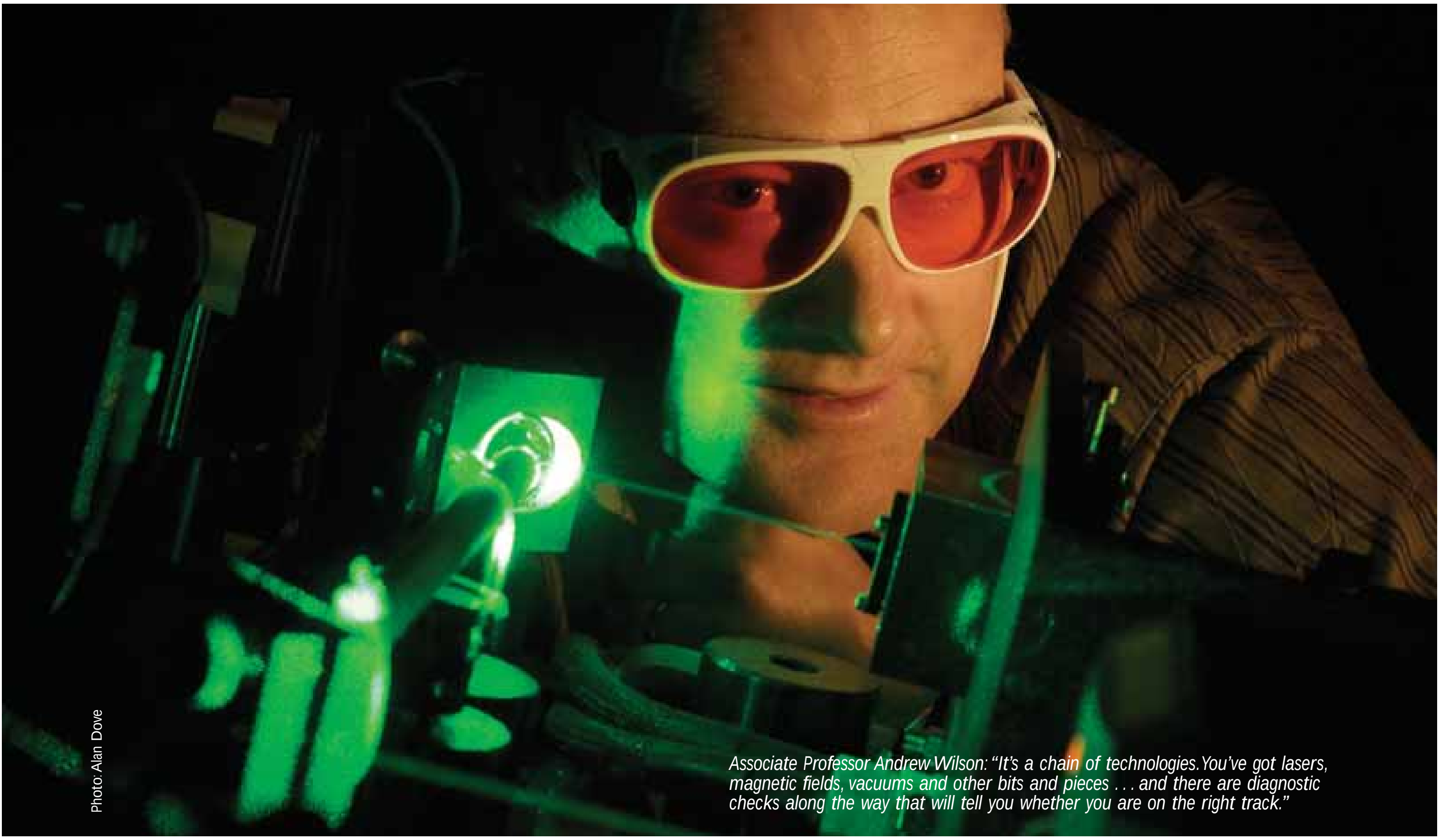

Photo: Alan Dove

Associate Professor Andrew Wilson: "It's a chain of technologies. You've got lasers, magnetic fields, vacuums and other bits and pieces . . . and there are diagnostic checks along the way that will tell you whether you are on the right track."

those guys were geniuses at working out what things matter and what things don't."

Wilson describes the process of building the experiment by analogy to constructing a state-of-the-art racing yacht: component by component, testing each individually along the way, then connecting with other components, testing again and tweaking and so on.

"It's a chain of technologies. You've got lasers, magnetic fields, vacuums and other bits and pieces – radio frequency technology, imaging technology – and there are diagnostic checks along the way that will tell you whether you are on the right track.

"You end up with about 10 different things in a row, all of which have to be working well and working with each other. Then you make tweaks and that's where the problems come in.

"But we knew we just had to get in there and make it work. We knew we were working on something good, and we knew if we could make it work it would make a big difference to ourselves and to Otago.

"Ultimately it was a bet on our own abilities. There were elements of luck, but basically it was just planning … and hard work."

Like a proud dad, Wilson basks momentarily in recollection of the eureka moment; the moment when all the planning and fund-raising and graft and self-belief paid off.

"Yeah, it was pretty amazing, really."

Simon Cunliffe