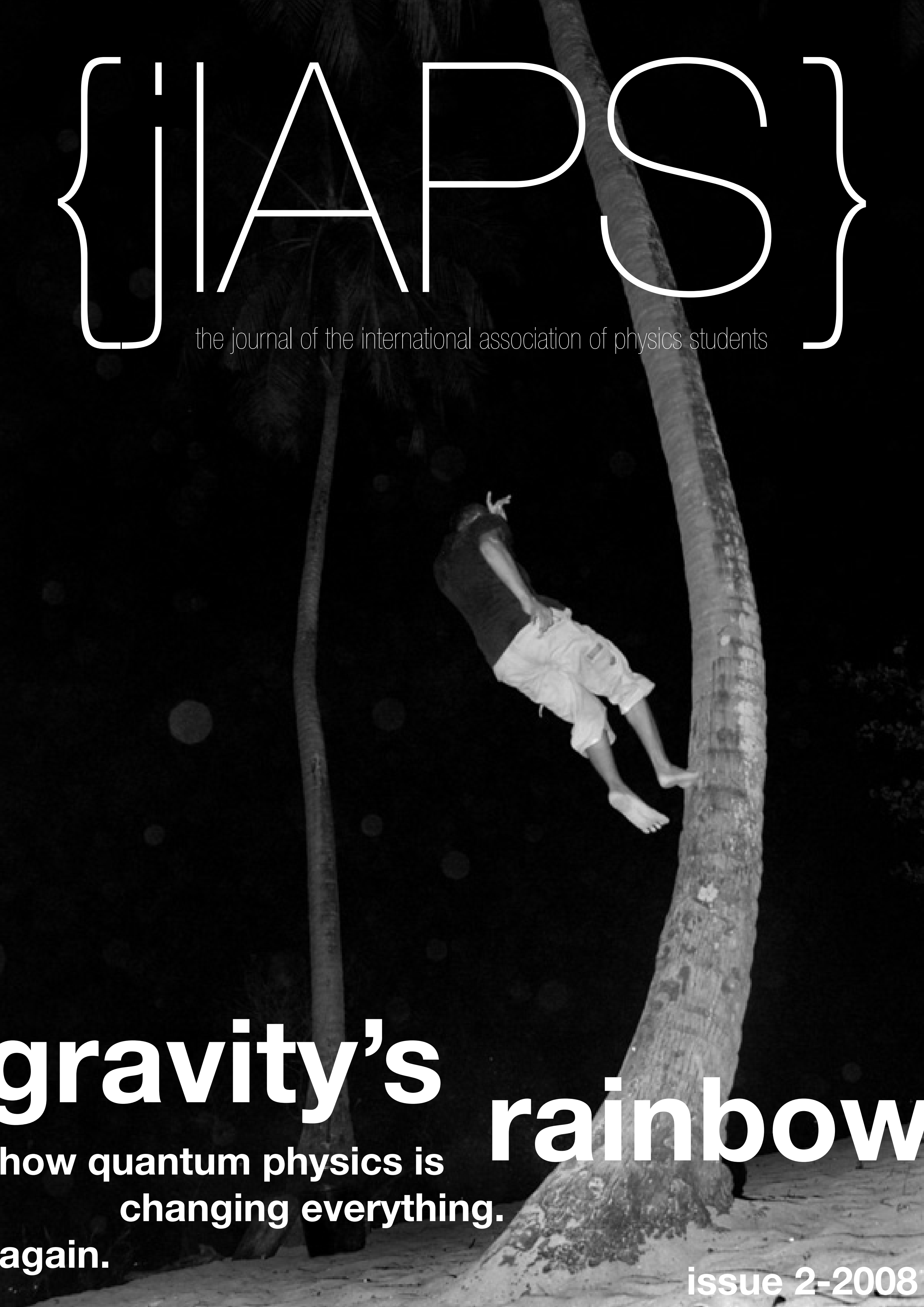

{jIAPS}

the journal of the international association of physics students

gravity's rainbow

how quantum physics is changing everything. again.

issue 2-2008

ISSUE 2-2008

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What is jIAPS?
jIAPS is the journal of the International Association of Physics Students (IAPS). IAPS is an international, non-political, non-governmental, non-profit-making, student-run educational association. It comprises students and recent graduates who are interested in physics (hereafter physics students). Its aims are to encourage physics students in their academic and professional work in an international context, to promote peaceful relations among physics students around the world and to expose them to the international community, help them to build professional relations and foster a collaborative attitude amongst young physicists across the globe.

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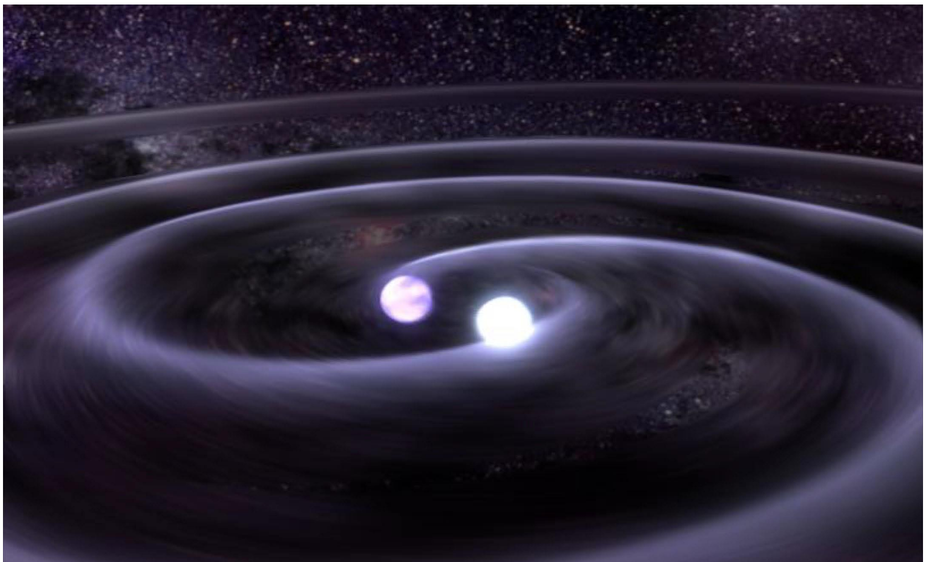

What's in this issue?

REGULARS

FEATURES

THE BIG STORY

the international conference of physics students

ICPS2008

august 2008 | www.icps.agh.edu.pl

A few words from...

the IAPS Executive Committee

IT'S THE TIME OF year when IAPS selects a new committee to continue its work for physics students around the world over the next academic year. The executive committee (EC) is made up of volunteer members of IAPS elected at the AGM. Anyone and everyone is encouraged to stand for election regardless of whether you've never heard of IAPS before or are an old hand, IAPS needs people with all sorts of skills and abilities and there is bound to be a role that suits you.

So who do we actually need? Firstly a president, the chair of the committee.He or she needs to be well organised, an expert at delegating and motivating people. The president calls the meetings, prepares the agenda, represents IAPS to external organisations and has the crucial casting vote. Ideally you'll have some experience of student organisations but most importantly you'll have loads of enthusiasm and a love for everything IAPS stands for.

We also need a treasurer; you'll be in charge of the IAPS bank account and will need to keep accurate records so some experience might be useful. You'll also need to persuade other richer organisations to give us money so we can continue to run events.

The last defined role is secretary, IAPS needs to have records of everything it does so that members know why actions have been taken. The secreatry needs to write up accurate minutes of every meeting and make sure that they go to members.

The rest of the EC need to contain individuals with enthusiasm and a passion for doing things, someone will need to arrange events, keep members up to date about activities, keep track of individual members, communicate with external organisations, run the website, the list is endless. So if you have a passion for communication, love arranging trips, or have plans for world domination via IAPS then please stand for election.

If you want to stand then you can send us (ec@iaps.info) a short piece about yourself and a photo, we'll put them on the website. You don't have to do this, you could, of course, just turn up at the AGM but it would be nice.

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the Editors

WELCOME TO THIS new issue of jIAPS. The journal is under new management; you might notice a few changes around the place. We want to create something worth reading, and so if you have any thoughts on the new look or on the style of articles, then let us know.

We wanted to give the opportunity for our contributors to include some more meaty articles, and so amongst other things that are nestled inside these (virtual) pages, you will find a series of larger, interlinking articles covering the fields of quantum physics and gravitation. If you don't think that you're interested in cosmology or astrophysics, give one of these articles a try and you might just surprise yourself.

Also on the menu in this issue is an interview with the legendary English astronomer Patrick Moore, as well as many other smaller articles and event updates. And if you're still not happy, then you can do something about it! We are always looking for writers, whether you want to write a few hundred words on the physics of the latest blockbuster, or – in the case of Steven Johnston in this issue – write a six page article which challenges the mind as much as it tugs at the imagination. It's up to you. Get in touch.

Euan Monaghan & Danielle Wills

jiaps@iaps.info

In brief

Sao Paulo's private 'ozone layer'

ALL BIG CITIES HAVE air pollution problems. For nearly twenty-million-inhabitants of Greater Sao Paulo, in Brazil, tropospheric ozone and particulate matter are the bad guys. But it's a good thing we have urban parks and leisure areas with "cleaner" air for exercise, right? Surprisingly, it's not quite true. Sometimes, even the other way around. In the biggest city of the Southern Hemisphere, ozone concentration levels inside urban parks and other leisure areas, such as the everyday football pitch, have been reported to be higher than in the car-filled avenues. To make matters worse, they seem to be even higher during weekends.

Ozone is good in the stratosphere, we know that, but at surface level it is highly toxic. It is formed by reactions in the atmosphere that include other pollutants emitted from fossil fuel combustion. These reactions are triggered by solar shortwave radiation. Ozone can also be destroyed by the same kind of compounds, especially in the absence of such radiation. In areas packed with cars it is formed but readily removed from the atmosphere, and doesn't accumulate much. But it seems that when ozone is formed in the avenues, before being consumed it is carried away by the winds. This means that it can reach higher concentration levels in areas with less or no cars. Normally, tropospheric ozone levels are low in the morning, but as cars fill the streets and sunlight hits harder, it stacks up, and by early afternoon it reaches its peak. It then decreases with the lowering sunlight and is consumed by pollutants emitted during the rush hour.

It seems that local variations in atmospheric composition are an important ingredient in this rather ironic picture. But the funny thing is, direct emission levels from car exhausts are decreasing in the city due to improved technology, resulting in cleaner air to breathe in the avenues. Despite this, ozone levels haven't decreased at all. In city parks near the urban centre, vehicular pollution is low, and so, depending on air circulation patterns, ozone can accumulate, especially when convergent air circulation takes place. Greater amounts of sunlight in those often open-air areas can also be blamed. Scientists are still figuring out how to deal with this and the so-called "weekend effect".

"Ozone is good in the stratosphere, we know that, but at surface level it is highly toxic"

So, make sure you check your city's air quality management information before going out jogging in the park. Especially during a sunny Sunday afternoon.

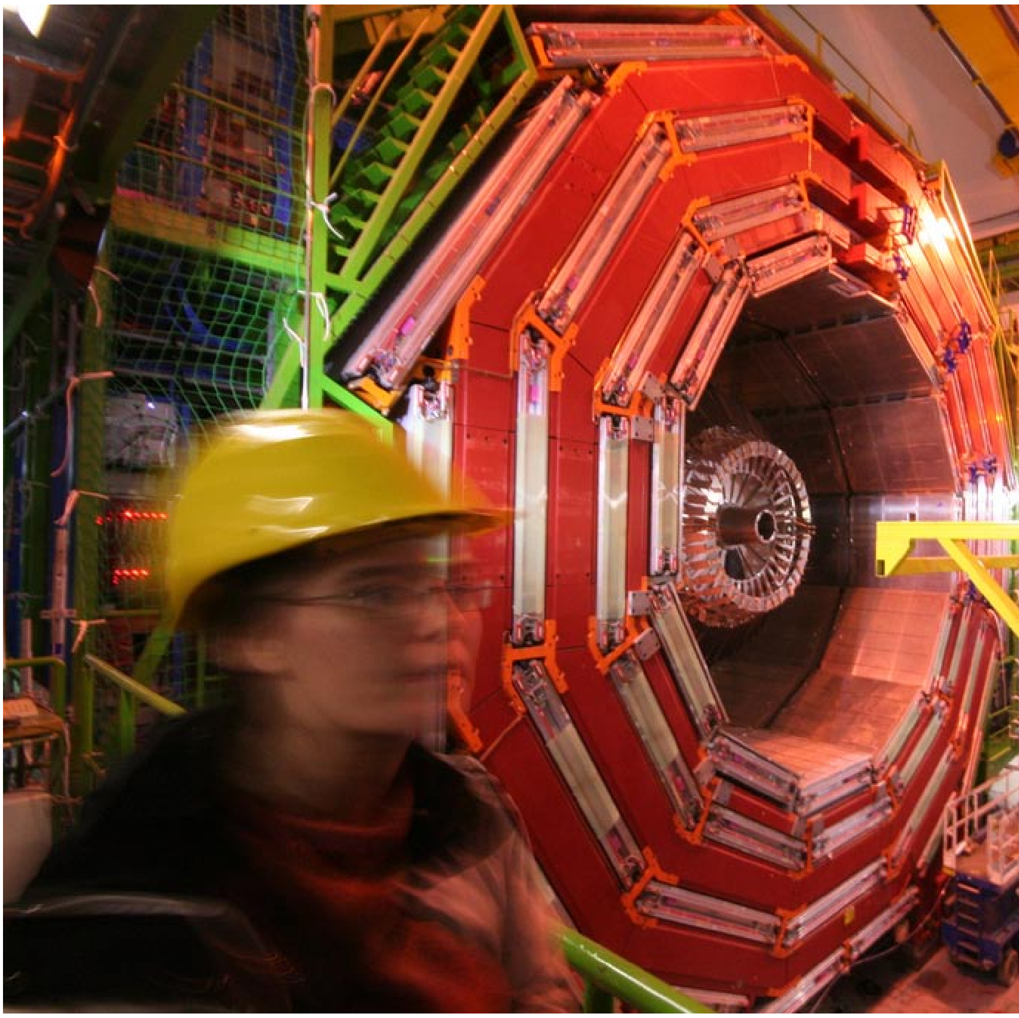
Júlio Barboza Chiquetto

Why the LHC will (almost certainly) not destroy the world

THE LARGE HADRON COLLIDER (LHC) looks like a Bond villain's lair come to life. The gigantic machine lies in a tunnel hundreds of meters under the border between Switzerland and France, forming a circle some 27 km in circumference. In order to look deeper into the fundamental building blocks of the universe, the scientists at the CERN facility will smash together beams of protons at energies approaching 7 TeV. This makes the LHC the most powerful particle accelerator in the world, so it's little wonder that there are some who are critical about its operation. They mostly seem concerned about black holes.

In nature, black holes are created when large stars collapse in on themselves, and even those same scientists at CERN don't discount the possibility that such a singularity would form. However, according to a recent report into the safety of the accelerator, "if microscopic black holes were to be singly produced by colliding the quarks and gluons inside protons, they would also be able to decay into the same types of particles that produced them".

So that's okay then.



Unsung hero: Thomas Young

LAST YEAR A BIOGRAPHY called 'The Last Man Who Knew Everything' hit bookshop shelves. The title was no exaggeration.

Thomas Young was born Somerset, England, in 1773, and from an early age he showed a startling aptitude for languages. By his mid-teens he had mastered Greek and Latin, and was familiar with dozens more tongues, both ancient and modern. It might seem surprising then that he trained in, and practiced medicine for most of his life – proposing the three-colour theory of retina colour detection in the eye among other things. It was in the course of discovering the cause of astigmatism in 1801 that he began to turn his attention to the general study of light. This path of discovery would lead him to make some of the most incredible contributions in the history of science.

Young's name might not have the same weight as his contemporaries like Joseph Fourier or Lord Kelvin, but glance at any physics text and he is virtually guaranteed to pop up at least a couple of times. Some of his main contributions include having the audacity to contradict Newton by proposing a wave theory of light, devising a measure of elasticity (Young's Modulus), and being responsible for the modern definition of the word 'energy'. The list goes on and on. And that's just physics.

Widely regarded as the last true polymath, Young turned his versatile mind to many fields during his 55 years. Young's Temperament is a method of tuning keyboard instruments, Young's Rule is a method for determining drug dosage for children, and the term Indo-European language? Oh, that was him. Languages were always his passion, and by 1814 he had fully deciphered and translated the Rosetta Stone, in the process revolutionising the study of Egyptian hieroglyphics.

Physics was just one of the fields that fascinated Thomas Young. In Westminster Abbey, his epitaph states that he was "a man alike eminent in almost every department of human learning".

Truly the last man who knew everything.

University spotlight: University of Leiden

Founded 1575

Number of students 16,000+

Famous for Leiden Observatory is the oldest astronomy observatory in the world, and it was in Leiden that Einstein received the great news that his theory of relativity had been confirmed.

Famous alumni Hendrik Lorentz and Pieter Zeeman, who were awarded the 1902 Nobel Prize for Physics for their discovery of the Zeeman Effect.

Motto Praesidium Libertatis (Bastion of Freedom)

Research Interests Theoretical Physics, Condensed Matter Physics, Quantum Optics and Quantum Information, Biological Physics, Molecular Nano-Optics and Spins, Astronomy and Cosmology

LEIDEN IS THE BIRTH place of Rembrandt, and home, it would appear, to the perfect Sunday morning croissant. Then for those of us students who don't partake in mornings, there are of course the late-night trains back from Amsterdam or Rotterdam, making Leiden the perfect little rabbit hole for you to bolt down when you are regretting that last coffee shop visit. That's not to say that Leiden isn't itself a bit of a party town – the many bars that line the streets are a testimony to that. Whether fresh flower and trinket markets are your thing, or shopping for hand-stitched corsets at the local goth shop, Leiden has it all. But with all this fun about who would find time for university? Well, luckily for the Leiden students, the University has produced enough world-class physicists to warrant a fair degree of lecture attendance…

The ESA astronaut selection process begins

DID YOU APPLY? The European Space Agency (ESA) began a large-scale astronaut recruitment drive earlier this year, the first for over a decade. Almost 10,000 people applied, and out of that number, 8413 provided the medical and other forms required to pass through to the first stage of the selection process. They are chasing just four vacant astronaut places.

The greatest percentage of candidates came from France (22.1%), followed by Germany (21.4%), Italy (11.0%) and the United Kingdom (9.8%). Women made up just 16% of applicants.

They now face what must be the toughest job application procedure in the world. Over the coming months the applicants will face two rounds of psychological testing, followed by a comprehensive five day medical. Only then, in late spring next year, will a final decision be made by ESA.

"We now have a large number of highly qualified applicants," said Michel Tognini, Head of the European Astronaut Centre in Germany. "I am confident that we will find the outstanding individuals we are looking for. "

For those brave few, the real test will be just beginning.

Events

Where?
Krakow, Poland

When?
6th-13th of August 2008

The International Conference of Physics Students (ICPS) is the annual conference of the International Association of Physics Students. Organised for physics students by physics students.

It is held once a year, and lasts for one week. Each year ICPS is attended by 300-400 students (both undergraduate and postgraduate) from over 30 different countries.

It comprises:

- student and guest lectures
- poster sessions
- excursions to places of scientific, cultural or historical interest, and a guided tour of the host city
- IAPS General Meeting and workshops
- parties, including the Welcome and Farewell Parties, and the National Party. At the National Party, delegates are encouraged to share examples of their national food, drink and entertainment
- It combines lectures given by your fellow students, with international discussion and new friendships. For young researchers it is often the first real international scientific conference and it allows you to gain an experience which will be fruitful in your future career.
- Last but not least it is a week of really great fun!

The conference is open only for members of International Association of Physics Students, but everyone can be a member of IAPS ! First check if any national or local committee of IAPS exists in your country or city. The list of IAPS committees can be found on the website: http://www.iaps.info/organization/members/.

Simposio Nacional de Estudiantes de Física 2008

Where?
Lima, Peru

When?
18th-22th of August 2008

The National Physics Students Symposium (SNEF) is the annual conference of Peruvian Physics students. Topics include: astronomy and astrophysics, geophysics and environmental physics, biophysics, nuclear Physics, medical physics, high energy physics. theoretical physics, condensed matter, nanomateriales, optics, econophysics, soil physics...

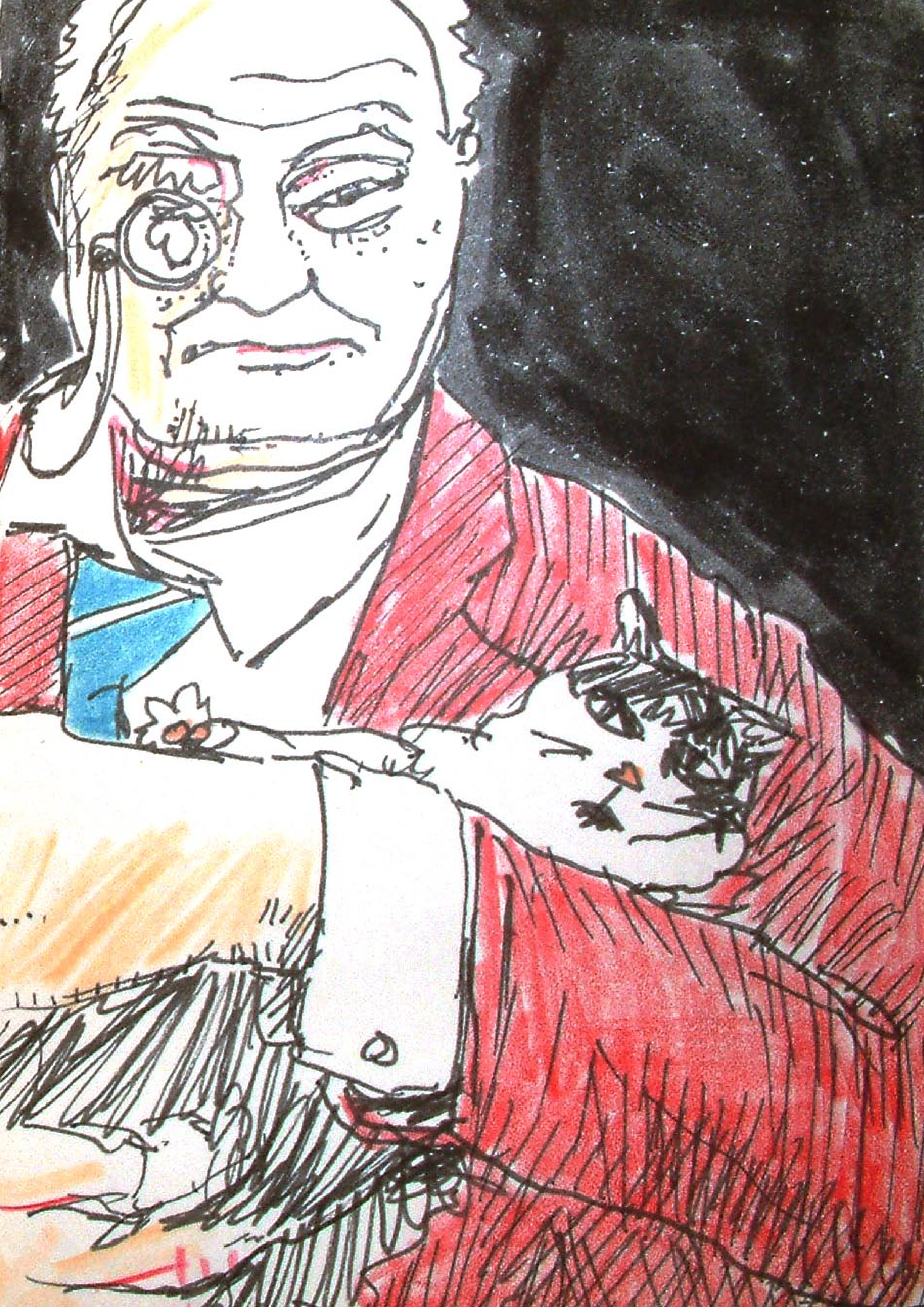
54th International Student Conference

Where?
Tokyo, Japan

When?
31st of August - 12th of September 2008

IAPS members are invited to apply for a places at ISC54. ISC is held annually in Japan, with 30 Japanese and 30 foreign delegates. Delegates are chosen based on an essay (in English) submitted to the organisers. This year's conference is in two parts, starting with a study tour of Osaka, Kyoto, Kobe, Okayama and Kyusyu, followed by the main conference in Tokyo.

For more information and links to all of these conferences, visit **iaps.info**, and click on 'events'.



Interview: Sir Patrick Moore

How did you first become interested in astronomy?
When I was 6 years old, I picked up a small book my mother had, it's over there, called the story of the solar system. I read that book through, beginning to end, and I was fascinated. I was rising 7. It was an adult book and my reading was alright. I was just hooked on it, simple as that. Reading a book.

You were there at the start of the space age. Did the first launch, Sputnik, come as a big shock?
No. We knew the Russians were getting ready to do it. And the Americans could have done it first, but there was inter-service rivalry there, and they didn't take the advice of the one man who could have done it for them, and that was Werner von Braun, the German. When they told him he could get on with it, he had a satellite up in a matter of weeks. He could have done it earlier. I knew von Braun. Interesting, because he was building the V-2 rockets at Peenemunde, used to bombard London, and in 1943, the RAF bombed Peenemunde. A few years later, I was having lunch with Werner von Braun in New York.

How did the launch change public perceptions?
Very markedly I think. People were still saying space travel wouldn't come. And when suddenly Sputnik 1 was buzzing around the Earth, people realised we could send things into space and therefore we could go there. It was a very quick turnaround in public opinion. It was amazingly quick.

If you had to make a prediction back then about where we'd be now, what would you have said?
I got it wrong. I said then, when the first man, Yuri Gagarin, went into space, I said we should have bases on the Moon by 1980. And probably get to Mars by the end of the century. I was wrong there. Arthur Clarke got it right, he said get to the Moon by about 1969. So I was about ten years wrong. Other people got it even more wrong. The space age seems to have slowed down. It has for two reasons. First of all, the Americans put all their faith in the Shuttle. It cost more, took longer to build and had some nasty accidents. That's one thing. And of course when the Soviet Union collapsed, the Russian space programme didn't have the money. It's got to be through co-operatives now, it's got to be done. And of course if we're going to go to Mars, radiation. We don't know yet.

Is it true that the Russians used your Moon maps for their lunar probes?
Yes it is. As you know, the Moon keeps the same face to the Earth all the time. Therefore the edge is very foreshortened. I'd been mapping the edges, called the libration areas. They did use my maps, yes.

At the beginning of the space age, the engineers who were working on the space programme were all very young.
Yes, true, there were a lot of young people. Perfectly true. The German team were very young indeed. Von Braun was hitting it when he was 20.

Do you think it has an impact on how fast things are developed?
Well of course there's all the modern technology now, and resources of whole governments behind you which you hadn't then. Space research was very much a fringe thing, before Sputnik 1.

What do you think has been the single greatest benefit from space exploration so far?
The main thing I think, first of all, international collaboration. That is

happening now. And secondly, of course, space research is bound up with all other sciences. I'll give you an example. A little while ago, I went down to this test thing in the hospital there. It was testing an unborn baby for defects, using equipment developed for use in space. It's all bound up together. These are the main benefits I think.

Is manned flight to the Moon or Mars likely to detract from scientific robotic missions?
I don't think so. They go together. Our unmanned programme in space research has gone on apace. It's gone as quickly as we might have hoped. We've explored all the planets now, got telescopes in space. That's all gone terribly well. It's the manned aspect which seems to have been held up, you see, because of those two things, the shuttle and the Russians running out of money. Nowadays of course there's a new thing, the Chinese and the Japanese are trying too. The Chinese have just launched their first Moon rocket, Chang-e. Once the Chinese come in it's going to move rather quickly.

Do you think there is any willingness in the British government, to put British people into space?
With what our present government is doing, I don't know. I don't think they do, frankly. One day we might have a sensible government but I can't see it yet.

Do you think we will maybe collaborate with the European Space Agency to put people into space?
We are now. There's collaboration now. I'm all for collaboration with the European Space Agency. I want to get out of Europe, because I'm a strong member of UKIP. I want to get right out of Europe.

But we're not signed up to ESA's manned spaceflight programme.
We're all working together. There's no space race now. There could be one between the Americans and the Chinese of course. Dear old Bush has restarted the cold war. There could be a space race there. Not with the Russians any more.

Do you think manned spaceflight would help encourage young people into science careers?
I'm sure it will. After all, the invention is there. Like polar exploration used to be in my grandfather's time. It certainly will. There will be, of course, we should have colonies on the Moon. So far as Mars is concerned, it depends upon two things. First of all, politics. One more war and of course space research goes back to the start. Though if someone stops George W Bush it may help. Secondly, radiation. Once we're beyond the Earth's atmosphere, we are subject to radiation and we are not sure how dangerous it is, and we are not sure how to deal with it. That could be the real holding up point on the voyage to Mars. We're going to be in space, exposed to radiation for months.

What about the psychological issues of putting a small group of people in a confined space for a few years?
Select the right people. It can be done. Select your astronauts very carefully indeed, I quite agree.

You have presented 'The Sky At Night' since it started. How has it changed over the years?
Well the science has changed. The Sky At Night hasn't really changed very much, I've seen to that. The thing about background music, out. What we've tried to do, we've tried to keep people...

A cat enters the room.

Patrick: Jeannie, my black and white cat.

jIAPS: She's lovely.

Patrick: She is lovely.

jIAPS: Who's the other cat in your photographs?

Patrick: That's Ptolemy. Ptolemy's in the garden, two lovely cats. Jeannie is 7, Ptolemy is 2. I've always been very cat-minded.

jIAPS: It's nice to have animals around.

So, with your work on The Sky At Night, have you noticed any changes in the audience's level of education over the years? Are we better or worse now?
No, I think it's about the same. The people know more about space research than they did. There are two things we do. Try and keep people up to date, that's the main thing. And encourage people to take an interest. There are many people who began taking up astronomy by watching The Sky At Night and have become professionals. There are quite a number of those. That makes the programme worthwhile I think.

What's the main challenge of explaining astronomy to non-specialists?
Don't use too many words and don't go on too long I think. That's what I try and do. Whether I succeed I have left to others to judge, that's what I try and do.

Is there any particular area that's more difficult than others?
Yes I think there is. When you come on to beginnings and endings. Beginning of the Universe. We can go right back 13.7 thousand million years to the big bang. How did that happen? Frankly we don't know. Trying to explain that is a difficult matter. And you can't very well understand infinity. You can't put infinity into words people can understand. I can't do it, neither could Einstein. I know because I asked him.

Do the audience show more interest in difficult topics like that?
There's a wide spread of interests, all the way around I think. Certainly is there life elsewhere, is there life on Mars, how did the Universe begin, how will the sun die? We can give some answers, we can't give the full answers. No-one can.

There are some people who say that all astronomy is a waste of money you could spend on more practical things.
There were people long ago who will have objected to the development of the wheel. You always get people like that. You always get the incredibly bone-stupid minority. Solid concrete from the neck up, nothing you can do about it.

When you're doing astronomy, what sort of telescopes do you use?
I originally had my three inch refractor. I've got now, my 15 inch reflector

and my 12-and-a-half inch. Sadly I can't get out there any more. My body has packed up. Old wartime injury in my spine has laid me low.

I'm sorry to hear that.
Can't do anything about that. Infernal nuisance, but there it is.

You don't get out at all to observe?
I can't take any pictures. Other people use my telescopes. That picture of Saturn was taken with my telescope the other day. But I can't do it now, very sadly. I've got old, It suddenly hit me. They said my spine was slipping, it happened when I was 30. It didn't until I was 77. At the age of 77 I played my last game of cricket. And took 6 wickets.

What causes more problems for astronomy here, the weather or the light pollution?
Both. Here of course, we have a lot of cloud, but the best observing sites in the world don't have that problem. I mean go to the VLT site in the Atacama desert, it's clear for 361 days of the year. I think it rains once a century. We have variable weather here. This is not the country for really big telescopes. We have got to admit that. That's why our main telescopes are in places like Hawaii, the Canary Island, where the weather is better.

Have you been to those?
Oh yes, I've been to all of them.

Any favourites?
I like the Lowell observatory in Arizona. I did a lot of work there in my Moon map days. That's my favourite telescope, the Lowell telescope. There are far bigger ones nowadays, but that one I like very much. Hawaii is the most picturesque, so is the Atacama.

What's the most impressive thing you've ever observed yourself with a telescope?
Oh, you've got to see a total eclipse of the Sun. When the Sun goes behind the Moon, the corona flashes out, it's unbelievable. Have you ever seen a solar eclipse?

Yes, I went to Turkey for the last one.
You're lucky, I couldn't go. I've seen 7, but I couldn't go to that one. The only one we had crossing England I was clouded out. The last one I saw was in the China seas. It was great. We had a Norwegian captain who of course got everything right.

We've got new spectral ranges for astronomy being opened up with satellites, we always seem to see something unexpected.
Yes you will, in astronomy always expect the unexpected. That's certainly been demonstrated in our solar system. You get surprise after surprise. The fountains of Enceladus, chemical lakes on Titan. And many more examples. And now this weird comet, Holmes' comet. Unlike any I've ever seen before.

Have you got any prediction for what will be the most interesting area of research to come?
Discovery of life elsewhere. Mars is the key here. No Martians, no little green men. If we find any trace of Martian life, it will show life will appear where it can. That's a very strong point for life being widespread in the Universe. Whether we will find it I don't know. We should know fairly soon.

What do you think of the possibility of life on Europa?
I would say less likely than Mars, on the whole. A sunless sea. Difficult to imagine life appearing there. It could, you never know. You have extremophiles. But I think on the whole, my bet's probably on Mars.

Any specific predictions for the next 50 years or so?
It depends on two things. Politics is one. Getting into space. We'll get more space telescopes, more space observatories. So far as travel to other worlds is concerned, beyond the Moon, it does depend how bad the radiation problem is, if there's any way of combating it. That, to me, is the great unknown. If we can cope with that problem, learn how to survive without wiping each other out, then yes, the possibilities are endless. I know one thing. In 50 years from now, the world won't be the same as it is now. It will either be much better, or much worse. It won't be the same. You will see it, I won't.

Have you got any message to give to young physicists?
Yes, you're living in exciting times.

"You can't put infinity into words people can understand. I can't do it, neither could Einstein. I know because I asked him"

Keep abreast of things and strike out on your own. Don't stick entirely to routine. Do your routine stuff and also look out for your own particular subjects, and see wher you get. You may make any number of amazing discoveries and there is scope for it now. Keep in touch, collaborate with everybody. Look around and also if you find anything interesting, investigate it for all you're worth.

If we could go back to manned spaceflight, or just science policy in general. In terms of encouraging the public to get behind a space programme, I think your programme is very helpful.
We do our best.

All science programmes are probably very good for that. Do you think there is enough science on TV? Could there be more?
You don't want to overdo it. There certainly could be more. I've stopped watching TV quite frankly. I watch the test matches, Wimbledon, the occasional news bulletin, and one superb programme: Yes Minister, superb programme.

Might that be the way to get people interested in science, through the media?
You've got to do it well. It's so easy to make a good subject boring. I remember hearing a lecture, I think it was on Mars, by an astronomer, some years ago, and even I couldn't keep awake. You've got to have people who can put it over. Some can, some can't.

Sometimes a big science documentary gets things wrong. Do you think that causes major problems?
Oh yes, you can easily get things wrong. There have been many, many boobs. There was the American sugar bowl radio telescope. They built this base and when they put the stuff on it the entire thing would collapse. So they filled it in and forgot it. Had magnesium flares in the spectra of late-type stars, couldn't understand this at all. Apparently what it was, someone had just lit a cigarette. It was the match.

I see a picture of you and Brian May there. What do you think of his taste in music?
Brian May is one of my closest friends. I don't like his music, it's not my music at all. He's one of my great friends. He's an astronomer. His degree is in astrophysics and his speciality is in zodiacal dust. That's what his thesis was on.

I heard he recently got his PhD.
He's a very clever astronomer. But his music is not mine.

Multi-talented man.
He is, he's a first class photographer too. One of my closest friends. We wrote a book together, called Bang. Seems to have done well.

He went back into academia, didn't he, after a very long time.
He began doing his thesis. He got his BSc, then began doing his thesis. Then Queen came along. For 30 years, he had to play in the band. And there it was. Five years ago, I said to him, 'look Brian, you're going back to finish your PhD'. He was rather reluctant, I must say, I bullied him and bullied him. So he said 'alright, I will'. He had one bit of luck, his thesis was on zodiacal dust. He'd done original research about 30 years ago. No-one had done much since. Therefore the research he had done, a long time ago, was still absolutely valid. Instead of going right back to the start, he could build on that. And he did so. He's now officially Doctor Brian May,

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"Look around and if you find anything interesting, investigate it for all you're worth"

Did you ever think about going to university after a certain amount of time?
The point is, I had my Cambridge place. I went into the RAF. At the end of the war I came out of the RAF and my Cambridge place was still there. But it meant taking a government grant, that went against the grain. I prefer to stand on my own feet. I thought 'I'll do a bit of writing, and I'll pay my own way through'. The book took off and I never had time.

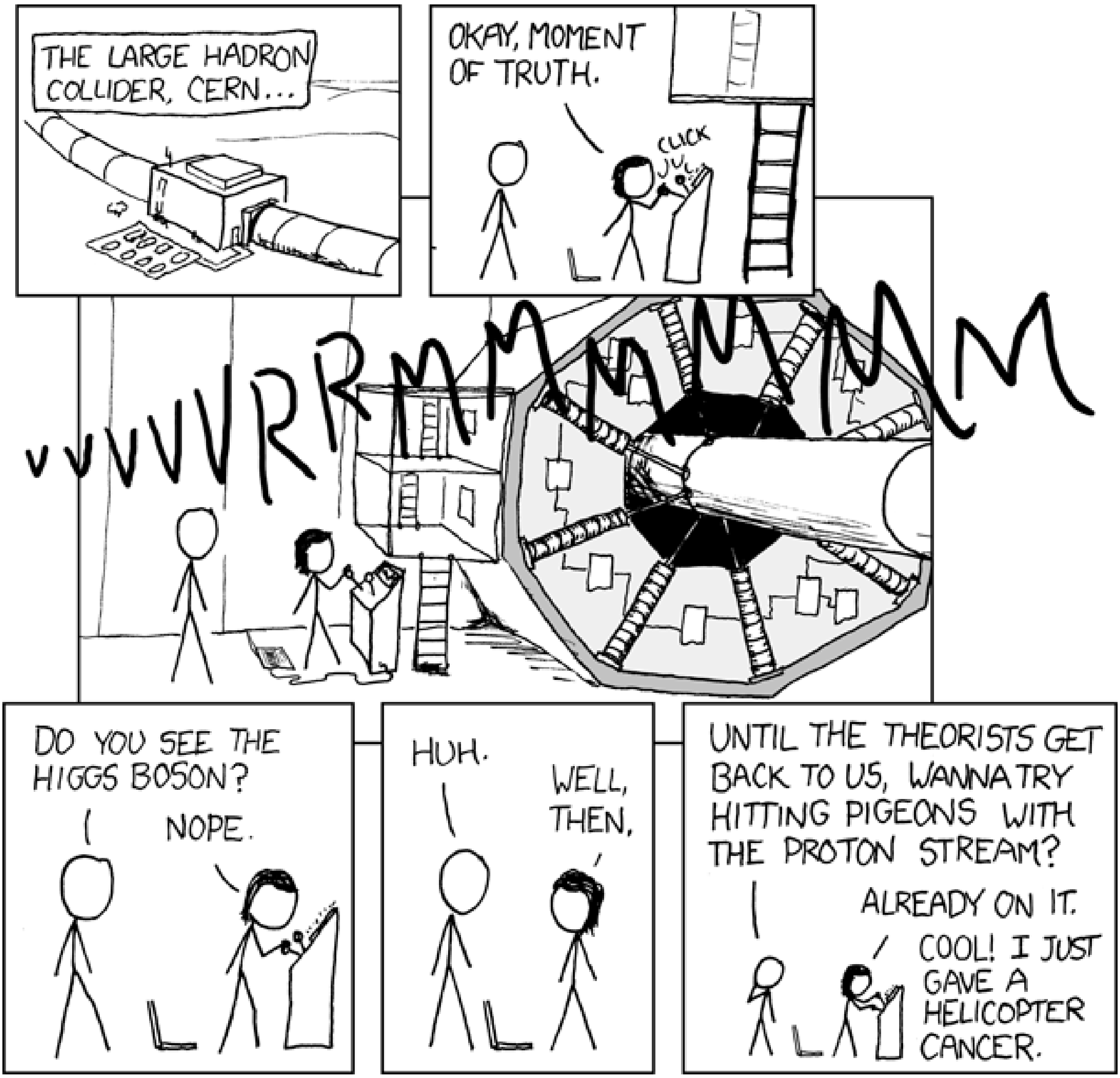
You never looked back?
I never had time! I always meant to do it, I just didn't have time.

I've noticed two typewriters. Which is the famous one you write all your books on?
That's my old Woodstock. Everything since I was 8 years old. I had a good way of teaching myself to type. When I was 8, I picked a book on the Moon. I wanted that book and I wanted it badly. Out of print of course. One copy in the RAS library and a friend of ours was a fellow and managed to borrow it for me. I had a 7,000 word book in my possession for a month. I remember thinking, 'if I type this book out, I'll have the book I want, I'll be able to type and I'll be able to spell'. It worked like a charm. There's a copy up there. By the end I was touch typing. With my two middle fingers I could type 90 words per minute. Now of course it's not so easy, my hands have gone. Damn nuisance.

Patrick was interviewed by Laura Rhian Pickard, Nick Powell and Job van der Zwan

xkcd.com

A WEBCOMIC OF ROMANCE, SARCASM, MATH, AND LANGUAGE.



The Big Story

How sure are you that spacetime is continuous?

Steven Johnston

June 20, 2008

In the 20th century two main pillars of physics were developed. The first of these, the general theory of relativity provides our best description of gravity. The second of these started as quantum mechanics, developed into quantum field theory and culminated, in the 1970s, with the Standard Model—our best description of the electromagnetic, weak and strong fundamental forces. Both these theories are experimentally well-tested but differ greatly from one another in the ideas they use to describe the universe.

General relativity is a completely classical theory in which no quantum mechanical effects are included. It describes gravity as the result of curved spacetime. Quantum field theory (including the Standard Model), by contrast, is a fully quantum mechanical theory of matter but within a fixed, flat spacetime background. In particular no gravitational interactions are included in the Standard Model.

One of the biggest tasks for 21st century physics is to unify these two pillars together: to develop a theory of *quantum gravity*. Physicists working on this are driven by the belief that the universe should be described by *one* physical theory—rather than two which apply in different physical regimes.

Clearly unifying these two pillars is a difficult task. Many clever physicists—including a number of Nobel prize winners—have worked on theories of quantum gravity but, as yet, no consensus has been reached. The difficulty is that the effects of *both* quantum mechanics *and* gravity only become important in physical situations so extreme they cannot currently be produced on Earth—even in the most powerful particle accelerators. This means there is little experimental evidence to lead physicists towards the right theory. This drought of relevant experimental data has let theorist's imaginations run free and many of their quantum gravity theories contain very speculative ideas. Extra dimensions, new symmetries of Nature and a plethora of as-yet-undiscovered particles are amongst the most popular.

Whatever the worth of these ideas it seems likely that either general relativity or quantum field theory (or both!) will need to be modified before a successful theory of quantum gravity can be obtained. It is worthwhile therefore to look at the basic assumptions that sneak into the theories and see if they can be modified. Here we look at one approach—causal set theory—which questions the assumption that spacetime is continuous.

Continuous or discrete?

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In both general relativity and quantum field theory spacetime is assumed to be continuous. This means that for any point in spacetime there are other points arbitrarily nearby—any finite spacetime region can be subdivided into smaller and smaller parts without limit.

One obvious modification is to take spacetime to be, in some sense, discrete. This would mean that a finite region of spacetime cannot be subdivided arbitrarily many times—that there is, in some sense, a smallest piece of spacetime. There's a variety of motivations for discrete spacetime and we'll look at one from quantum field theory and one from general relativity.

A major obstacle to the development of quantum field theory was the presence of infinities as answers to physical questions. These infinities (or divergences) were eventually side-stepped by the process of renormalisation in which the infinite values were reassigned to unmeasurable quantities while the physical quantities received (experimentally correct) finite values. One can argue that the occurrence of the infinities is due to the theory's use of continuous spacetime. The infinities can be traced back through the calculations to the small-scale behaviour of the theory and their presence may indicate that continuous, infinitely divisible spacetime should not be used.

Within general relativity there are spacetimes with singularities where the laws of physics "break down". The most famous example of a spacetime with a singularity is a black hole. Inside the black hole there is a singularity at which the gravitational forces on an object become infinite. The presence of these singularities possibly indicates that the small-scale theory of spacetime requires modification.

Allowing the *possibility* of discrete spacetime then what's the next step? Just declaring spacetime to be discrete is not enough—the spacetime events would just drop into a pile of formless dust. We need to describe how they fit together, how they acquire structure.

In causal set theory spacetime is discrete and causality is used to define its structure. In particular the causal relations between events in spacetime play a fundamental role. Causality is so important an ingredient that we'll now give a short review of its role in the continuum spacetimes of general relativity. If the review gets too mathematical then don't worry—just concentrate on the ideas.

Spacetime and causality

The special theory of relativity was the first theory to use a unified "space + time = spacetime" description of physics. Its spacetime model is 4-dimensional *Minkowski spacetime* (this was later also used as the background spacetime for quantum field theory).

In general relativity, to include gravity, spacetime is allowed to be curved. The flat Minkowski spacetime is replaced by a general 4-dimensional *Lorentzian manifold* (M, g). Points in the manifold M (spacetime events) correspond to locations in spacetime. At each point in M there exists a tangent space containing the tangent vectors at that point. The Lorentzian[1] metric g is just a map

[1] Lorentzian means that if we write g as a 4×4 matrix then it has 1 positive eigenvalue and 3 negative eigenvalues. Here we're using the $+ - - -$ signature convention.

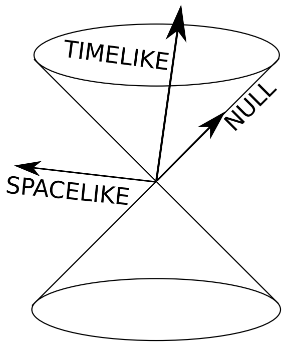

Figure 1: Tangent vectors and the light cone

(linear in each argument) that assigns real numbers to pairs of tangent vectors. With this metric we can classify tangent vectors at a point into three different types. For X a tangent vector we say it is

- Timelike if $g(X,X) > 0$
- Null if $g(X,X) = 0$
- Spacelike if $g(X,X) < 0$

Timelike vectors lie within the point's light cone, null vectors lie on the light cone and spacelike vectors lie outside the light cone.

We will also assume the manifold is *time-orientable*. This means we can consistently choose past and future timelike and null directions everywhere within M. Given a timelike or null tangent vector we can therefore classify it as either past-directed or future-directed.

A *future-directed causal curve* is a curve in M whose tangent vector is always future-directed and either timelike or null. These curves are central to the notion of causality in general relativity. They can be thought of as possible worldlines for a material particle—they take the particle from the past to the future and always stay within their future light cone.

For two spacetime points x and y in M we say "x causally precedes y", written $x \preceq y$, if there exists a future-directed causal curve from x to y. We may also say "x precedes y", "x is to the causal past of y" or "y is to the causal future of x".

If the manifold contains no closed causal curves (that is, curves that travel forward in time, staying within their light cones, but return upon themselves in the past!) then we say the Lorentzian manifold is *causal*. In this case the relation $\preceq$ is a *partial order*. This means it is:

- Reflexive: $x \preceq x$,
- Antisymmetric: $x \preceq y \preceq x$ implies $x = y$,

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- Transitive: $x \preceq y \preceq z$ implies $x \preceq z$,

for all points x,y and z in M.

A causal Lorentzian manifold (M, g) therefore defines a *partially ordered set* (or *poset*). In general a poset is a set together with a partial order defined on pairs of elements from the set. Here the *spacetime poset* is $(M, \preceq)$ with the set of spacetime events M and the partial order $\preceq$.

The partial order $\preceq$ on spacetime points can be contrasted with the total order $\leq$ on the integers. For *any* two integers we can tell if one is greater than or equal to the other: $-1 \leq 2$, $4 \leq 4$ etc. This means $\leq$ is a *total* order. The causal order $\preceq$ on events in spacetime is only a *partial* order because we can only tell if one event precedes another for *some* pairs of events. In particular if no future-directed causal curve can connect two events then it's meaningless to say which is to the causal past or future of the other.

The causal ordering for spacetime events contains a lot of information about the structure of the spacetime. A 1977 theorem by Malament shows that, under appropriate conditions, two Lorentzian manifolds (M, g) and (M', g') with the same causal structure[2] are the same, up to a *conformal factor*. This means 1) the manifolds M and M' are "the same" (i.e. there is a one-to-one, onto map from one to the other) and 2) the metrics g on M and g' on M' differ only by a conformal factor: g and g' are equal up to a rescaling by a positive number which varies from point to point in the manifold.

This fairly technical theorem means that a Lorentzian manifold can be almost uniquely specified by the causal ordering of its events. The word "almost" here refers to the conformal factor that's left unspecified by the causal order. This conformal factor can be related to the spacetime volume assigned to regions of spacetime. Fixing the conformal factor is therefore equivalent to fixing a *volume measure* that assigns non-negative real numbers (i.e. volumes) to regions of spacetime.

The conclusion we can draw is that spacetimes in general relativity may be viewed as a partially ordered set together with a volume measure. From this viewpoint the usual metrical, topological and differential structures of a Lorentzian manifold are secondary to the causal order and volume measure.

Causal sets

Causal set theory throws out the model of spacetime as a continuous Lorentzian manifold. Instead it models spacetime as a *causal set*. As in general relativity this is still a partially ordered set $(C, \preceq)$ but there is a crucial difference. The set (C) still represents spacetime events and the partial order relation $(\preceq)$ still represents the causal order between pairs of events but we now impose a *new* condition that this spacetime poset be *locally finite*.

A poset is locally finite if, for every pair of elements x and y, there are only finitely many elements z causally between them (i.e. finitely many z such that $x \preceq z \preceq y$). It is this condition which introduces *discreteness* into causal set theory.

[2]Meaning there exists a map $f : M \to M'$ such that $x \preceq y$ in M if and only if $f(x) \preceq f(y)$ in M'

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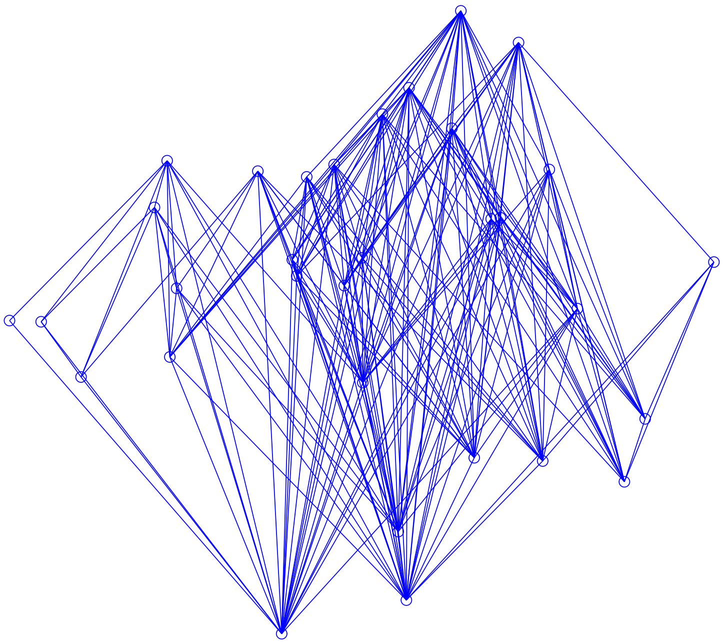

Figure 2: A small causal set drawn as a Hasse diagram. Spacetime events drawn as points and causal relations drawn as lines from lower to higher points.

In the continuum we needed both the causal order and a volume measure to completely specify the structure of spacetime. In a causal set we have the causal order but what about the volume measure? Since the local finiteness ensures a form of discreteness we can simply *count* the number of elements in a region to find its volume. The volume of causal intervals (i.e. all z such that $x \preceq z \preceq y$ for fixed x and y), for example, will always be finite because they contain finitely many elements. We can picture each element in a causal set being assigned a tiny spacetime volume. Counting these tiny volumes up for all elements in a region gives the total volume for the region. For a realistic theory we expect the individual smallest piece of spacetime volume to be of order the Planck 4-volume. The Planck length $\ell_P = \sqrt{G\hbar/c^3}$ is the only quantity with dimensions of length that can be formed from the gravitational constant G, Planck's constant $\hbar$ and the speed of light c. The Planck time $t_P = \sqrt{G\hbar/c^5}$ is similarly the only quantity with dimensions of time it's possible to form. The Planck 4-volume is then $V_P = \ell_P^3 t_P$. It's very small: $V_P \approx 2.2 \times 10^{-148}\text{m}^3\text{s}$. It's this small size that explains why we haven't noticed any spacetime discreteness yet!

At the end of the 19th century most scientists believed matter was continuous. Under a weight of accumulated evidence the theory of continuous matter was thrown out and replaced by the atomic theory of matter. Perhaps the development of quantum gravity will require a similar shift in our understanding of spacetime. If so, causal set theory presents a simple model for discrete spacetime. Hopefully this article has given you a taste of what causal set theory is based on and the review articles listed in the references include more motivations and further references.

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2. Joe Henson, "The causal set approach to quantum gravity", arXiv:gr-qc/0601121

quantum gravity

BACK TO THOSE TWO great pillars of science: quantum mechanics and general relativity.

General relativity is the best description we have for the effects of gravity and the motion of galaxies and other larger structures in our universe. It involves describing time as a dimension in addition to those of space and allowing them to interact. Then gravity acts to stretch and deform this spacetime, changing the paths of moving bodies. This has been tested within our own solar system and has been seen to give better results than the previous laws of Newton. General relativity has also suggested the existence of exotic effects such as black holes and the expansion of the universe, which have since been observed, and also gravitational waves.

Quantum mechanics has been used to make some of the most accurate predictions ever (e.g. magnetic moment of the electron) and is regularly applied in modern technology such as superconductors and photoelectric cells. The rules of quantum mechanics are made for the scale of fundamental particles, however the quantum nature of particles has effects on much greater scales. These scales go up to and beyond the collapse of stars, where the quantum statistics obeyed by the electrons support white dwarf stars against gravitational collapse. The forces between the particles must also be described by quantum mechanics and this has accompanied the uniting of forces which were previously thought to be distinct. There are only four fundamental forces which need to be quantised: gravity; the electromagnetic force which is seen around us; the weak nuclear force which causes the radioactive decay of unstable particle structures; the strong nuclear force responsible for opposing the electromagnetic repulsion within the nucleus and in doing so allowing the creation of atoms. The electric and magnetic forces had been successfully united into one electromagnetic force by the work of James Clerk Maxwell, over 35 years before the introduction of quantum mechanics. This was later united with the weak nuclear force and the strong nuclear force into a single unified theory called the standard model.

Gravity is, as yet, not included in a coherent theory with these other forces, making this unification the target of much research. The unification of gravity will require it to be quantised, as the other forces have been observed to be. Quantised gravity has prompted new avenues of research and new descriptions of our universe.

A leading avenue of research is called string theory and it is being studied greatly in modern physics. String theory starts with the suggestion that fundamental particles, such as the electron, are not particles like points or even small balls, but instead they are strings with a length but no thickness. This in itself aids many of the theoretical difficulties associated with quantum mechanics, where calculations with point particles produced infinities. These could already be overcome within the mathematical calculations, but made adequate physical interpretations hard to come by and difficult to justify or explain. Having strings with a length avoids many of these problems. Having these quantised strings also necessarily introduces the gravity of general relativity. This is a remarkable post-diction (predicting an effect after it has been observed) and is in itself great incentive to study string theory further. String theory however brings new problems but also new opportunities for experimentation.

With time, string theory was revised and improved over many years to become superstring theory. The changes resolved some problems but also introduced new difficulties. Superstring theory involves the addition of fermionic particles (particles with half-integer spin), which are essential for a description of our universe, as fermionic particles do exist. The addition of fermions leads to multiple theories, which differ in the properties of their strings. Such differences include whether the strings are open (have ends) or closed (form loops), and whether they are chiral (they look the same in a mirror). Having multiple theories and not knowing which to choose is a difficulty, but one which was overcome. Between these different theories dualities were found, which showed that any theory could be changed to any other. This means that there are not five theories, but one which we can write in five different ways. Unifying the theories was a great triumph of the so called "second superstring revolution". However not all problems have been overcome and some predictions of string theory are highly controversial and not easy to accept. A notable example is the prediction of extra dimensions.

String theories require that the number of dimensions is a very specific value and that it is not the four that we experience (three space, one time). The number of dimensions of superstring theory has to be ten. Explaining why we do not see these extra dimensions is an additional challenge to string theorists, however showing they do exist with experiments would be a big benefit to the study of string theory. One suggestion as to why we have not seen the extra dimensions is the possibility that they are inaccessible to us. This implies that we are confined to a four dimensional "brane" within the ten dimensional "bulk" and the particles and the forces (besides gravity) are not permitted to leave the brane.

"Quantised gravity has prompted new avenues of research and new descriptions of our universe"

Another possibility is that the extra six dimensions are freely accessible to us but that they have gone unnoticed because they are extremely small. We call these dimensions compact.

The compact dimensions must take some shape and the range of shapes they can take is limited to a number, albeit a large number. We call one class of these shapes Calabi Yau manifolds. Each of these manifolds can be stretched and skewed to look very different but still have the same shape. We describe the extent of this stretching with numbers we call moduli. The range of possible shapes and sizes the extra dimensions can take makes it very hard to find any more predictions using string theory

The effects of string theory depend greatly upon the Calabi Yau manifold used and since we do not know which to use for our universe we can not predict what properties particles in our universe will have. But we need to make predictions in order to decide whether string theories are correct. Just as we justified general relativity by its predictions for the solar system, and quantum mechanics using its predictions for the small particles, string theory must also make predictions. We must either find predictions of string theory which do not depend on the shape and size of the other dimensions or justify the choice of one Calabi Yau manifold over all others. One way to select a shape is by using its potential. Just as rain water will run from wherever it lands, through valleys towards the sea, so we expect the universe to change from whatever its starting shape is to the shape with the lowest potential, provided there is a valley (a path) it can move along. The existence of such a path is not a given however, and finding one requires that changes of shape, as well as size, be permitted. A possible method of finding a path between shapes involves taking one of the sizes, called moduli, as far as it can go and then just a bit further. This may result in the shape being changed as new holes are torn in the manifold. One example of such a change is called a conifold transition. If such transitions are possible then we predict that, whatever the starting Calabi Yau manifold, the extra dimensions will eventually tend to the manifold with minimum potential. Such tearing of our dimensions sounds disastrous, but it may not be; if the manifold reseals in a new shape as quickly as it tears then the transition will not be a catastrophic event but will happen smoothly. However other problems may work to prevent this process.

Taking the moduli to their extreme values means putting a lot of energy into a very small region of a very small dimension. We have already said that string theories necessarily include gravity and so this gravity must be taken into account. Such energy concentration may result in black holes being formed since the high energy density acts like a big mass in a very small region, meeting the requirement for black hole formation. If a black hole is formed all around the point of transition, then whether or not the transition occurs is no longer significant, as the black hole will prevent its effects from affecting anything outside. Establishing whether or not black holes form is a necessity in deciding whether the conifold transitions are a plausible solution to the problems of predictions in string theory. This requires the use of computer simulations to see if the moduli can be taken to their extreme values, while at the same time avoiding black holes. Based on current and ongoing research it seems that the creation of black holes is unavoidable and that this method will not be the one which shows string theory can make predictions. The black holes themselves are of great interest since they are black holes with some compact dimensions. These are known as Kaluza-Klein black holes after the people who used the compact extra dimensions to mimic the electromagnetic force.

Without conifold transitions to test string theory, other predictions must be sought. Superstring theory requires supersymmetry. This is a symmetry which pairs each fermionic particle to a new bosonic particle (a particle with integer spin), for instance the electron is paired to a new selectron. This symmetry can be tested by looking for the partner particles in accelerators. Finding supersymmetry is plausible within the next few years and, while it would not prove string theory correct, it would be a positive step. Finding extra dimensions would also be a big plus for string theory, but again not a proof. Such discoveries and others could be possible within large, high-energy particle accelerators. The most notable of these is the LHC (Large Hadron Collider) currently being constructed at CERN by cooperation of many European countries. Its very high energy may allow for creation of the exotic particles of supersymmetry or even the discovery of extra dimensions. The LHC is due to be started this year and its discoveries are eagerly awaited by particle physicists.

Neil Butcher

gravity waves

GENERAL RELATIVITY MODELS GRAVITY as a distortion of space-time caused by the presence of massive objects – stars, planets, black holes, galaxies and the like. If we place a small test mass, say an asteroid, near a massive object like a star, the asteroid will experience a force pulling it towards the star, due to the way space-time curves near the star. So when the star moves, or the amount of mass it contains changes suddenly such as in a supernovae explosion, there will be a change in the force felt by the asteroid. We expect the effect of this change to propagate outwards through the action of a force carrier – the ‘graviton’ or gravitational wave.

Gravitational waves are transverse waves which travel at the speed of light in a vacuum, and propagate as a deformation of space-time. Unlike electromagnetic waves however, which propagate largely as dipole radiation, gravitational waves travel as quadrupole radiation. This form of radiation can be understood as the wave oscillating in two spatial dimensions while travelling in a third: space-time is stretched in one transverse direction and compressed in the other. Then the first becomes compressed and the second stretched, and so on. There are two possible polarisations, the ‘+’ polarisation having the direction of stretching and squeezing at 45 degrees to the ‘x’ polarisation.

As the wave propagates, the time it takes for a photon to travel between two points changes. The distance as measured by a co-ordinate system does not change, as the co-ordinate labels move along with space-time. However, light travel-time between two points can be used to measure the passage of a gravitational wave.

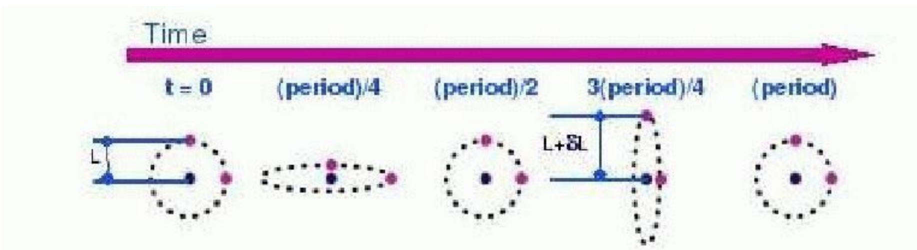
What then are the sources of gravitational waves? Gravitational waves are expected from any asymmetric, moving mass distribution. This includes clusters of objects and systems involving two or more stars, as well as explosions such as gamma ray bursts.

In the case of binary systems, gravitational wave emission is expected to be detectable from systems involving white dwarfs, neutron stars and black holes. As two stars (or black holes) orbit each other, they are observed to gradually move closer together. In order to do this, they must be losing energy. This is expected to occur by emission of gravitational waves and is seen as indirect evidence of their existence. A direct measurement of gravitational waves from such a system would help to constrain parameters such as the masses involved, separation and eccentricity of the binary system.

Such systems involving white dwarfs or neutron stars are expected to be common and easily detectable with future gravitational wave equipment. We also expect to see gravitational waves as a star falls into a black hole, or as two black holes merge. This could be particularly important in understanding the creation of supermassive black holes when two galaxies collide.

Violent cosmic events such as supernovae and gamma ray bursts are also expected to have associated bursts of gravitational radiation. Gamma ray bursts, whether from a collision of two neutron stars or a ‘hypernova’ at the end of a very massive star’s life, are energetic events and detectable by their electromagnetic emission. Positional association of known gamma ray bursts with the gravitational waves detected in a given area should give some indication of the gravitational wave emission from a given event. Bursts of gravitational radiation may also be caused by instabilities in low-mass X-ray binaries. It has even been theorised that, should cosmic strings exist, they may involve cusps of high mass whose movement could be seen through gravitational radiation.

In terms of diffuse radiation, relic gravitational radiation from the Big Bang (analogous to the cosmic microwave background) is expected to be detectable. Originating from 10^{-22} seconds after the Big Bang, compared to 10^{12} seconds for the cosmic microwave background, the gravitational wave background is expected to be a great source of



A description of the polarisation states of gravitational waves information about the early universe. All measurements will, however, have to deal with a background from unresolved astrophysical sources. Modelling the expected emission from common types of sources, such as white dwarf binaries, could help to filter these signals.

Currently there are two methods for detecting gravitational waves, each sensitive to different frequencies such that emission from different classes of sources may be detected. At the time of writing, neither of these methods has in fact shown conclusive evidence for direct detection of gravitational waves.

The first of these methods involves 'resonant bars'. A resonant bar is essentially a massive suspended bar that is deformed slightly when a gravitational wave passes through it. If the bar is vibrating at a resonant frequency, the gravitational wave can be detected as a deviation from that resonance. The bar is usually cooled to suppress thermal noise, most operating between 0.1 K and 5 K. The acoustic signal from the bar can be amplified and measured. There are numerous such experiments in existence, all with slightly different frequency bands, but most have a peak sensitivity at 1 kHz and a bandwidth 10-50 Hz. Current detectors include ALLEGRO (USA), ALTAIR (Italy), AURIGA (Italy), EXPLORER (Switzerland), NAUTILUS (Italy) and NIOBE (Australia).

The second method involves the use of interferometers. In a Michelson interferometer, light from a monochromatic source (usually a laser) is split into two beams. These pass along arms at right angles to each other and are reflected back and then recombined. This gives an interference pattern, dependant on the wavelength of the light and the relative lengths of the arms, which is detected at a photodiode. When a gravitational waves passes through such a system, one arm will be compressed while the other is stretched, and this change in relative arm length causes a change in the interference pattern as seen at the photodiode. Ground based interferometers have arms many kilometres in length. Current detectors include LIGO (USA), VIRGO (Italy), GEO600 (Germany), AIGO (Australia) and TAMA3000 (Japan).

As a gravitational wave passes through the Earth, these interferometers will each be at a different angle to the wave, so will measure different changes in arm length. Combining measurements should help to accurately determine the source position and the polarisation of the wave.

Ground based detectors are carefully designed to minimise noise, but are still subject to false signals. Seismic waves passing through the area can produce noise, along with thermal expansion and contraction of the apparatus suspending the test masses. There is also photon shot noise – basically a statistical fluctuation – from the photodiode which is used to detect the interference pattern. These noise sources constrain the frequencies at which the interferometer should be able to detect gravitational waves. LIGO and similar ground based interferometers are most sensitive to frequencies in the 0.1 – 1 kHz range. The LIGO detector should be able to measure a fractional change in arm length of 10^{-21} m.

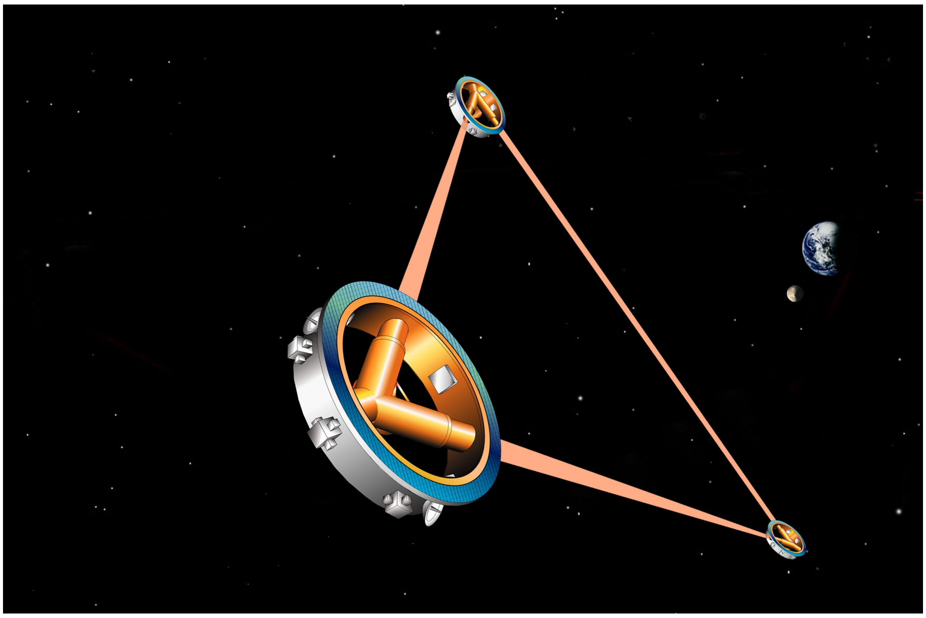
In addition to ground based detectors, NASA and ESA are planning to launch a space based gravitational wave detector by 2018 – the Laser Interferometer Space Antenna (LISA). LISA will consist of three spacecraft flying in formation, with laser beams between each of the spacecraft forming 'arms' analogous to those in a Michelson interferometer, with laser light from any two spacecraft interfering at the third.

Each laser 'arm' will be 5×10^9 m long. LISA is expected to be able to detect changes in arm length of 10^{-11} m, and should detect gravitational waves in the 0.1 – 100 mHz band and will thus detect very different sources to those observed by ground based detectors. Due to its sensitivity to a different frequency range, LISA can be used in conjunction with ground based detectors to give a full picture of the gravitational wave universe. Of course, there may be other sources at any frequency that are as yet unknown.

The three spacecraft will orbit the Sun 20° behind the Earth, gradually changing their orientation as they do so. This should allow them to detect gravitational waves from different sources at different points in the orbit and pinpoint their locations. A technology demonstration mission, LISA Pathfinder, is expected to be launched in 2009.

Gravitational wave astronomy is a comparatively new field, with technology only now approaching the stage where direct detection becomes possible. Data from gravitational wave detectors could lead to progress in areas which are not yet fully understood. Perhaps more importantly, it may prove to be an opportunity to test the very fundamentals of physics through the discovery of new and unexpected phenomena in the universe.

Laura Rhian Pickard



The LISA spacecraft cluster

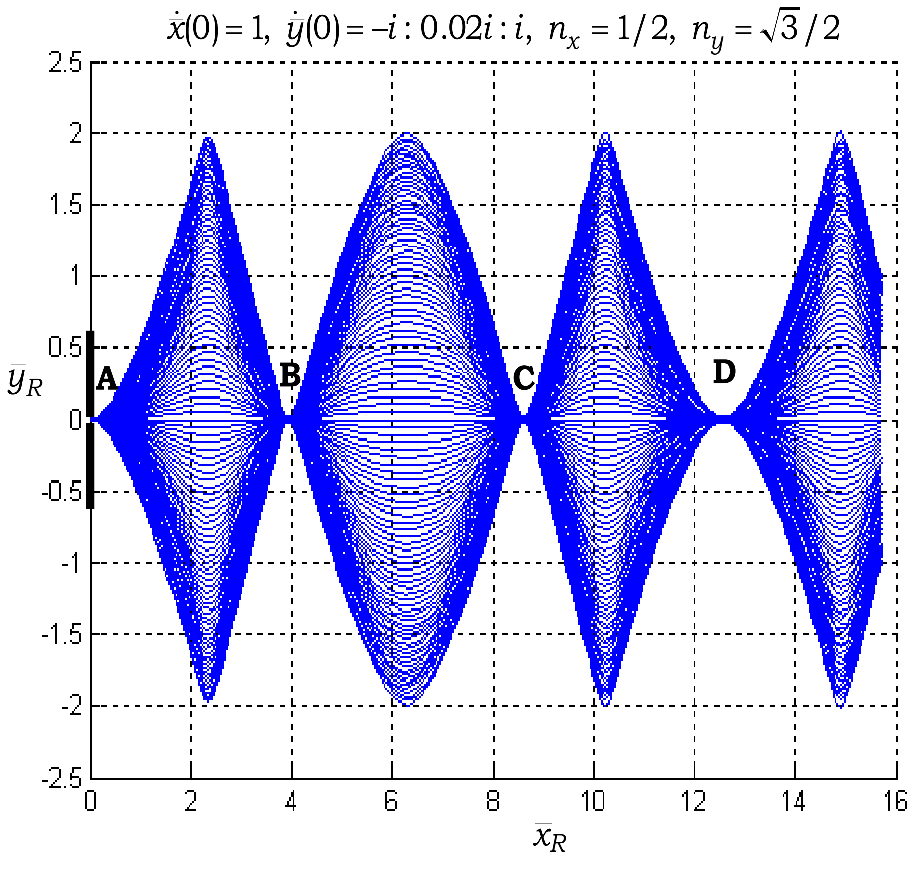
A note on the following article: due to its non-deterministic nature, the completeness of quantum mechanics has been queried since its beginning. Various eminent physicists, including Einstein and more recently Gerard 't Hooft, have tried to come up with more satisfactory theories. However, none of these have yet been accepted by the scientific community. What follows is a possible solution to an open question. - The Editors

THE NATURE OF THE MICROSCOPIC WORLD BEHIND QUANTUM MECHANICS

GOING DOWN TO THE atomic scale, the behavior of a particle becomes very unpredictable. Quantum mechanics is better at describing microscopic properties than classical mechanics. It gives us the most precise and successful numerical predictions in the history of science. But realists have pointed out a conradiction arising from quantum mehanics. It is certain that the probabilistic interpretation goes against the law of causality, and is unable to describe the fundamental physical processes of the universe. According to quantum mechanics, measurements of some properties, a particle's momentum for example, can yield a range of possible results with varying probabilities. In other words, the objective physical process once taken for granted by physicists - the existence of definite properties that suitable observations can reveal - doesn't apply to the microscopic world.

The greatest conceptual difficulties of quantum mechanics are those that come from the violation of causality. These compelling results unearth the incompleteness of quantum mechanics as revealed by the EPR experiment[1] and the double-slit experiment, where the former lies in the our awareness of definite position and momentum at the same time, and the latter shows the wave-particle duality, which is the most unusual character of quantum particles. Moreover, this is just the start of the battle to uncover the covert facts of quantum mechanics. More quantum strangeness is rooted in the relevance of cause and effect at a microscopic level, such as the uncertainty principle, entanglement, tunneling effect and so on. These phenomena violate human experience of an orderly, causal universe. It seems that the usage of quantum mechanics has been widely accepted while ignoring its essential features. This metaphysical quantum theory perfectly interprets experimental results, but gives us nothing which approaches a realistic description with regard to the nature of the quantum world, and becomes the most wizardly of theories.

The need for a more complete theory has been revealed as our understanding of the physical universe has deepened, and, in particular, as exploration of the beginning of our universe has been carried out. One of the possible theories is the "hidden variable theory" proposed by D. Bohm[2]. This suggestion of invisible variables returns to the idea of empirical grounds and preserves causality for the particle experiencing quantum behaviour, and is based on a wave concept. It provides a possible sketch of the origin of "multi-path" methods, which



The multi-path behavior for a free particle passing single slit with horizontal incident velocity are an alternative perspective on the issue of a particle's wave-like property proposed by R. Feynman[3]. His standpoint agrees exactly with all that went before from the numerical prediction point of view, but is presented in a causal way. It concludes that there are many trajectories between two fixed points, which become one trajectory, the classical one, at the macroscopic level. However, this causal behaviour emerges from a contradiction of quantum theory, and has not yet been fully understood from the human viewpoint. In terms of physical laws in the objective physical process, it appears that an invisible physical strength acts on a particle and creates all possible trajectories. Obviously, more questions arise from the deterministic viewpoint of this hidden variable theory, such as: "What is a matter wave exactly?" and "Why is there an invisible part which does generate an effect on particles?" These puzzling questions could be straightened out if we could visualize this invisible part in some way. Therefore, the next problem to be addressed is how to convert hidden variables into realistic physical quantities and provide a concrete picture that can give us a convincing theory, which would account for all weird quantum phenomena and describe every property of the quantum world.

The main purpose of this article is to explore the process of visualizing hidden variables, and to represent a complete theory within microscopic physics. One can imagine that there is a bee in a house with no window. The bee has a special power allowing it to pass through walls. Of course, we cannot see the bee while it is outside the house and we are inside. It can only be seen after passing through the wall and coming back into the house. Hence, what we observe if the bee passes in and out of the house is that it appears all of a sudden and disappears again. In such a situation, we have no idea when it will come back to the house for the reason that we cannot see anything outside, but what we can do is to estimate the probability of being stung by the bee given the position we are in inside the house. This is the probabilistic interpretation proposed by quantum mechanics to describe a quantum system.

On the other hand, let us replace all the walls of the house by transparent glass. Then we can see everything outside the house from the inside. Now, we can observe where the bee is and even how it moves after it passes through the glass wall to go outside. There is no problem for us to predict its flight path, position, velocity and heading. In other words, we can tell when and where the bee comes back into the house in a deterministic way, without estimating the stinging probability. A comparison can be made here:

"An invisible physical strength acts on a particle and creates all possible trajectories"

the transparent walls symbolize the visualization process; the motion of the bee outside the house in the former case is an objective physical process. Consequently, a continuous and deterministic interpretation of the quantum world can arise if we can find some method of replacing the invisible border.

It is straightforward to think of extending dimensions to bring transparent walls into existence. To examine the part invisible to the senses at quantum level, a rational theory of complex space could strike a bargain, in which the imaginary part can represent the invisible world. In fact, it is not an idea originating from intuition only. The complex concept was objective in Schrodinger's equation and can be seen in the appearance of the imaginary factor "i", and has been accepted as a genuine mathematical tool. In fact, ignoring the imaginary sign in wave mechanics can be attributed to practical experimental results, which cause people to look to the atomic scale. Because of the limited observable dimension, imaginary features of nature which could explain experimental results have been eliminated by empiricists. This is the main reason why quantum mechanics is an incomplete theory, for its grounds for existence rely on observation that has been criticized from the philosophical aspect and the causality of its nature.

In pioneering work on causal quantum physics, a remarkable achievement based on the complex concept has been proposed by C. D. Yang[4]. In his study of physical processes in a complex domain, astonishing results have been acquired. They reveal that Schrodinger's equation is a deformation of the Hamilton-Jacobi equation when considering the existence of a complex dimension. General relativity and causal quantum physics can for the first time be on an equal footing in the foundation of the Hamiltonian outlook on causal physical processes. The biggest difference between the microscopic and classical Hamiltonians is the additional term in the microcopic Hamiltonian, namely the quantum potential. This means that there is a special field in the atom scale. It decreases as mass grows, and finally vanishes in our daily scale. This field is called the quantum field, and can take responsibility for all marvelous quantum phenomena. Thus, an object having specific physical quantities can be discussed after a complete description of its energy has been expressed. In other words, those who once considered it the most bizarre quantum particle in the can think of it as a classical particle.

One of the most elusive parts of this causal quantum physics, or so-called quantum Hamiltonian mechanics, is the existence of complex dimension. It becomes an objectionable point for those who only can be convinced through measurements. In reality, there is an objective world whose nature and reality are independent of human observers. Hence, if the projection of causality on our living world, given by the complex dimension, can bring us a compatible result with what we can observe, then it could be considered to bring complex dimension into existence. Unlike the quantum potential proposed in a hidden variable theory, the quantum potential we discuss in complex space can produce compatible outcomes with a quantum probabilistic interpretation. The unpersuasive explanation of motion in an eigenstate, once a fatal wound as a causal theory in Bohmian mechanics, becomes describable in quantum Hamiltonian mechanics. It is reasonable to explain the multi-path behavior by thinking of no specific initial position, since the imaginary initial position cannot be found as the real one has been fixed in an experimental process. In addition, a particle is moving in a complex domain when a complex force associated with the quantum potential acts on it. As a result, a non-classical trajectory, which deviates from the classical straight line, can be observed in the double-slit experiment. After a long period, the ensemble of trajectories forms a wave [5], which has been regarded as the matter wave, shown by the interference of the dark and bright band on the screen. It is the best way to illustrate the strange on-again-off-again property of a quantum particle by extending dimension to a complex domain. In such a way, we can see everything through the transparent wall, and can explore all unexplainable and unpredictable quantum strangeness.

Therefore, the wave function given by Schrodinger's equation describes a particle's motion statistically and cannot provide more detail about each trajectory. It is clearer to think of it as a water flow; we cannot know a specific molecule's motion by observing its whole flow, and can only understand the probability of this molecule passing by a specific area. This is the limitation of describing a quantum motion based on wave mechanics since it provides a macroscopic observation which cannot be overlooked. On the contrary, a fully informative view of a particle's motion can be presented in terms of causal description from the same wave function. We can observe a specific particle's motion with the help of quantum Hamiltonian mechanics since all the information about its motion can be traced in complex space. In other words, the incomplete quantum mechanical description can be regarded as a macroscopic observation and becomes a functional tool that can only extract a portion of the information from real conditions. Moreover, wave description itself has constraints on the local and accuracy standpoints of quantum motion. On the subject of the EPR problem, the non-local property can be explained by the propagation of information through the quantum field between two particles. And the uncertainty principle can be regarded as a consequence of statistical observation. Now we have a logically consistent and empirically adequate deterministic theory of quantum phenomena.

In summary, the revolutionary viewpoint of the complex dimension not only visualizes hidden variables but also provides them with a realistic physical meaning. As a causal theory, quantum Hamiltonian mechanics can be fully understood based on the classical standpoint, and invigorates complete description of the microscopic nature. However, this complex extension should be amenable to revision on empirical grounds as a scientific hypothesis. The prediction of small perturbation of the electron's spin momentum[6] would be one crucial testimony, waiting for the comparison with experiments. Also, the flying time of a photonic tunneling effect can be found by solving the equation of motion of the photon, which can be examined by experiment. The oscillation period of the ammonia molecule can be estimated precisely by averaging the time taken to complete a cycle. Those issues have been executed in our laboratory recently, and could be worked out in the near future. We conclude that quantum mechanics is a theory of phenomenology which gives average values for observed quantities, while quantum Hamiltonian mechanics is a theory of fatalism presenting specific particles and trajectories. Quantum Hamiltonian mechanics as a causal theory extends our understanding of the true nature of the microscopic world. It defends causality and preserves physical laws while revealing the most mysterious feature of nature, indicating what is behind quantum mechanics.

This article was written by **Shiang-Yi Han**, who is a PhD student in Prof. C.D. Yang's laboratory in the Astronautics and Aeronautics Department of National Cheng Kung University in Taiwan.

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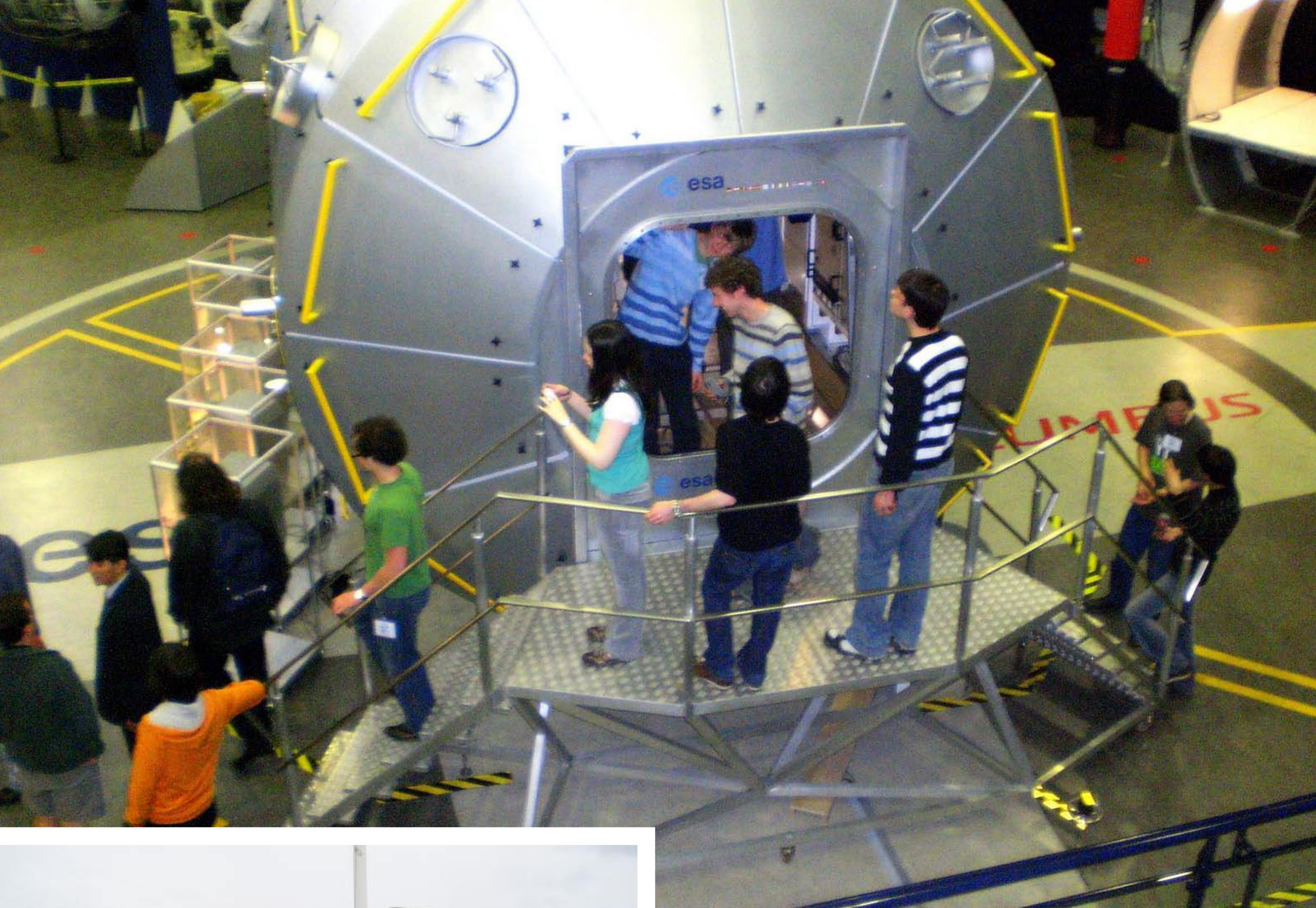
On the back cover: images from the recent IAPS trip to The Netherlands. The main attraction of this trip was a tour of ESTEC, the European Space Research and Technology Centre , located in Noordwijk. Participants saw a range of facilities and viewed the Herschel and GOCE spacecraft, both due to launch later in 2008. The event also included a visit to the Netherlands Organisation for Applied Scientific Research (TNO) in Delft, the Windmill Museum and Planetarium.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