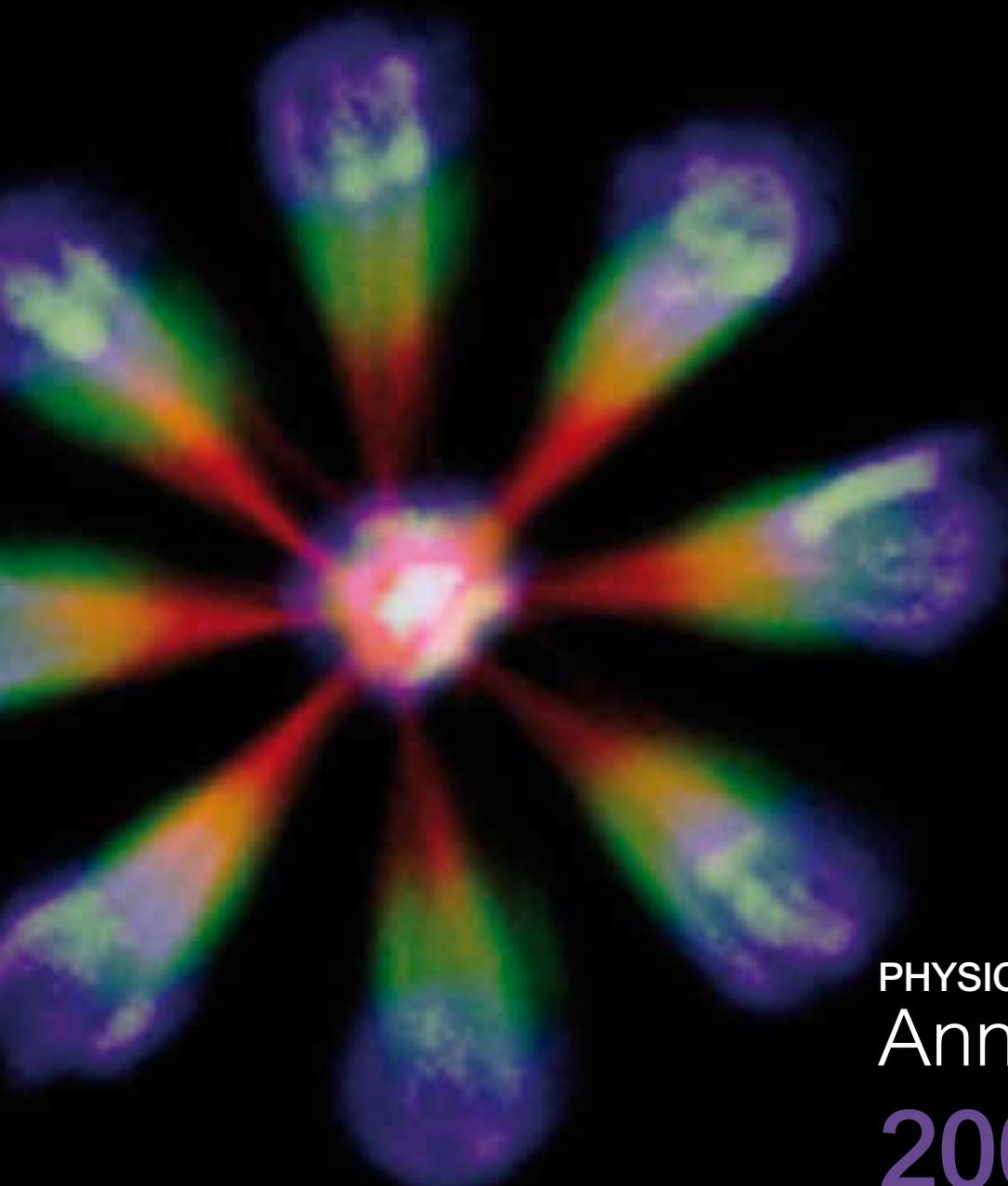


UCL DEPARTMENT OF PHYSICS AND ASTRONOMY



UCL



PHYSICS AND ASTRONOMY
Annual Review
2009–10

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Cover image: **'Castor in Bloom'** by Dr Stephen Fossey

This image is a composite of digital photographs taken of the bright star Castor during testing of a new CCD camera on the Radcliffe telescope at UCL's observatory in Mill Hill (ULO).

The telescope has a 24-inch lens to focus the light, and like all such instruments brings light of different colours to a focus at slightly different distances from the lens.

The best-focus position for each colour is determined by placing a mask with a circular pattern of holes over the lens, and images through red, green, and blue filters are taken at several focus positions; the mask produces separate images of the star in each out-of-focus colour, with the colour in best focus being more concentrated towards the central spot.

Hence, each 'petal' of the 'flower' is Castor's spectral image, dispersed by the telescope lens.

Introduction



The year of 2009 has seen the Department continue to prosper.

For example our success in the 2008 Research Assessment Exercise (RAE) was rewarded with a significant increase in the financial support for our research. This was particularly creditable as the new method used for distributing the funding for top-quality research in the UK led to many major departments losing money to small, active departments in the same research area.

The post-RAE era is a good time to reflect and during 2009 there was a review of Physics at UCL, followed by a review of the overall Maths and Physical Sciences (MAPS) faculty. Both these reviews were chaired by Prof. Malcolm Longair FRS from Cambridge and contained significant international input. The reviews were extremely positive; one of the reviewers for the Department commented that “In numerous areas, the research is undoubtedly world-leading... We congratulate the Department on [its] performance.”

At the same time the reviews highlighted a number of areas in which we could do better. In particular, the panel gave us helpful advice on how to improve the organisation of Biological Physics in the Department, which is discussed on page 28, while the need to further strengthen our postgraduate recruitment is touched on below.

The steady increase in the number of applicants for undergraduate studies has continued, although the college has severely capped the number we can actually recruit. Our intake on both our taught masters and certificate courses has increased rapidly, and the number of research students we recruit has also grown. We continue to receive many more applications from well-qualified students wishing to study for research degrees than we can offer places to. We would dearly like to do something about this issue, and both subject and faculty reviews identified it as key objective for the Department. To this end, alumni receiving this review will find a letter about the Provost’s Impact Studentships scheme enclosed.

The Department has continued its success in attracting outstanding young scientists on long-term fellowships, see page 8, and our research successes have also continued to be reflected by the award of significant prizes, see page 10. On a personal level I was deeply honoured to be elected a Fellow of the Royal Society and to have the privilege of signing in the same book as Newton, Dirac and many other ground-breaking scientists. For me it has been an interesting year in many ways, particularly memorable was my visit to the Siberian Branch of the Russian Academy of Sciences in Tomsk at the start of March. When I arrived it was -17°C but it soon warmed up to -5°C , so my hosts took me for a picnic in the forest, see photo.

Although my comments above suggest that the Department continues to thrive, it is hard not to look at the future without considerable concern. STFC, which funds the vast majority of our high energy physics and astrophysics research, has just hit yet another major funding crisis. The results of which are already hitting us and will continue to do so over the next few years. The government has also announced significant cuts in university funding to spread over the next few years. How these will impact us in detail is still unclear, but it is obvious that the future contains difficulties and a probable contraction in what we can do.

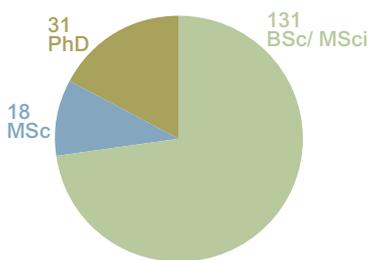
A handwritten signature in black ink, which appears to read "Jonathan Tennyson".

Professor Jonathan Tennyson FRS
Head of Department

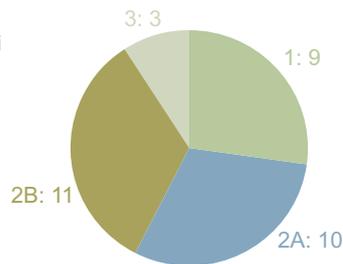
Student Highlights and News

Student Entry and Pass Figures for 2009

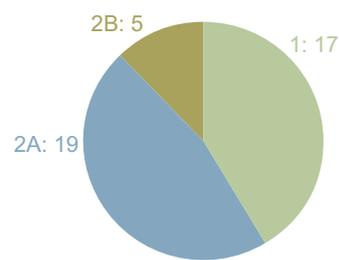
Intake



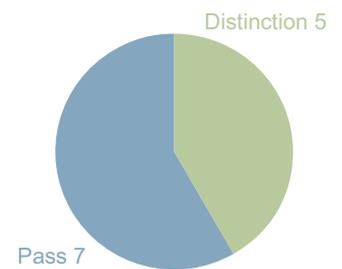
Awards



Bachelor of Science (BSc)



Master in Science (MSci)



Master of Science (MSc)

2009 PRIZE WINNERS



The 2009 prize winners

UNDERGRADUATE PRIZES

Oliver Lodge Prize

(Best performance 1st year physics)

Arnold Mathijssen

Halley Prize

(Best performance 1st year astronomy)

Shaghayegh Parsa

C.A.R. Tayler Prize

(Best 2nd Year Essay)

Kenneth Tang

Wood Prize

(Best performance 2nd year physics)

Wei Zhou

Higgins Prize

(Best performance 2nd year astronomy)

Kirthika Mohan

David Ponter Prize

(Most improved performance in Department, 2nd year – joint winners)

Shun Ng and Dino Osmanovic

Corrigan Prize

(Best performance in experimental work, 2nd year)

Charmaine Wijeyasinghe

Additional Sessional Prize for Merit (2nd Year)

Tamsin Nooney

Best Performance 3rd Year Physics

Soliman Edris

Best Performance 3rd Year Astronomy**Sidney Tanoto****Additional Sessional Prize for Merit (3rd Year)****Robert Michaelides****Burhop Prize**

(Best performance 4th year physics)

Noel Hustler**Herschel Prize**

(Best performance 4th year astronomy)

Kalle Karhunen**Brian Duff Memorial Prize**

(Best 4th year project in the Department)

Ingo Waldmann**William Bragg Prize**

(Best overall undergraduate)

Holly Alexander**Tessella Prize for Software**

(Best use of software in final year physics/astronomy projects)

Gihan Weerasinghe**POSTGRADUATE PRIZES****Harrie Massey Prize**

(Best overall MSc student)

Lucinda Clerkin**Carey Foster Prize**

(Postgraduate research, physics AMOPP)

Lorenzo Lodi**HEP Group**

(Postgraduate research, physics HEP)

Simon Bevan**Marshall Stoneham Prize**

(Outstanding postgraduate research, physics CMMP)

Andrew Walters**Condensed Matter and Materials Physics**

(Outstanding postgraduate research, physics CMMP)

Jennifer Brookes**Jon Darius Prize**

(Outstanding postgraduate research, astronomy)

Manda Banerji**DEPARTMENTAL TEACHING PRIZE – Joint Winners****Dr Stephen Fossey****Dr Martin Smalley****RESEARCH HIGHLIGHT****Exofit: Orbital parameters of extrasolar planets from radial velocities****S. T. Balan, O. Lahav**

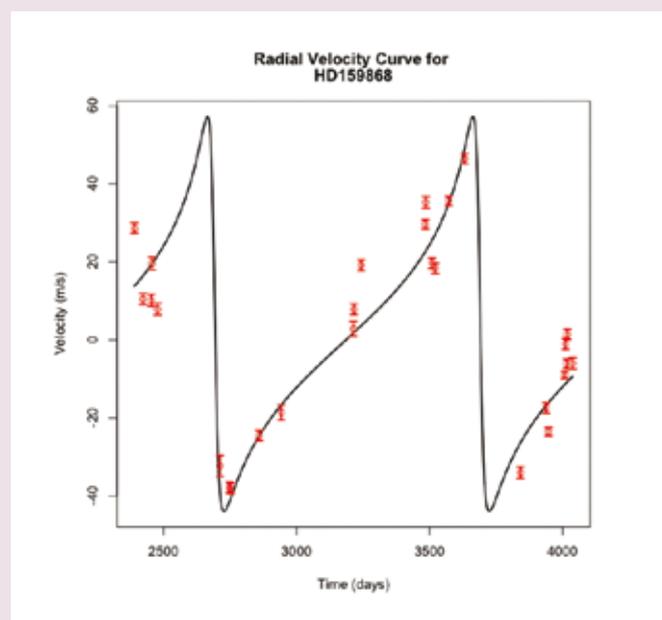
Monthly Notices of the Royal Astronomical Society, 394, 1936 (2009)

One of the most exciting developments in astronomy is the discovery (starting in 1995) of extra-solar planets, i.e. planets around host stars, outside our solar system. Over 400 exo-planets have now been discovered. The most successful method for detecting extra-solar planets is the radial velocity method which detects small, periodic Doppler shifts in the apparent motion of the star caused by the orbiting planet.

Prof. Ofer Lahav, with his then MSc student Sree Balan, developed a method called ExoFit for estimating orbital parameters from radial velocity data. In short, ExoFit is a computer program that takes data obtained from observing a star's 'wobble' and tells you information regarding the planet. It can also assess if there are more than one planet around the star.

As a follow-up, A group of seven 3rd year undergraduates, led by **Greg Lever**, applied ExoFit to many radial velocity observations in a systematic and uniform way. In doing so they discovered with ExoFit, a second planet in one of the systems (HD11506). However it transpired that another team discovered it independently a few months earlier.

Balan, Lever, and Lahav are now applying ExoFit to all available radial velocity data, with the goal of generating a uniformly-derived catalogue of parameters for all known exo-planets.



Example of a fit by ExoFit from Balan & Lahav (2009)

PHD'S AWARDED

Sabina J A Abate

Measuring cosmology from dark universe
(Supervisor Dr S Bridle)

Marin B. Andrews

The influence of a migrating planet on the topology and chemistry of a protoplanetary disc
(Supervisor Dr S Viti)

Martina Avellino

Entanglement and quantum information transfer in arrays of interacting quantum systems
(Supervisor Prof. A J Fisher)

Simon Bevan

An investigation into the feasibility of a sea water or ice based acoustic UHE neutrino telescope
(Supervisor Dr D Waters)

Thomas Boness

Quantum chaos and entanglement in spin chains: Dynamics of a periodically kicked Heisenberg ferromagnet
(Supervisor Prof. T S Monteiro)

Simon J Brawley

Collisions of positron with atoms and molecules
(Supervisor Prof. G Laricchia)

Jennifer C Brookes

A microscope model of signal transduction mechanisms: Olfaction
(Supervisor Prof. A M Stoneham)

Thomas J Byatt

Supersymmetry or universal extra dimensions? Utilizing the ATLAS experiment at CERN
(Supervisor Dr N Konstantinidis)

Peter J Douglas

Atomic dynamics in optical traps: Experiments with caesium atoms
(Supervisor Prof. F Renzoni)

Shiva L King

Measurement of the double beta decay half-life of ^{100}Mo to the $0^+ 1$ excited state, and ^{48}Ca to the ground state in the NEMO 3 experiment
(Supervisor Dr R Saakyan)

Iraklis Konstantopoulos

Studies of the formation and evolution of extragalactic star clusters
(Supervisor Prof. L Smith)

Jennifer S Lardge

Investigation of the interaction of water with the calcite (1014) surface using ab-initio simulation
(Supervisor Dr D Duffy)

Manh Duc Le

Magnetism and quadrupolar order in f-electron systems
(Supervisor Prof. K A McEwen)

Ho-Chi Lin

Local approach to quantum entanglement
(Supervisor Prof. A Fisher)

Lorenzo Lodi

Theoretical rotational-vibrational spectroscopy of water
(Supervisor Prof. J Tennyson)

Mercedes Ramos Lerate

A far-infrared spectroscopic study of the Orion KL region
(Supervisor Prof. M J Barlow)

Jose Reslen

Quantum effects in low temperature bosonic systems
(Supervisor Prof. S Bose)

Alexis Rutherford

Electronic effects in radiation damage simulations
(Supervisor Dr D Duffy)

Fabrizio Sidoli

The massive star population of Wolf-Rayet galaxies
(Supervisor Dr L Smith)

Bruno Silva

Rotation-vibration states of triatomic molecules at dissociation
(Supervisor Prof. J Tennyson)

Jiayu Tang

Investigating future probes of cosmic acceleration
(Supervisor Dr J Weller)

Hoi Yu Tang

On the stability of liquid-like Argon nanoclusters
(Supervisor Prof. I Ford)

Troy Vine

A direct measurement of the decay width
(Supervisor Prof. M Lancaster)

Andrew Walters

Using x-ray and neutron scattering to study the dynamics of low-dimensional systems
(Supervisor Prof. D McMorrow)

William Whyatt

The clumpiness of the interstellar medium
(Supervisor Dr S Viti)

Joseph Wood

Atoms, ions and molecules in intense ultrafast laser fields
(Supervisor Prof. R Newell)

Erdal Yigit

Modelling atmospheric vertical coupling: The role of gravity wave dissipation in the upper atmosphere
(Supervisor Prof. A Aylward)

Captain Ben Babington-Browne

Captain Ben Babington-Browne from 22 Engineer Regiment, Royal Engineers, died in a helicopter crash in Afghanistan on 6 July 2009.

He was a former undergraduate student in the Department who graduated in 2005 with a BSc in Physics with Medical Physics, he then went on to become an army officer. Staff in the department, together with colleagues in UCL Medical Physics & Bioengineering, who knew Ben during his studies are greatly saddened by the news. He was a valued and respected member of the UCL community.



Image courtesy of the Ministry of Defence

Alumni Matters

The annual Alumni dinner took place on the 8 May 2009. Although the numbers were somewhat disappointing compared with previous years, it was made highly worthwhile by the varied experiences of the participants. Two of whom graduated 50 years apart! The department and myself value greatly the relationship with our Alumni, which must, by its very nature, be intermittent and largely intangible.



The current head of the department **Prof. Jonathan Tennyson FRS**, who is now in his second five year term, gave an excellent after dinner speech. He described his 25 year experience in the Department and how the Department has developed over the years into one of the leading physics and astronomy departments in the UK.

This year the Annual Dinner will take place on Friday 7 May 2010. Since the number of attendees at other Alumni events at UCL were down last year, we have made efforts to reduce the cost of the dinner to £40.

Prof. Roger Davies, Chairman of Physics and Wetton Professor of Astrophysics at The University of Oxford, will give the after dinner speech. He graduated from the department in 1972.

Prof. Tegid Wyn Jones

The Physics and Astronomy Football Team (PAFT)



PAFT is an 11 a-side football team comprising of undergraduate physicists and astronomers. They competed in the Grass Roots League (GRL) which is an inter-departmental league within UCL. Other teams included the Civil Engineers, Chemical Engineers,

Computer Technology, Islamic Society and the Chinese Society. The GRL comprises of two competitions; the league, and a knockout tournament.

PAFT Captain, **Nasik Ahmed** reported that last year PAFT managed to win both titles in one season, a feat which has never been achieved before – as far as the Captains can remember! They hold an exemplary record of winning 10 out of 12 games.

RESEARCH HIGHLIGHT

Ice XV: A new thermodynamically stable phase of ice

C. G. Salzmann, P. G. Radaelli, E. Mayer, J. L. Finney

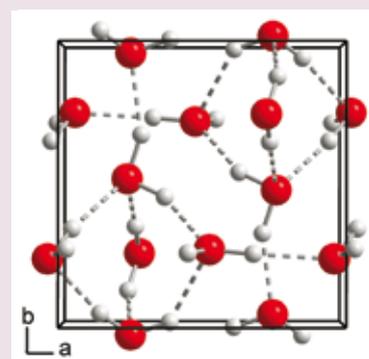
Physics Review Letters 103, 105701 (2009)

Scientists have discovered another form of ice, ice XV, and in doing so have crossed one of the remaining frontiers in ice research. It was known that this phase should exist, but until now no-one had been able to make it.

This latest addition to the already rather large family of ice phases (the UCL team having been involved in discovering four of these over the past ten years) is stable below -150°C and at pressures between eight and fifteen thousand atmospheres. It might therefore be found in nature in the interiors of icy moons of the outer planets.

Previous theoretical work had suggested that the water molecules in ice XV should line up parallel to each other – the structure was expected to be ferroelectric. However, the experiment now reported by the team in Physical Review Letters has shown that the opposite is true and that ice XV is in fact antiferroelectric: half the molecules line up in one direction, and the other half in the opposite direction.

In addition to the behaviour of ice at low temperatures being important in understanding ice elsewhere in the solar system, resolving the reasons for the failure of the theoretical models will help us to improve our understanding of the subtle behaviour of water that is critical to our understanding of its role in chemistry and biology.



Ice XV

Careers with Physics and Astronomy Degrees

Dr Louise Dash

Research Associate at the University of York (MSci Physics 1998, PhD Physics 2002)



I transferred to UCL in the final year of my MSci Physics degree when the Physics Department at Birkbeck closed in the autumn of 1997. I studied for this degree as a part time, mature student and although it wasn't the best of

circumstances in which to arrive, I liked UCL enough to stay on to do a PhD with Prof. Andrew Fisher. Being able to work on physics full time instead of fitting it in around a day job was sheer luxury for me!

During my time at UCL I met my future husband, Hervé Ness. Hervé was working as a research associate with Andrew when we met but was subsequently offered a position in Paris. After completing my PhD at UCL I was lucky enough to be offered a research associate position within the CMMP group. However it soon became clear to me that I needed to move to France, and so in the summer of 2003 I secured a position at Ecole Polytechnique.

2005 was a momentous year for us, Hervé and I got married and our first son, Isaac, was born. I decided not to go back to work straight away, but by the time Isaac

was 18 months old I knew that life as a stay-at-home mother wasn't for me.

The solution presented itself in the form of a job opportunity back in the UK at the University of York, working in a collaboration called the European Theoretical Spectroscopy Facility. Hervé and I work together as a jobshare, so effectively we both work part-time.

It's an arrangement that works quite well for us, although it does have its drawbacks, the main one being that we have to share a single salary! Our second son, Felix, was born in 2008. Life as physicists with a family is complicated but fun – when we go to conferences, for instance, the children come too. We have a good work-life balance, but our ultimate goal of finding suitable permanent positions for both of us in the same place is proving elusive; we are still trying to solve our many-body problem.

Best friends Jeanette and Alix met on their first day at UCL. They bonded instantly over a shared desire to go to the Comedy Store, and in their second year they shared a flat above a (flammable) falafel restaurant on Wardour Street. Since leaving UCL they independently made their careers in broadcasting.

Jeanette Goulbourn

Freelance TV Director (BSc Physics with Space Science 1994)



As a child I dreamed about working in space, and growing up, my 'work experience' was a trip to the Mullard Space Science Laboratory where my connection with UCL began. As a sixth former I attended the UCL 'Women in Physics' trip and unbeknownst to me, a lifelong love of London and a best friendship was about to be forged.

I took the Physics with Space Science degree and in my last year took a science communication module which changed the course of my life – this looked at science in the media and I loved it, so much so, that I went on to take the MSc in Science Communication at Imperial College.

I loved learning about the philosophy and rhetoric of science in the media but also the practicalities of writing

articles, producing radio programmes and making television shows. As part of this course we had to carry out a work placement and mine led me to my first job in television as a researcher at Windfall Films on a science documentary. It was a fascinating job investigating the story of 'Escape for Sea', which led me to research everything from Nazi experimentation via visiting Naval submarine bases, to being winched out of a dinghy off the coast of Wales, something I'm happy to say I've never had to repeat!

I kept my connection with science moving to the BBC to work on a children's science show and from there moved to direct films and produce the Blue Peter science special. I loved my job and the people around me but felt

there was something missing, however the day I sat in the director's seat in a live studio I knew that I had found my calling! I've since directed music shows, cookery programmes and won a BAFTA for a sitcom but still keep my hand in with science having directed Richard Hammond's Blast Lab last year. I have a number of projects in the pipeline at the moment including Daily Cooks Challenge, Swap Shop and a new children's game show.

It has been a winding path that led me from a Physics with Space Science degree to Television Director but I know it has been a privilege to be able to follow it, the excitement is not knowing where it will lead next...

Alix Pryde

**Controller of Distribution, BBC
(BSc Physics 1994)**



"How did you get from studying physics to doing THAT?!"

That's the question I've been asked in every job I've had since completing my PhD 12 years ago. Until my current job, that is.

In 2009 I became the BBC's Controller of Distribution. That means I'm responsible for the team that ensures that the BBC's television and radio broadcasts make

a successful journey from our buildings to your home, 24 hours a day, 365 days a year. I'm also responsible for advising the BBC's Executive strategically on developments in the distribution arena, and for delivering new technologies that enhance listening and viewing for the UK's licence fee payers. The most recent example is bringing High Definition, or 'HD', broadcasts to digital terrestrial television, better known as Freeview. The UK's first Freeview HD signals went live at the start of December 2009 in Manchester and in London, where I had the honour of flicking the 'ON' switch at Crystal Palace. Other transmitters across the UK are now being converted rapidly so that half of the population will have access to Freeview HD signals by the 2010 World Cup and the whole of the UK will be covered by the end of digital switchover in 2012.

So as you can imagine, my new role has brought me back to the world of kilohertz, Argand diagrams and Yagi aerials that I encountered in my undergraduate studies in Physics at UCL. And hence it's finally put a stop to THAT question.

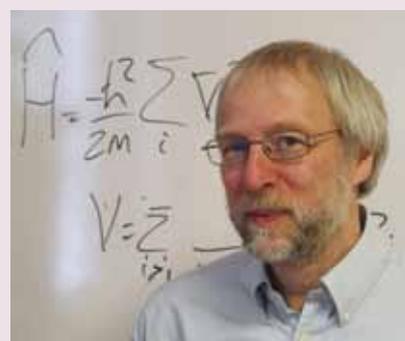
After graduating from UCL in 1994, I completed a PhD in the theoretical physics of crystals at Cambridge University, then joined strategy consultants McKinsey & Co. I finished its two year business analyst programme and went 'in-house' as a strategist for Kelvin MacKenzie's radio company The Wireless Group plc (which owned talkSPORT among other stations). I was headhunted by the BBC in 2002, which coincidentally was where my best friend from, UCL, Jeanette Goulbourn, was working as a director of live television programmes such as Blue Peter.

My time at UCL, through the wise and wonderful people I met there, gave me not just a greater knowledge of physics, but also of the world and, probably most importantly, myself – my flaws as well as strengths. This understanding has been vital to the progress I have made to date and I'm sure will continue to be...whatever I go on to do, physics-related or otherwise.

RESEARCH HIGHLIGHT

Fellowship of the Royal Society (FRS)

We are delighted to announce that **Jonathan Tennyson** has recently been elected a Fellow of the Royal Society. This is one of the highest accolades in science, his fellowship citation is below.



'Tennyson is distinguished for his fundamental work on the theory, calculation and application of molecular spectra, obtaining results of great importance in astronomy and planetary studies. His work with Miller, using first principles quantum mechanical calculations to assign an emission spectrum of H₃⁺ in the Jovian ionosphere, led to a new observational handle which is still being actively pursued world-wide. Similar calculations led to a major break-through in understanding the spectra of water and the assignment of a very complicated spectrum of water recorded in sunspots, the detection of water in an extrasolar planet and the development of a comprehensive ab initio model for the system. Tennyson has also made major contributions to the theory and calculation of electron-molecule collision cross sections. He now leads a collaboration of several groups developing and using a world-leading R-matrix computer program; he developed and implemented a new algorithm which has revolutionised the scope of possible calculations.'

Calling all Alumni: We would love to hear about your career and life since leaving UCL, with a view to possibly including your story in the next Annual Review.

If you would be willing to write a piece for the next Annual Review, please contact Kate Heyworth via email k.heyworth@ucl.ac.uk

Staff Highlights and News

Promotions

Promoted to Professorial Research Associate

Prof. David Walker

Promoted to Reader

Dr Dorothy Duffy
Dr Christian Ruegg

Promoted to Senior Lecturer

Dr Phil Jones

Long-term Fellowships

Dr Filipe Abdalla

Royal Society University Research Fellowship

Dr Janet Anders

Royal Society Dorothy Hodgkin Fellowship

Dr Agapi Emmanouilidou

EPSRC Career Acceleration Fellowship

Dr Steven Schofield

EPSRC Career Acceleration Fellowship, to be held in the London Centre for Nanotechnology (LCN)

Retirements

Prof. Mike Gillan

Prof. Roy Newell

Resignations

Prof. Linda Smith

Following a more than 25-year association with UCL, Linda has moved permanently to the Space Telescope Science Institute, Baltimore. She has just completed a 3-year leave of absence at the Institute, funded by the European Space Agency, where she was leader of the group responsible for two Hubble Space Telescope instruments.

Academic appointments



Dr Filipe Abdalla

Lecturer in cosmology, from UCL. Also awarded a Royal Society University Research Fellowship



Dr Jochen Blumberger

Lecturer in condensed matter and materials physics, from Cambridge. Also holds a Royal Society University Research Fellowship



Prof. Steven Bramwell

Professor in condensed matter and materials physics, joint with the LCN. Prof. Bramwell moved his Chair from Chemistry



Dr Hiranya Peiris

Lecturer in cosmology, from Cambridge University. Also holds an STFC Advanced Fellowship



Dr Giorgio Savini

Lecturer in astronomical instrumentation, from Cardiff University



Dr Nguyen TK Thanh

Reader in condensed matter and materials physics, from Liverpool University. Also holds a Royal Society University Research Fellowship. Her work is located at the Royal Institution

Public Lectures in 2009

The Department organises a number of public lectures throughout the year, for details of the 2010 lectures please check the physics and astronomy website

www.phys.ucl.ac.uk

Public lectures will be advertised roughly one month prior to the event.

Physics Colloquium

Léon Sanche (University of Sherbrooke), 'Low Electron Induced Processes in Dielectrics, Icy Satellites, Stratospheric Clouds, Nanolithograoogy and Radiotherapy'

February 2009

The Elizabeth Spreadbury Lecture

Prof. Rolf-Dieter Heuer (Director General of CERN), 'The Large Hadron Collider: Shedding light on the Dark Universe'

March 2009

Physics Colloquium

Professor Tom McLeish (University of Durham), 'Listening to Noise in Biological Physics: from Protein Dynamics to Evolutionary Landscapes'

June 2009

The Bragg Lecture

Hermann Gaub (University Munich), 'Mechanoenzymatics'

October 2009



The Elizabeth Spreadbury Lecture

The HEP group organises an annual lecture to commemorate Elizabeth Spreadbury. Elizabeth was UCL graduate and a PhD student who was killed when hit by a car in Geneva while cycling home from a night shift on the OPAL experiment, the predecessor of the LHC.

Reflecting Elizabeth's interests, the lecture is given every year, either by a distinguished astronomer or particle physicist. The lecture is supported by a trust fund established by gifts from Elizabeth's parents. They also donated her collection of physics books to form the core of a library for current group members.

RESEARCH HIGHLIGHT

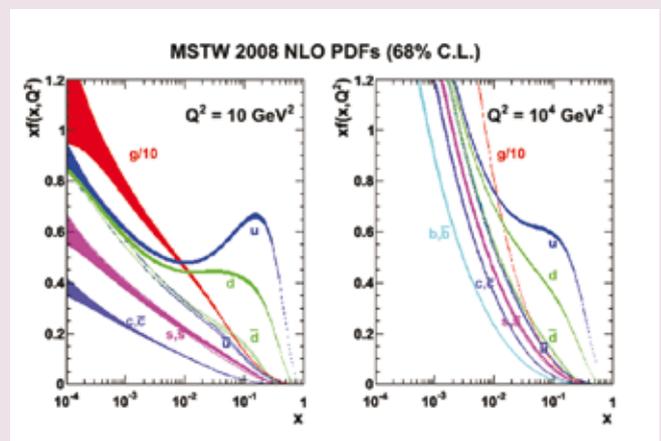
Parton distributions for the Large Hadron Collider (LHC)

A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt
European Physical Journal, 63,189-285 (2009)

There has been a great deal of publicity recently about the LHC. This has understandably focused on new particles that may be discovered there, in particular the Higgs boson. However, our understanding of Standard Model physics underlies the observation and interpretation of any new physics at the LHC. Most fundamentally, despite the fact that the ultra-high energy collisions that will take place are between protons, our calculations of production rates for Higgs, supersymmetry and even mini black holes, and the backgrounds for these, are all in terms of parton-parton collisions.

The partons are the constituents of the proton — the quark particles and the gluons which provide the strong force binding the proton together. Hence, LHC physics relies on understanding the parton distribution functions (PDFs) of the proton, which depend on the momentum fraction of the proton carried by the parton x , and the scale of the collision process Q^2 . These can be obtained by working with the theory of Quantum Chromodynamics (QCD) and fitting to all current available data from collider experiments.

The authors of the above publication form one out of only two groups in the world which perform 'global fits' for PDFs (the other, CTEQ, is from the USA), improving the understanding of QCD and enabling predictions for the LHC. A major new update, MSTW2008, was recently released, with improvements in theory and comparison to many new data sets. These have already been used in determining the bound on the Higgs particle at the Tevatron, the LHC's competitor near Chicago, and will play an equally central role in LHC searches.



The MSTW2008 parton distributions plotted as a function of x for two different scales. The width of the bands represents the uncertainty of the distributions

Staff Prizes and Awards

Institute of Physics (IOP) Awards

2009 Occhialini Medal and Prize

Prof. Gaetana Laricchia (AMOPP)



Conferred jointly by the Institute of Physics (IOP) and the Italian Physical Society (SIF)

'For distinguished work on experimental positron physics,

in particular for developing and using the world's only positronium beam.'

Moseley Medal

Dr Matthew Wing (HEP)



'For his outstanding contributions to the experimental programme of the HERA collider at DESY, the leading experimental facility for

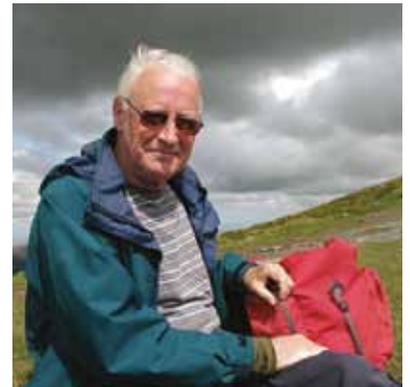
studying the detailed sub-structure of the proton. In particular his work has led to a deeper understanding of the strong force and will have important applications to the LHC and future colliders.'

In addition Dr Rachel Mckendry (LCN) was awarded the Paterson medal and prize.

Royal Astronomical Society (RAS) Awards

The Gold Medal for Astronomy

Prof. David Williams (Astro)



'Professor Williams has made seminal contributions to astronomy, particularly in the field of astrochemistry, applying it in progressive phases of star formation, from prestellar objects to protostars to the disks and planets found around young stars. He has also applied this technique in environments found at the end of the lives of stars, from planetary nebulae like the one that will emerge at the end of the Sun's life to the ejecta from supernova explosions from more massive stars. Professor Williams effectively introduced the field of astrochemistry as a modern discipline to the UK and assembled a community that enabled it to blossom into a major research area.

Professor Williams led research groups in Manchester and London, produced more than 300 publications in refereed journals and numerous books and is a former President of the RAS. He is honored in recognition of his role as a distinguished scientist, teacher and organiser'

The Fowler Prize for Astronomy

Dr Sarah Bridle (Astro)



'Dr Bridle has made important contributions to cosmology, in areas ranging from the cosmic microwave background radiation to gravitational lensing and surveys of the redshifts of galaxies. She has completed work on how to maximise the amount of information (and hence progress the field) obtained from the next generation of data sets that will come from instruments such as the Square Kilometre Array (the large radio observatory planned for the next decade).

Dr Bridle is honoured in recognition of her status as a young scientist of proven achievement and great promise.'

In addition to the above prize Sarah also won a €1.4million European Research Council (ERC) Young Investigator award and gave birth to baby Scott John Alan Grainge.

Photograph by Max Alexander

European Physics Society (EPS) High Energy and Particle Physics Prize

The Gargamelle Experiment



Figure 1. The Gargamelle bubble chamber as seen from the inside

Members of the HEP group circa 1973 have shared the 2009 European Physical Society (EPS) prize for High Energy Physics, together with other members of the Gargamelle collaboration. This prestigious, biennial prize was awarded '[f]or the observation of the weak neutral current interaction'. This was the first evidence of the Z boson, one of the carriers of the weak nuclear force, from a study of the interactions of a neutrino beam in a heavy liquid bubble chamber.

The experiment itself took place 37 years ago and was led by the French physicist Andre Lagarrigue who designed the huge bubble chamber (figure 1).

The discovery was nominated for a Nobel Prize but regrettably he suffered a heart attack and died as he was lecturing to undergraduates at the Ecole Polytechnique.

The UCL HEP group were very much to the fore in this collaboration and members of the group included **Fred Bullock, Mike Esten, Tegid Jones, John Mackenzie**, Alan Michette (now at King's College) and James Pinfold (now at the University of Alberta).

In the experiment the 20 GeV proton beam of the proton synchrotron ((PS) now the injector to the LHC!) was extracted from the synchrotron and passed through a long, thin beryllium target. In the target, pions and a smaller number of kaons, were produced. These were then partially focussed by the large magnetic horn designed by Van der Meer. The particles then decay to muons (heavier versions of the electron) and neutrinos, the muons stopping in an iron shield and the neutrinos head through the bubble chamber.

At the outset of this experiment, it was anticipated there would be interactions where the unseen neutrinos exchanged a charged W boson with either a proton or neutron (nucleons) or more rarely, the electron in the heavy liquid, the neutrino changing into a muon. Thus in every event, however complex, an outgoing muon should be observed. These events were certainly seen, but in addition, events not containing a muon were observed. This is evident in figures 2 and 3 where the unseen neutrino enters the chamber from the left.

This was the discovery of the weak neutral current mediated by the Z boson. It was the first evidence of the partial unification of the weak and electromagnetic interactions and led to the award of the Nobel Prize to Glashow, Salam and Weinberg.

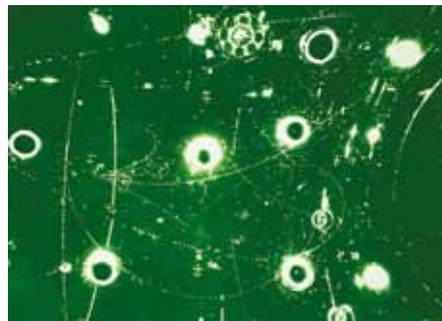


Fig 2. A hadronic weak neutral current event, whereby a neutrino has interacted with a nucleon in the heavy liquid by exchanging the Z boson to yield an event containing a nucleon and pions.



Fig 3. A leptonic weak neutral current event in which the neutrino has scattered off an electron in the heavy liquid by exchanging the Z boson.

Images courtesy of CERN

NASA Group Achievement Awards

Dr Giovanna Tinetti (Astro)

As part of the Exoplanet Spectroscopy Team



Photograph by Max Alexander

'For outstanding research which produced the first detection of methane in the atmosphere of an exoplanet'.

Dr Nick Achilleos (Astro)

As part of the Cassini Magnetosphere Target Working Team

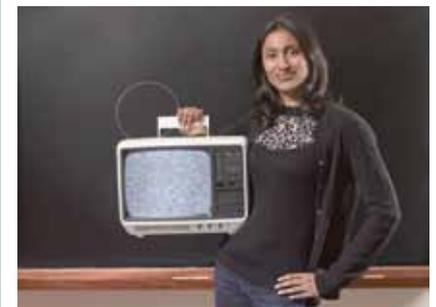


Photograph by Max Alexander

For 'contributions towards making the Cassini field and particle measurements an outstanding success'.

Philip Leverhulme Prize

Dr Hiranya Peiris (Astro)



Photograph by Max Alexander

'These Prizes, with a value of £70,000 each, are awarded to outstanding young scholars who have made a substantial and recognised contribution to their particular field of study, are recognised at an international level, and whose future contributions are held to be of correspondingly high promise.'

Staff Profile

Dr Stephen Fossey

Steve is based at the University of London Observatory (ULO), with over 15 years teaching and research experience, he is a popular teacher and a valued member of the observatory community.

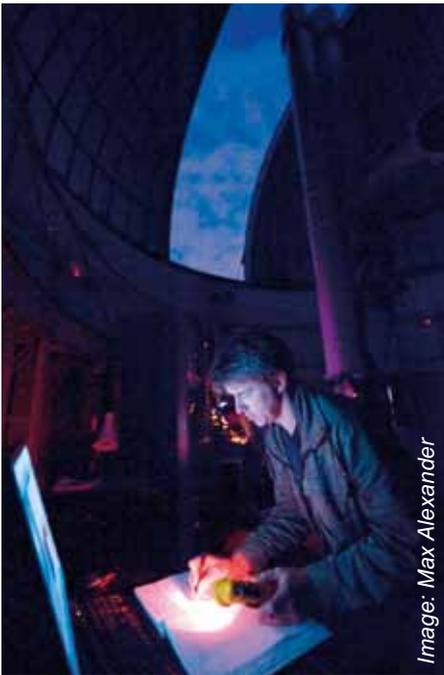


Image: Max Alexander

Dr Steve Fossey prepares for a night's observing with students on the Radcliffe 24-inch telescope at ULO.

Steve joined UCL as an astronomy undergraduate in 1980 and has been working at ULO as a Demonstrator since 1992. In 2009 he was awarded the Departmental Teaching Prize, jointly with Dr Martin Smalley.

ULO is based in Mill Hill, North London, and students visit the observatory for practical classes; on clear evenings they use state-of-the-art, computer-controlled telescopes and cameras. Observing is usually conducted from the warmth of a control room, but students are also advised to wear warm clothes for working in the unheated domes. Steve recalls one student who arrived in summer clothes, subsequently refused several offers of

a coat, and ended up shivering so much that the entire viewing platform he was standing on was shaking! The staff at ULO, both academic and technical are extremely proud of the facilities and the work which is conducted there. It is the enthusiasm of not only Steve but the entire staff body at ULO which helps the make the student experience such an enjoyable and worthwhile adventure.

Steve's research expertise is in optical observational astronomy, concentrating on the analysis and interpretation of data from spectroscopic observations of the interstellar medium, and more recently, the study of transits of extrasolar planets. One of the highlights of his career to date has been working on high-resolution

spectroscopy using UCL's Ultra High Resolution Facility (UHRF) on the Anglo-Australian Telescope. A collaboration with Prof. Peter Sarre (Nottingham) was fostered by their independent recognition of a link between certain unidentified interstellar absorption lines and a set of spectral emission lines seen in other objects. They then used the UHRF to discover structures in the unidentified spectral lines, and demonstrated they were likely to be caused by large molecules in interstellar gas. This was an exciting breakthrough at the time as the discovery had the potential to unlock a problem which has remained intractable for many years.

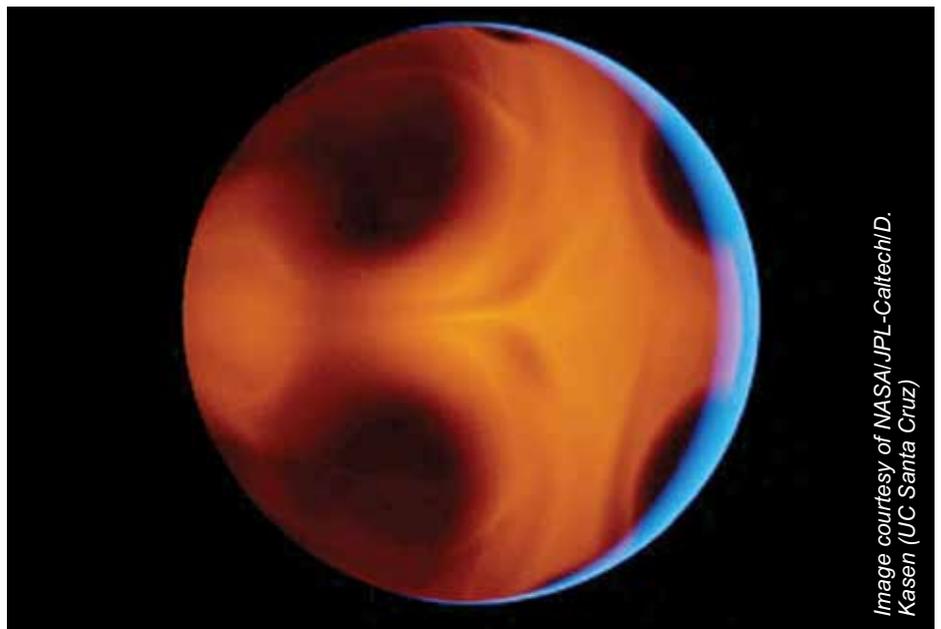


Image courtesy of NASA/JPL-Caltech/ID. Kasen (UC Santa Cruz)

Atmospheric simulation of the exoplanet HD 80606b.

In February 2009 a UCL team of astronomers and undergraduate students, led by Dr Steve Fossey, discovered that the extrasolar planet known as HD 80606b passes directly in front of the Sun-like star it orbits. The red regions are hot spots arising from rapid heating of the atmosphere during the planet's close, searing encounter with its parent star.

Future research plans for Steve include continuing to work on studies of the interstellar medium, along with further study of exoplanets. His exoplanet work, with undergraduate contribution, has led directly to the publication of the first detection of a transit of the unusual, eccentric-orbit exoplanet HD80606b (see the image opposite on atmospheric simulation). In teaching, Steve hopes to be able to combine student experience of hands-on observing with training in remote and robotic operation of telescopes at ULO and overseas. Such techniques will provide students with greater opportunities to collect their own data, and train them in a mode of observing which is becoming increasingly important in astronomical research worldwide.

Steve is also heavily involved in public outreach projects and in 2008 worked with Alexandra Park School in North London to develop and deliver teaching materials; this work was recognised through a London Education Partnership Award. Additionally, he helps out with open evenings at ULO, so if you are interested in meeting Steve in his ULO den, please come along to one of the public open days, details for which can be found on the physics and astronomy website.

RESEARCH HIGHLIGHT

'Magnetricity' sees monopoles flowing in a magnetic field

S. Bramwell, S. Giblin
Nature 461, 846 (2009)

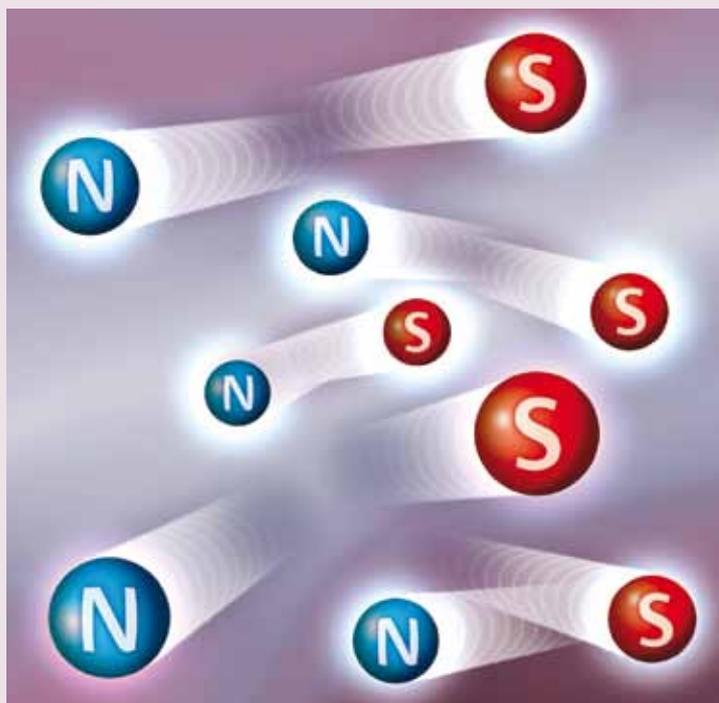
Steven Bramwell and Sean Giblin announced the discovery of the magnetic equivalent of electricity. The discovery is highly significant and paves the way for the control and exploitation of magnetic charge currents ('magnetricity').

It is well known that electric charge can be separated into positive and negative, and then divided into elementary units (electrons, protons). 'Magnetic charge', which defines the north and south poles of magnets, is generally considered not to be separable in this way, although to do so would not, in fact, violate any laws of physics (for physicists: magnetic charge describes sources and sinks in the H-field, not the B-field).

The researchers showed that in a particular type of substance- a so called 'spin ice'- magnetic charge exists in well defined atom sized packets that form currents just like electric currents in ionic solutions. Adapting a 1934 theory of ionic current, they were able to characterise the conductivity (including deviations from Ohm's law) and to measure the elementary magnetic charge.

Spin ice magnetic charges were previously predicted theoretically and termed 'monopoles', due to their close analogy with Dirac monopoles, particles predicted to exist though still unobserved. Recent papers in Science (including one by Prof. Bramwell and collaborators) pointed to the likely existence of spin ice monopoles, but this work relied heavily on the theory of spin ice.

In Prof. Bramwell's latest Nature publication the method of charge measurement is material-independent. The experimentally measured elementary magnetic charge was found to be 5 Bohr magnetons per Angstrom, which is precisely equal to the theoretical prediction, proving the existence of spin ice monopoles beyond doubt.



The magnetic equivalent of electricity in a 'spin ice' material: atom sized north and south poles in spin ice drift in opposite directions when a magnetic field is applied.

Physics and Astronomy Outreach Projects

The Science Centre at UCL

Mr Tom Skilbeck describes below, the work of The Science Centre. The Science Centre provides science lectures for school children, aimed at years 12 and 13. The lectures are also open to members of the general public. It has been run by Dr Sadiq Kadifachi since 1987 and hosted at UCL for the past 13 years.

Mr Skilbeck regularly brings his daughter Olivia to the lectures. Olivia attends Wycombe Abbey School, Buckinghamshire.

'The Science Centre at UCL provides a comprehensive science education support service for science students. Core to its mission is the series of weekly Friday evening lectures given during term time by some of the top university academic staff and researchers in the UK.

The presentations are on a wide variety of scientific topics in the fields of physics, biology, chemistry, biochemistry, astrophysics, medical physics, engineering, computer science etc, and incorporate the latest relevant scientific thinking. The standard of the lecturers is very high and the content pitched at the level of the intended school 6th form audience (although the lectures are open to all members of the public). Not surprisingly, the lectures are immensely

popular with schools in the London area and those from outside town within reach of UCL by the start of the lectures.

The structure of each lecture varies from formal computer image supported presentations to informal hands-on practical demonstrations involving significant audience participation, depending on the preferred style of the presenter. This variety adds greatly to the enjoyment of those able to attend the lecture series as no two talks are alike. The lectures usually last about one hour and are followed by a lively half an hour of formal audience questions. The meeting then disbands and is followed by an informal scientific discussion *mêlée* involving the speaker and interested audience members, which can last up to a further hour.

Lecture participants are not expected to have extensive scientific knowledge beyond the school syllabus, but clearly, enthusiasm and self study greatly extend the benefits to be derived from each talk. In addition, audience members may be exposed to areas of science with which they are not very familiar, and these can prove to be life-changing inspirational moments for some, especially with reference to choosing courses for university study. Despite coming from a wide variety of educational backgrounds, there is always a great *élan* and *esprit de corps* amongst the audience members at each lecture, which is very much to the credit of the Science Centre and its director.

The Science Centre also provides a valuable scientific literature support service, in terms of scientific magazines



Dr Mike Porter (UCL Chemistry Department) giving a demonstration lecture on 'chemistry through the looking glass'



Prof. Michael Green FRS (Cambridge University) giving a lecture on 'superstrings theory', in the Chemistry Auditorium theatre.

'The first talk we attended entitled 'chemistry through the looking glass' (by Dr Mike Porter) was very informative and had several demonstrations to help understand mirror molecules. It was fascinating to find out that these molecules have different properties even though they have the same atoms in the molecule. These molecules exist naturally and can also be man made and each mirror molecule can have a different effect on the body. Thalidomide is one of these molecules where the left hand molecule causes deformities in babies and the right hand molecule relieves morning sickness.

The second was a discussion about 'superstring theory', (by Prof. Michael Green) and the current understanding of how the Universe is made up. Students again were intrigued to find out that there is a Planck distance and a Planck time, which appear to be the fundamental measures of distance and time.

We have brought between 30 and 40 students, mainly sixth form and have discussed the talks with enthusiasm and all of them have requested that we attend more talks which we intend to do.'

Lynn Peek, Chemistry teacher

Southend High School for Boys, Southend-on-Sea, Essex

and books which may be read on site or borrowed. Scientific information and assistance is also provided for students, and this can be particularly useful for school project and coursework. Dr Kadifachi is very attentive to the individual needs of students.

The UCL Science Centre can greatly assist science candidates by expanding their scientific horizons beyond the strictures of the school scientific syllabus. It fully deserves its continuing success and support.'

Tom Skilbeck



Dr Stan Zochowski (UCL Physics and Astronomy) giving a lecture demonstration on magnetism. This sixth form student is cooling a piece of Terbium to liquid nitrogen temperature.

'How I wish we had had this opportunity so many years ago when I was thinking about University. Here I am now, having only just discovered the UCL Science Centre lectures, reorganising my life so as to fit them in.

Hugely instructive, great fun and with insights on the cutting edge of discovery, they have woken my son (who goes to Acland Burghley School) up to the delights of science and several contemporary acquaintances too. I was struck by the interest, the absorption, of the young people who had given up their time to attend. This was not a game or an entertainment, this was about their lives and where they wanted to be sometime in the not too distant future.

The lectures are always full to overflowing. The atmosphere is great. All we need now is the new year list of subjects.'

*David Green, parent
London*

RESEARCH HIGHLIGHT

MINOS Co-spokesperson

Prof. Jenny Thomas has been elected Co-spokesperson of the MINOS experiment, an international collaboration of 140 scientists from across the world. Jenny is a member of the High Energy Physics (HEP) group and Chair of the STFC Science Board.



The MINOS experiment set out to study a recent discovery that neutrinos, elusive neutral partners of the charged leptons of which there are three types, or 'flavours', have a very small but non-zero mass and because of this 'oscillate' from one flavour to another as they travel along at almost the speed of light.

The neutrinos are produced at the NuMI facility at Fermi National Accelerator Laboratory in Illinois and are first measured there before their journey of 730 km through the earth to northern Minnesota where their flavour and energy are measured again. The experiment has already measured the neutrino oscillation parameters to the highest precision in the world and is now starting to take data with anti-neutrinos.

"It is really an exciting time to be taking over the helm of this experiment" says Jenny, "we have a number of world leading measurements in the process of being published but we also have another data set of the same size which we will analyse in the new year. The anti-neutrino running has just started and the comparison of the neutrino oscillation parameters and those of the anti-neutrinos will be a very important fundamental measurement with broad implications for particle physics and cosmology. Presently MINOS is leading the world on a number of neutrino measurements and will continue in that position for some time".

The International Year of Astronomy (IYA) 2009

The 62nd General Assembly of the United Nations declared 2009 to be the International Year of Astronomy (IYA).

Astronomy related milestones in 2009 included: the 400th anniversary of the earliest use of the telescope for astronomical observations, first by the English polymath Thomas Harriot and subsequently (and more famously) by Galileo; the 400th anniversary of the publication of Kepler's 'Astronomia Nova', in which he laid out his laws of planetary motions; and the 40th anniversary of the first manned Moon landings.

Activities were organized throughout the world to celebrate IYA, including, at UCL, 'Moonwatch' at the Observatory, 'Your Universe' and 'Galileo Galileo!'

Dr Mark Westmoquette describing his work on the M82 galaxy in one of his lectures during the 'Your Universe' festival.



Your Universe

Your Universe is the UCL festival of astronomy celebrating IYA 2009. The festival proved to be a huge success and ran twice in 2009 for a total of nine days. We were delighted to have the President and Provost of UCL, Prof. Malcolm Grant touring the exhibits and delivering an exciting opening speech for the autumn event. Activities included around 30 thought-provoking lectures, along with many interactive displays such as 'Play God: build the Universe', which involved building the Universe along a fourteen metre time line and 'The Magic Planet' (figure 1). This was



Figure 1. PhD student Emily Hall explaining the 'The Magic Planet' exhibition. Here the planet is displaying an image of Jupiter.



Figure 2. Small groups of school children toured the optical laboratories and research offices during the autumn event.

a spherical projection able to reproduce any planet or star with all its motions, colours and landscapes. For the earth, you could choose to see clouds, weather patterns, movements of the continents, global warming and many more. The autumn event saw small groups of school children touring the optical laboratories and research offices (see figure 2).

Major exhibits were provided by the University of London Observatory showing posters, videos and portable telescopes to observe the Sun, Venus, the Moon and Jupiter.

A secondary school teacher commented

'A fantastic day. Took a group of fifteen year olds and they were genuinely inspired by the work carried out at UCL. Our tour guide was really personable and engaged well with the students. Their highlight was the chance to observe Jupiter and its moons through one of the university's telescopes. They also found the lecture on astrobiology absorbing and rushed to buy books at the end! It is really positive that KS4 students can meet and talk with PhD students about the work they carry out. Thank you very much.'

All lectures, tours and exhibitions were run by UCL Physicists and Astronomers, with invaluable help from PhD and Certificate in Astronomy alumni students. Their contributions and enthusiasm made Your Universe an extremely enjoyable and worthwhile initiative.

Your Universe will be part of the UCL contribution to the National Science and Engineering week 2010, with events scheduled for 12, 13, 14 March.

Please visit www.ucl.ac.uk/youruniverse for further details.

Explorers of the Universe: A photographic exhibition by Max Alexander

Max Alexander is a professional photographer and an alumnus of our further-education Certificate in Astronomy.

He won one of only three IYA-related 'Large Awards' made by the Science & Technology Facilities Council (STFC) as part of their public engagement programme. Max's vision was a major photographic exhibition representing British astronomy through both portraiture and reportage. He asked Prof. Ian Howarth to advise him, initially in drawing up a list of subjects which reflected both the diversity of STFC-supported astronomy, and the diversity of the people involved; and subsequently in other aspects of the project, including short texts outlining the science represented in each image.

The subjects for the final selection of 44 portraits, exhibited at the Royal Albert Hall before going on an international tour of cultural and science centres, range from Lord Rees of Ludlow (the Astronomer Royal) to a 9-year-old amateur. Of particular interest is how well women from UCL are represented, reflecting the strength and breadth of the science they pursue. Of the nine women featured, six are affiliated with UCL, and four are staff members in this Department.



Image courtesy of Max Alexander

Dr Serena Viti

Max's photographs of **Dr Sarah Bridle**, **Dr Hiranya Peiris** and **Dr Giovanna Tinetti** can be seen on page 10/11 of this review. In brief, Sarah is a cosmologist with a particular interest in the use of cosmic gravitational lensing as a probe of the distribution of matter in space. Hiranya Peiris studies the Cosmic Microwave Background, the afterglow of the Big Bang. While Giovanna Tinetti is pioneering a new field of research: the difficult process of measuring the chemical compositions of the atmospheres of planets around distant stars, through the spectral signature of light transmitted through those atmospheres.

Dr Serena Viti studies starbirth and associated chemical processes, both in our own Galaxy and in the distant universe. She is shown here in a chemical laboratory; by happy coincidence, the theme of birth was echoed by Serena's own condition at the time her portrait was taken.

Galileo, Galileo!

Galileo, Galileo! was a project conceived and coordinated by Dr Andrew Charalambous.

It created an opportunity for three artists, Doug Burton, Isambard Poulson and Iwona Abrams, to produce and exhibit work inspired by astronomy. The artists' work was exhibited at the Islington Arts Factory on 23-30 Oct, with a concluding discussion evening 'What does science get from Art?' at UCL in December.



Some of the *Galileo, Galileo!* art work on show at the Islington Arts Factory during a week long exhibition in October, 2009.

This project aimed for art and science to interact in a way which is creative, exciting and visibly inclusive. Science and art are interleaved with each other, and yet they are often portrayed as separate worlds that are poles apart. The interaction between the artists and scientists has created opportunities for better understanding of each other. Art is a catalyst for discussion; not only amongst the art community, but also amongst the science community. It is as important for scientists as it is for the general public to question, re-think and explain the reasons for their work and their understanding.

The artists were introduced to tools and techniques used by astronomers. During 2009 they visited the Royal Observatory Edinburgh, met with astronomers from the Department and visited the Observatory. These experiences enabled the artists to begin to explore astronomers' methods for research and current thinking, as well as the history of astronomy. This project was possible because of the generous support from Arts Council England, Royal Astronomical Society, UCL, and in association with IYA.

RESEARCH HIGHLIGHT

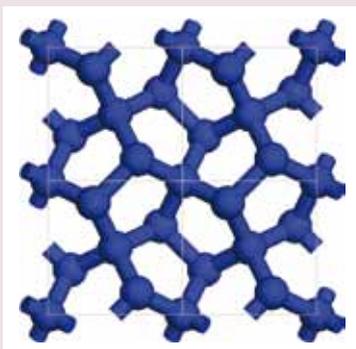
High-pressure phases of nitrogen

C. J. Pickard, R. J. Needs

Physics Review Letters, 102,
125702 (2009)

Nitrogen, as the main constituent of air, is all around us in molecular form – the two nitrogen atoms bound together by extremely strong triple chemical bonds.

Remarkably, when nitrogen is subjected to pressures of around a million atmospheres it adopts a three dimensional framework structure in which each atom is singly bonded to three of its neighbours. The structure is known as “cubic gauche” and was predicted by Mailhot in the early 1990s, and confirmed experimentally by Eremets and co-workers in 2004.



A dense layered phase of non-molecular nitrogen, discovered using Ab Initio Random Structure Searching.

If it could be recovered to ambient pressures, this solid would be expected to be an extremely high energy density material. Chris Pickard and Richard Needs (Cambridge) have applied their Ab Initio Random Structure Searching (AIRSS) approach to crystal structure prediction (this is described in more detail on page 24) to explore the other possible structures of nitrogen at high pressure. They found six new phases which are more stable than those previously studied at some pressures, both new dense packings of molecular nitrogen, and framework structures which are more stable than cubic gauche at very high pressures. Their technique was also featured in *New Scientist*, ‘Solving the crystal maze: The secrets of structure’.

Large Hadron Collider (LHC) Workshop 30 March – 1 April 2009, UCL

We all hope the Large Hadron Collider, which finally started taking collision data at the end of 2009, will be the machine for big discoveries that will possibly change our view of the world of particle physics. However we also know that we can only believe the new experimental results after the accelerator and in particular, the detectors, are well understood. The ideal scenario would be to ‘switch off’ the new physics in the beginning, re-discover the Standard Model as we know it from previous experiments, then explore the wonders of new physics.

The accelerator ramping-up scenario, where at the start we will run at a reduced energy and collision rate, seems to favour this vision. The apparently well-known standard processes can show interesting and unexpected behaviours at LHC energies, and the very high rates and detector coverage will allow high-precision exploration of new corners of the parameter space.

Since the UCL HEP Atlas group is planning to be in the front line in the analysis of the first LHC collisions, a three-day international workshop, jointly organised with Durham on Standard Model discoveries at the LHC was held at UCL between March and April 2009.

The interest in this topic was demonstrated by the attendance of almost 100 theoretical and experimental physicists. Discussion focussed on topics such as the production of vector bosons, top quarks, soft hadrons (the “underlying event”), the exchange of colour-singlet objects and the modern tools (algorithms, MonteCarlo generators, etc.) developed to study them, all in an informal and very lively atmosphere.

Even if the goal is not to start a new regular conference, there will certainly be a follow-up to this meeting some time in summer 2010, when the first LHC data will be available and we’ll see how accurate our ideas and predictions were.

Topics include:

- QCD
- Tools
- Diffraction
- Top physics
- Vector bosons
- Underlying event

<http://www.hep.ucl.ac.uk/smlhc/>
 contact: mario.campanelli@cern.ch
georg.weiglein@durham.ac.uk

University College London
 30th March–1st April 2009

Early LHC Data | For the Standard Model

Research Groups

High Energy Physics (HEP)

Particle physics seeks to understand the evolution of the Universe, in the first fraction of a second after its birth in the Big Bang, in terms of a small number of fundamental particles and forces. The processes involved ultimately resulted in the creation of atoms and the complex molecules that led to our existence.

To probe the conditions that existed in the first billionth of a second after the Big Bang requires extremely high energies or probes to extremely small scales. Experiments capable of reaching such extremes of energy and size are very technically challenging. The challenges include devising precision detectors which can operate in hostile environments, particle accelerators which can achieve high energy collisions, super-sensitive detectors capable of identifying very rare decays with very small 'background noise', high-speed electronics which can read out millions of pieces of information per second, and robust and flexible software which can analyse the data in a distributed computing system all over the world. **Dr Rob Flack** describes just one project which members of the HEP group are involved, the SuperNEMO and NEMO 3 experiments.

SuperNEMO and NEMO 3

In the 1930s an Italian physicist, Ettore Majorana, hypothesized that the neutrino was different from other particles; the neutrino was its own antiparticle. For example the electron carries one unit of negative electric charge and has a mass approximately 2000 times smaller than a proton. The antiparticle of the electron is the positron and can be easily distinguished from the electron because although both of them have the same mass the positron carries 1 unit of positive electric charge.

The neutrino, on the other hand, does not carry electric charge, it is neutral. Hence the question, how can it be distinguished from its antiparticle?

Today we call particles like the electron and the positron, Dirac particles. If the neutrino is its own antiparticle it would be known as a Majorana particle.

There are three types or flavours of neutrinos; electron-neutrino, muon-neutrino and the tau-neutrino. An interesting characteristic of the neutrino is its ability to change, quite spontaneously, from one flavour to another as it traverses freely through space.

For example the fusion process that powers the Sun produces electron-neutrinos. From the energy generated by the Sun it is possible to calculate how many electron-neutrinos ought to reach the Earth. The observation did not match the theory and the number observed was about one third of that predicted; moreover muon-neutrinos were observed coming from the Sun which was impossible. The only explanation was that the electron-neutrinos were changing into the other flavours in flight. Many experiments have now been carried out to show that this is indeed the case.



Figure 1: The NEMO 3 detector under construction in the LSM. The figure shows the tracker and the calorimeter arranged together in wedges. UCL takes a leading role in the acquisition and analysis of the data.

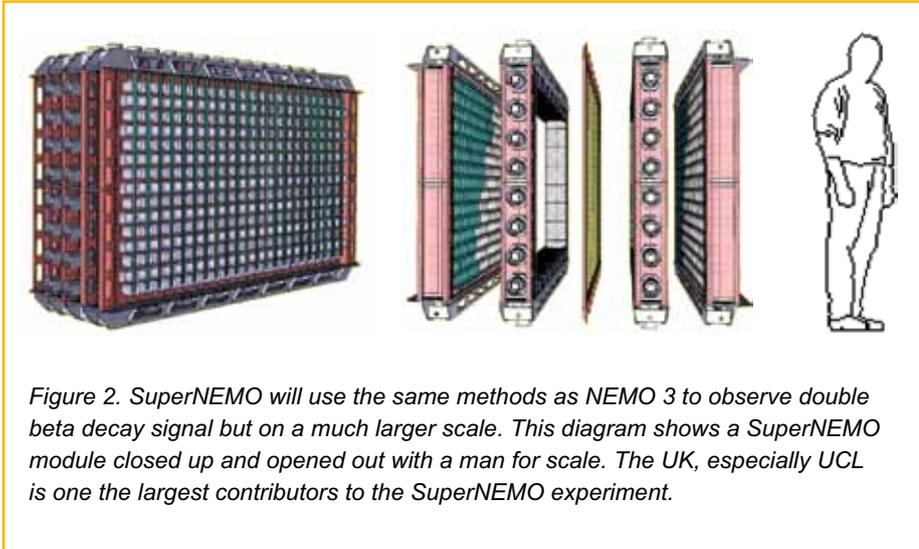


Figure 2. SuperNEMO will use the same methods as NEMO 3 to observe double beta decay signal but on a much larger scale. This diagram shows a SuperNEMO module closed up and opened out with a man for scale. The UK, especially UCL is one the largest contributors to the SuperNEMO experiment.

This process of changing flavour is called neutrino oscillation. Why or how it does this we don't know. For many years it was thought the neutrino did not have any mass. Neutrino oscillation implies that the neutrino has mass and it is known to be very small, more than a million times smaller than the electron. The neutrino is the lightest particle known but the second most abundant one in the universe. At this time, although we know the mass is very small, we still do not know it absolutely.

The Super Neutrino Ettore Majorana Observatory, SuperNEMO, is an experiment designed to measure the mass of the neutrino and to answer the question whether the neutrino is a Dirac or Majorana particle. It is a collaboration of 100 physicists from nine countries. The UK and especially UCL is one of the largest contributors along with the University of Manchester and Imperial College. SuperNEMO follows on from a series of experiments NEMO 1, 2 and 3 and as the name implies it is much larger version and is also far more sensitive. NEMO 3 is still operating today and we are about to begin the construction of SuperNEMO. The NEMO experiments have been observing a process called 'double beta decay'.

There are three kinds of radioactive decay called alpha, beta and gamma. Alpha decay is where an unstable nucleus emits two protons and two neutrons bound together to make the nucleus of a helium atom.

Gamma radiation is a very high energy photon. Beta decay occurs when a neutron decays to a proton and emits an electron and an electron-antineutrino. Conversely a proton can convert to a neutron emitting a positron and an electron-neutrino. The energy carried away by the two particles is called the Q-value and is distributed randomly between the two particles. Therefore if the energy of the electron was measured for many beta decays it would be spread out from zero, when the neutrino carries all of the energy up to the Q-value where the electron carries all of the energy. Most of the time the energy of the electron is around $Q/2$.

Some isotopes can, very rarely, perform two beta decays simultaneously and this process is called double beta decay. Double beta decay is a single process that emits two electrons and two antineutrinos.

There is never a mixture of one electron and one positron plus the associated neutrinos. This process has been observed by NEMO 3 and has measured the half-life for seven different isotopes to be of the order of 10^{19} years. This should be compared to Uranium and Thorium which have half-lives of 10^{10} years.

Therefore in constructing SuperNEMO the amount of normal radioactivity has to be kept very low or it will obscure the signal for double beta decay. It is also thought that an even rarer process can happen where the two electrons are emitted without the two antineutrinos. This is called 'neutrinoless double beta decay' and has yet to be observed but if it is then it will mean that the neutrino is a Majorana particle. In this process the electrons would carry all of the energy and will have a single value, the Q-value for double beta decay. Therefore knowing the Q-values for the isotopes is crucial for the observation of the neutrinoless double beta decay.

It also turns out that the half-life of the neutrinoless double beta decay is directly related to the mass of the neutrino and can be calculated once

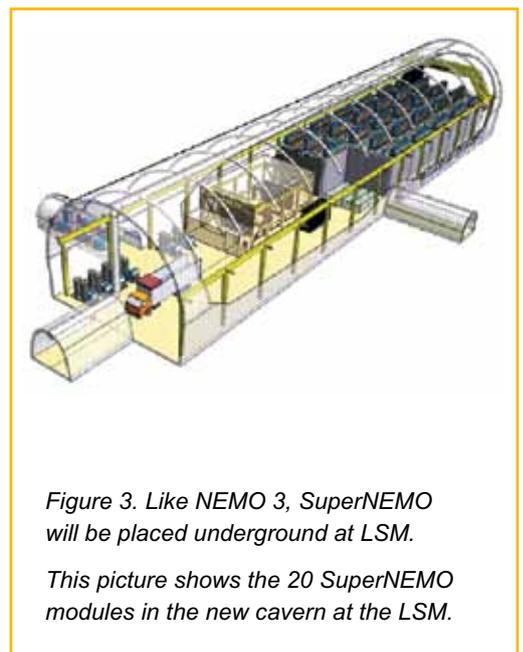


Figure 3. Like NEMO 3, SuperNEMO will be placed underground at LSM.

This picture shows the 20 SuperNEMO modules in the new cavern at the LSM.

the half-life is known. A detector built to observe the double beta decay process has three basic parts; sufficient isotope to provide enough events to observe the process, a tracker to measure the charge of the emitted electrons and a calorimeter to measure the energy of each electron. Both NEMO 3 and SuperNEMO have these ingredients.

NEMO 3 has seven different isotopes that all undergo double beta decay with differing Q-values. The detector is a vertical cylinder (figure 1). The isotopes are spread over curtain like foils suspended inside the detector. The electrons from the double beta decay process leave the foil in opposite directions therefore the tracker and the calorimeter are in two halves placed either side of the foil. The tracker is essentially many Geiger-Muller type detectors (Geiger cells) set in a grid. As the electron passed through each Geiger cell a signal is generated so its path can be traced. After passing through the tracker the electrons then

enter an energy measuring device called a calorimeter. In the calorimeter each electron hits a scintillator which absorbs the energy and then re-emits it as light. A device called a photomultiplier tube converts the light to an electronic signal. The amplitude of the signal is proportional to the amount of energy carried by the electron. A solenoid surrounds the whole apparatus providing a magnetic field which has the effect of bending the path of the electrons; negative particles bending oppositely to positive ones. Therefore we can confirm that we are seeing electrons. To shield the detector from cosmic radiation it was placed underground in the French Alps in the Laboratoire Souterrain de Modane (LSM).

SuperNEMO will use the same methods as NEMO 3 to observe the double beta decay signal but on a much larger scale (figure 2).

In NEMO 3 the total mass of all of the isotopes is 10 kg whereas in SuperNEMO it will be 100 kg.

Consequently the area of the foils over which the isotope is spread will be much larger and there will have to be a bigger tracker and calorimeter. The baseline design splits the detector into 20 rectangular modules each with 5 kg of isotope. The tracker for each module will have to be wired using a robot because the number of wires is too great for a human operator to do in a reasonable space of time. Like NEMO 3, SuperNEMO will also be placed underground. The present laboratory space at the LSM is too small for 20 modules and will have to be extended, (figure 3). Construction of the first module is due to begin in 2010 in a specially built UCL laboratory on the same site as the Mullard Space Science Laboratory (figure 4). It will then be moved to the new cavern at the LSM and begin taking data in 2013. The other modules will be installed in 2014/15 and as each one comes on line so they will also start taking data. The experiment requires five years of data and therefore will run until at least 2020.



Figure 4. The Nu-laboratory at MSSL where the first SuperNEMO module will be built in 2010. This laboratory is a clean room and was opened in 2008. It will be used for projects in the relatively new field of neutrino astronomy.

Atomic, Molecular, Optical and Positron Physics (AMOPP)

The Atomic, Molecular, Optical and Positron Physics group has an enormous range of research activities, both theoretical and experimental.

The research spans from the fundamental to the applied and encompasses the following broad topics: positron, positronium and electron collisions, ultracold gases, quantum chaos and statistical physics, ultrafast laser spectroscopy and strong laser interactions, biological physics and optical tweezers, atomic and molecular spectroscopy, and quantum information. The group comprises of 15 members of academic staff, almost equally divided between theory and experiment.

A number of AMOPP theorists study Quantum Information, a relatively young branch of physics, in which the counter-intuitive properties of quantum mechanics are investigated, in order to exploit them for new applications such as quantum computation and quantum cryptography.

There are diverse research activities within this sub-group. **Dr Dan Browne's** interests include the special 'non-classical' correlations which arise in many-body quantum systems and how they may be exploited for quantum information processing, as well as the implementation of quantum computing in optical systems. **Prof. Tania Monteiro's** theoretical quantum dynamics research investigates the role of nonlinear dynamics, including chaos, in cold atoms as well as in other physical systems relevant to quantum information and quantum sensing. In the last year, the response of a Bose Einstein Condensate to short pulses from a laser was found to be associated with a type of resonance which is extraordinarily sensitive to the pulse period; and a new type of quantum ratchet which may be used

to manipulate fermionic atoms was proposed. **Dr Alexandra Olaya-Castro** studies coherent quantum phenomena in complex molecules, work which hopes to shed light on the question of whether quantum effects may play an important role in photo-synthesis in plants.

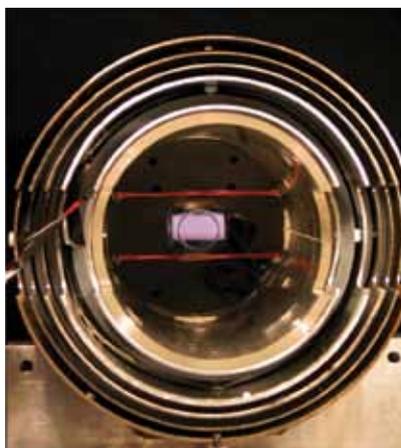


Figure 1: A quantum memory unit in Prof Eugene Polzik's laboratory in Copenhagen. Dr Serafini is collaborating with this group and providing theoretical input on the project.

The centre of the unit is a gas cell filled with a vapour of Caesium atoms. The metal circular objects are magnetic shielding to help protect the stored quantum information from external noise sources and thus prolonging the lifetime of the stored information.

This article will focus on the research from the groups of **Dr Alessio Serafini** and **Prof. Sougato Bose**. They study the theory underpinning experimental realisations of quantum information in a variety of physical systems - including trapped atoms, light and chains of interacting particles.

Towards a quantum memory

Light is an ideal carrier for quantum information over large distances, since single particles of light, 'photons', interact only very weakly with their environment as they are transmitted. Thus photons are the leading technology for quantum cryptography, a technology where quantum effects are exploited to achieve unbreakable encryption. Quantum cryptography has already been achieved over long distances (e.g. 150 km between Geneva and Neuchatel in Switzerland). However to increase this distance further new technologies are required. In particular a form of error correction, known as a quantum repeater must be implemented. To achieve a quantum repeater, quantum information must be stored and basic logic operations, the building blocks of a quantum computer, must be performed upon it.

It is difficult to store quantum information in the form of light (since light travels fast - at the speed of light!), so an important component of a quantum repeater is a quantum memory. This is a device which captures and stores the quantum information stored in a photon or light pulse and allows it to be read out at a later time, when it is needed. Such a device is called a quantum memory.

Quantum memory experiments are very demanding, essentially because the unavoidable interaction with the environment rapidly spoils the coherent properties of the stored quantum states. Furthermore it is difficult to control the operations by which quantum information is transferred from the light

onto the memory (this usually consists in a cloud of highly polarised atoms), and vice versa.

As a result of these difficulties, the test of these memories requires a thorough theoretical analysis to understand precisely how well the memory is performing. For example, whether the quality of the quantum information is high enough to satisfy the 'fidelity threshold' which memories have to beat to be considered legitimate 'quantum' memories. Dr Alessio Serafini has collaborated on a project to determine how this 'fidelity', which measures the quality of the quantum memory, may be calculated in experiment.

An experimental project is currently underway in Prof Eugene Polzik's group in Copenhagen (figure 1) where a quantum memory has been constructed using a cloud of Caesium atoms trapped in a gas cell. The quantum information in a light beam is transferred onto these atoms, and subsequently transferred back out onto light to be read out. This experiment may demonstrate the storage of a intrinsically quantum, and very important, family of states called squeezed states for the first time.

Quantum wires with entangled ends

Identifying viable ways to connect and network quantum processors to make a powerful quantum computer has a high technological incentive. For example, such quantum computers, when realised, would enable the simulations of complex systems, and thereby enhance nano-technology.

An important property of elementary quantum particles is called spin. The spin of a particle can be understood as a kind of intrinsic angular momentum in many elementary particles. In the context of quantum information, the spin can be considered to store quantum information in its internal state. When two neighboring spins interact, quantum information can be transferred from one spin to the other.

In a quantum computer, quantum information will need to be transmitted between components of the computer. One can envisage one way of achieving this by constructing a type of connecting wire from a line of stationary spins continuously interacting with each other (a spin chain).

If the interaction between the spins can establish a high amount of 'quantum correlations' or entanglement between the two extreme ends of the wire, then that can be exploited to connect two quantum processors. It is, however, notoriously difficult to ensure this type of 'distant' entanglement, as typically the entanglement in spin chains is extremely short ranged. Much work in 2009 in the group of Prof. Sougato Bose has accordingly focused on devising clever tricks to create such entanglement. One way to do this is to start from a chain of spins in a so-called Neel state, in which alternate spins point in opposite directions (figure 2) and suddenly switch on 'exchange interactions' (interactions that swap the directions of two spins) between neighboring spins of the chain. As shown by Prof. Bose and his PhD student **Hannu Wichterich**, in the course of time a large entanglement develops between the ends of the chain which could be used to link two quantum processors, named Alice and Bob in the figure.

Another way is to use a spin chain is with a so called 'Kondo cloud' where a block of spins are entangled with a single impurity spin. This form of entanglement was thought to be profitless, however Prof. Bose, along with research fellow **Dr Abolfazl Bayat** and in collaboration with Prof Sodano from Italy found that a sudden change in just one of the couplings of the chain can entangle the remotest spins of the chain by an amount which can be distance independent! They show that the 'useless' entanglement of a spin with a Kondo cloud is converted to a useful form, where it is entangled directly with another spin. This would also be a mechanism for directly 'detecting' the extent of a Kondo cloud in a system (which is a holy grail in condensed matter physics), using purely quantum information means.

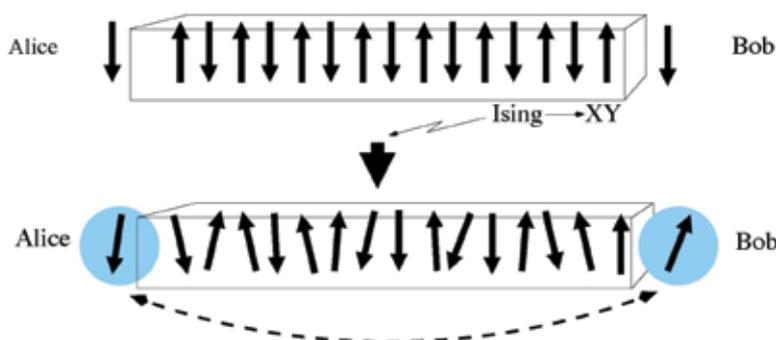


Figure 2: A line of interacting spins is called a spin chain. Spin chains may be important parts of a quantum computer, allowing quantum information to be transferred from one component to another.

Prof Bose and his group showed that by modifying the interactions between spins, high quality quantum correlations could be generated between the ends of the chain, labelled 'Alice' and 'Bob'. This indicates that the spin chain may be used to 'teleport' information around a quantum computer.

Condensed Matter and Materials Physics (CMMP)

The CMMP group offers one of the most exciting environments in the UK for studies in condensed matter physics.

Research within the group spans a wide spectrum of subjects including quantum computing, organic electronics, superconductivity, the physics of the Earth's deep interior, biomagnetism, nanoscale imaging. Currently the group comprises around 90 members, including 26 academic staff and over 50 PhD students, making it one of the largest condensed matter groups in the UK.

Prof. Chris Pickard describes below a strikingly simple and effective scheme which he devised for the prediction of crystal structures from nothing but the knowledge of the atoms involved. He calls it Ab Initio Random Structure Searching (AIRSS), and with his group is exploring its application to problems ranging from the behavior of matter at huge pressures to the understanding and design of energy materials.

Predicting crystal structures

The discovery that matter is made up of atoms ranks as one of mankind's great achievements. Twenty first century science and technology will be dominated by a mastery of our environment at the atomic level – either through biological, chemical or physical means. An obvious challenge for a condensed matter theorist must be – given a collection of atoms, how will they arrange themselves, or what structure will they adopt?

Describing matter at the atomic level demands the use of quantum mechanics - a mechanics for the very small. In principle, to understand and predict the behavior of matter at this scale requires the full solution of the quantum mechanical Schrodinger equation. This is a challenge in itself, but in an approximate way it is now possible to quickly compute the energies and properties of fairly large collections of atoms, using, for example, density functional theory (DFT).

A key question which follows from this is whether it is possible to predict how those atoms will be arranged in Nature - ex nihilo, from nothing but our understanding of the basic laws of physics? Some have referred to our inability to routinely do so as a scandal - but most have simply assumed it to be a very difficult problem.

A minimum energy must be found in a 'many dimensional space' of all the possible structures. Empirical potentials allow a rapid evaluation of total energies, and their energy landscapes have been studied extensively. But only a first principles, quantum mechanical, description of the bonding between atoms can offer reliable predictions of previously unseen structures.

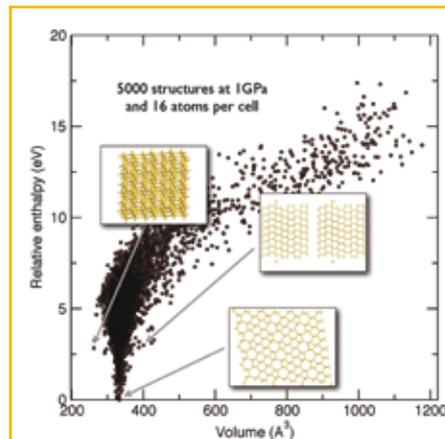


Figure 1: Scrambled silicon. Prof. Chris Pickard discovered a very simple algorithm for the prediction of crystal structures; he calls it Ab Initio Random Structure Searching (AIRSS).

This figure shows the results of applying this method to silicon. Despite no constraints being imposed on either the initial shape of the unit cell, or the positions of the atoms in it, many of the final structures exhibit high symmetry and sensible chemical bonding patterns. A few structures are highlighted – a dense (low volume) phase called beta-tin, a very low energy metastable structure containing five and seven-rings, and a slab of mis-stacked silicon.

Those researchers brave enough to tackle this challenge from first principles have done so by reaching for complex algorithms – such as genetic algorithms, which appeal to evolution to “breed” ever better structures (with ‘better’ taken to mean more stable).

However, Chris Pickard has discovered to his surprise, and to others, that the very simplest algorithm - just throw the collection of atoms into a box, or unit cell, and move the structure ‘downhill’ on the DFT energy landscape - is remarkably effective for moderately sized systems if it is repeated many times. Figure 1 shows the results of doing just this for silicon. It is obvious that the challenge becomes exponentially greater with system size, but to some extent this can be tempered by the judicious choice of constraints. These might be chemical constraints - instead of atoms, molecules can be used as the randomised object. Or crystal symmetry and chemical coordination can be exploited to reduce the dimensionality of the structure space.

The unconstrained approach needs no prior knowledge of chemistry. Indeed the scientist is taught chemistry by its results – which is critical if the method is to be used to predict the behavior of matter under extreme conditions, such as very high pressures (see the examples in figures 2, 3 and 4), where learned intuition typically fails.

It is a unique moment in high pressure physics. Astronomers are, daily, finding new extrasolar planets. The largest, because they are the easiest to detect, have dominated the earliest discoveries. Thus, while Jupiter once set the maximum pressure relevant to the planetary sciences, far higher pressures are now of interest. At the same time, laboratory experiments are now becoming possible at multi-terapascal pressures. Given the relatively few theoretical studies at such high pressures, this has presented an opportunity for the random searching method.

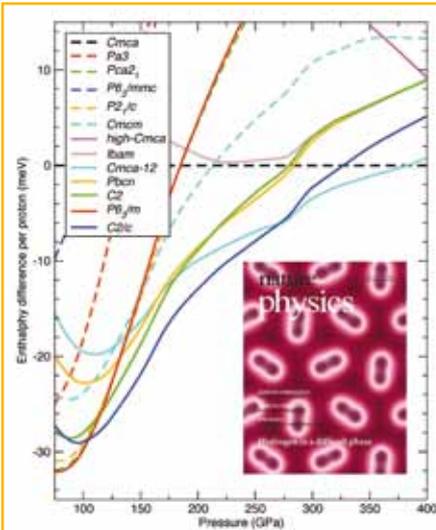


Figure 2: Hydrogen in a difficult phase. The solid lines represent new phases obtained from AIRSS. The most stable structure is a strong candidate for phase III which the first time reproduces both the observed spectroscopic signature and insulating nature. The hydrogen molecules possess a significant electric dipole, as can be seen in the asymmetry in the charge density plotted in the inset image.

(Published in *Nature Physics* 2007)

Materials science aims to create materials that exist nowhere else in the universe, with unique properties, and that are often far from being thermodynamically stable. There has been much discussion of materials design from first principles. Some target property is chosen and the structure and composition is adjusted to attain it. There can, however, be a considerable gulf between a theoretically proposed structure and its synthesis in the lab. AIRSS offers a possible alternative - a route to materials discovery which is decoupled from costly and time consuming experiments. By its nature, the random searching approach generates many more metastable phases than the globally stable one and the ease with which the structures might be synthesised may be indicated by their ease of discovery by random searching. A structure occupying a large region of structure space should be easy to find both theoretically and experimentally. The resulting databases of theoretical structures can be stored and later queried for extreme properties.

The AIRSS Group

Prof. Chris Pickard was awarded a prestigious EPSRC Leadership Fellowship in 2008 and is building a research group focused on extending and using AIRSS to explore materials structure at the atomic level. The random searching approach, being trivially parallelizable, is a perfect fit to the modern, commodity multicore, computer architecture. The group is building a 'computational crucible' designed for the very highest throughput of computed structures. **Dr Andrew Morris** pioneered the use of AIRSS to predict the likely imperfections of crystals (defects) and is now extending these ideas to understanding lithium battery materials.

Dr Maria Baias joined the group with considerable experience in experimental solid state nuclear magnetic resonance (NMR). She is combining AIRSS calculations with DFT predictions of NMR parameters and NMR experiments to

understand the very complex symmetry breaking in ferroelectric perovskites.

Dr Miguel Martinez-Canales has just arrived in the group and will be exploring materials under extreme conditions – theoretically!

The 16 October 2009 issue of *New Scientist* featured a article 'Solving the crystal maze: The secrets of structure' highlighting Chris Pickard's work.

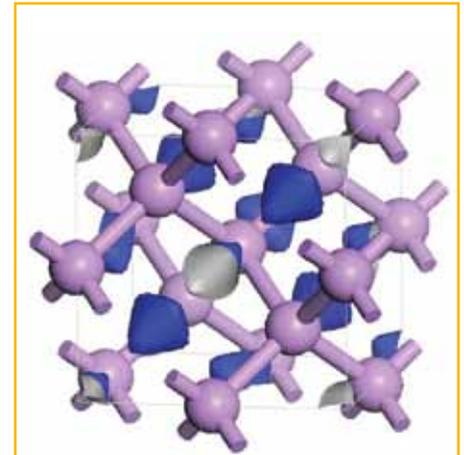


Figure 4: Dense lithium: an elemental electride. The high pressure phase diagram of lithium is very rich, and a great challenge to both experiment and theory.

An AIRSS study has found that lithium adopts the diamond structure above 450 GPa. Being a relatively open structure, this is a surprise.

However, the puzzle is resolved by thinking of the structure instead as a closely packed ionic structure, with the 2s electron of the lithium squeezed into the voids. Such an ionic crystal, with an electron as an anion, is known as an electride.

(Published in *Physical Review Letters* 2009)

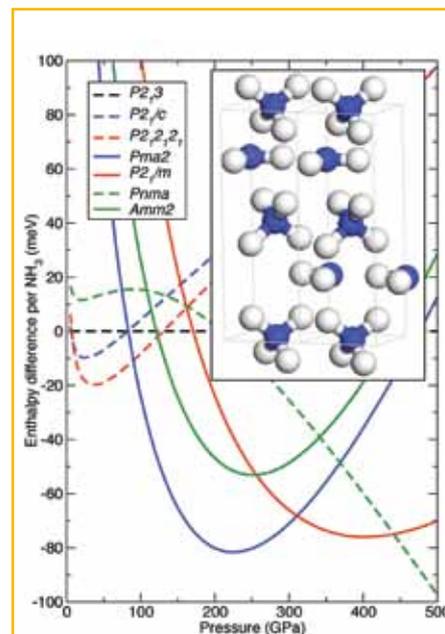


Figure 3: Ammonia: an ionic crystal. Solid ammonia is predicted to be formed of layers of NH_2^- and NH_4^+ at pressures of about 100GPa, which is readily accessible in modern diamond anvil cell experiments. Above 450GPa it is predicted to return to a hydrogen bonded molecular crystal consisting of NH_3 units. In the above enthalpy plot solid lines indicate ionic compounds.

(Published in *Nature Materials* 2008)

Astrophysics (Astro)

The Astrophysics Group at UCL is one of the largest and most active in the UK. The main subgroups are Atmospheric Physics (APL), Circumstellar and Interstellar Environments, Extrasolar Planets, Galaxies & Cosmology, Massive Stars and Clusters, Optical Science Laboratory (OSL), Star Formation and Astrochemistry and the University of London Observatory (ULO).

The group is also involved with the UCL Institute of Origins which is a multi-disciplinary collaboration between the departments of Physics & Astronomy; Space & Climate Physics; Mathematics; and Earth Sciences, to research into the origins and evolution of the Universe, and the basis of life. A small selection of highlights from research undertaken in 2009 is presented below.

Launch of Planck and Herschel satellites

On 14 May 2009 the rocket carrying the Planck satellite and the Herschel Space Observatory, funded by the European Space Agency (ESA), was successfully launched from the Kourou space port, in French Guyana.

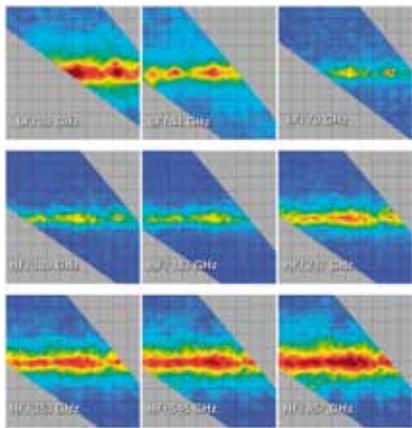


Fig 1: The Planck satellite was launched with the Herschel Space Observatory in May 2009 and will perform detailed measurements of the Cosmic Microwave Background.

This mosaic of maps zooms in on a small part (20x20) deg. of the First Light Survey, in which our own Milky Way shines very brightly. The nine frequencies cover a range from 30 to 900 GHz. Galactic synchrotron emission dominates at lower frequencies and galactic dust emission at the highest, with the CMB peaking in the 70 and 100 GHz bands.

The Planck mission will perform detailed measurements of the Cosmic Microwave Background and its polarisation by making full sky maps at 9 different wavelengths in the range 300 micrometres (microns) - 3cm. This is illustrated by figure 1, which zooms in on the region around the Milky Way. The satellite reached its destination at 1.5 million km from the Earth and, while spinning on its axis, from where it will scan the sky with its multi-wavelength detectors. This is a multi-national collaboration involving 16 countries, including 7 UK institutions involved with hardware building and software development. The UCL participation in Planck includes **Dr Giorgio Savini**, who selected and calibrated the optics for the High Frequency Instrument, and **Dr Hiranya Peiris**, who is involved with preparing and interpreting the cosmological data that Planck will harvest.

The Herschel Space Observatory took up its station 1.5 million km from the Earth and is already sending back large quantities of high quality imaging and spectroscopic data (figure 2). Herschel has a 3.5m primary mirror, the largest currently in space, and three instruments that between them cover the 57-670 micron wavelength range. UCL has a significant involvement in the UK-led SPIRE instrument, which has several sensitive heat sensitive arrays for imaging three separate wavelengths at 250, 350 and 500 microns, together with an imaging Fourier Transform Spectrometer (FTS) that can cover the 194-670 micron wavelength range with a good resolution.

A team from the Astrophysics Group that includes **Prof. Mike Barlow**, **Dr Giorgio Savini**, **Dr Roger Wesson**, **Dr Mikako Matsuura** and **Dr Jeremy Yates** has helped characterise the in-flight performance of the FTS, whose sensitivity has been measured to be two

to three times better than pre-launch estimates. They have also been leading the scientific analysis of a series of spectra obtained during Herschel's Science Demonstration Phase of high luminosity evolved stars, in whose copious mass loss outflows many molecular and dust species are formed.

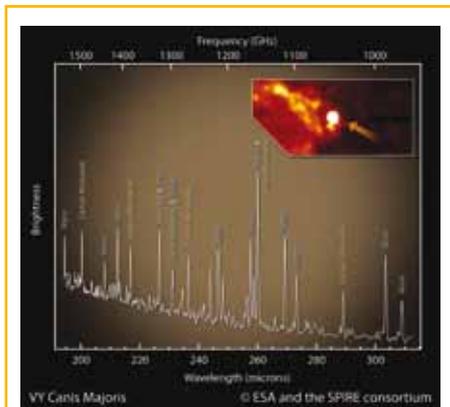


Fig 2: Members of the group are involved in the analysis of imaging and spectroscopic data from the Herschel telescope. In particular, the analysis of the data from the SPIRE instrument and looking at the SPIRE spectrum of VY CMa.

This graph shows part of the SPIRE spectrum of VY Canis Majoris (VY CMa), a giant star near the end of its life, which is ejecting huge amounts of gas and dust into interstellar space, including elements such as carbon, oxygen and nitrogen (which form the raw material for future planets, and eventually life).

The inset is a SPIRE camera image of VY CMa, in which it appears as a bright point-source near the edge of a large extended cloud. The spectrum is amazingly rich, with prominent features from carbon monoxide (CO) and water (H₂O). More than 200 other spectral features have also been identified, many due to water, showing that the star is surrounded by large quantities of hot steam.

Observations like these will help to establish a detailed picture of the mass loss from stars and the complex chemistry occurring in their extended envelopes.

An ESA Press Release featured the SPIRE FTS spectrum of VY Canis Majoris, a very bright oxygen-rich M-type supergiant star with a surface temperature of about 3000 K. Its 194–670 micron spectrum is dominated by strong lines of carbon monoxide and water vapour (steam). Numerical models of the FTS spectrum will determine the relative abundances of the different molecular species.

The FTS spectrum of the carbon star IRC+10216 (a.k.a. CW Leo) exhibits strong absorption lines, due to the molecular species of hydrogen cyanide (HCN), CS and CCH. The presence of weak water vapour lines in the spectrum points to potentially interesting and unusual formation mechanisms. Carbon stars result from the dredging up, from the star's core, to the surface of such large quantities of carbon atoms that the original preponderance of oxygen over carbon at the surface of the star (as in the Sun) is swapped over. This fundamentally alters the chemistry of the surface layers and outflows of such stars. When oxygen dominates ($C/O < 1$), as with VY CMa, then oxygen-rich molecules and dust particles condense but when carbon is sufficiently enriched ($C/O > 1$), as with IRC+10216, then carbon-rich molecules and dust particles can form.

Over the next few years Herschel promises a rich harvest of data in the submillimetre wavelength region, the last astronomical spectral domain yet to be fully explored.

Monitoring the Earth's upper atmosphere: magnetic fields and mirror images

The Atmospheric Physics Laboratory (APL) is involved with the ESA Swarm mission to measure the Earth's magnetic field using 3 satellites in near parallel polar orbits in the upper atmosphere. The precision of the measurements of the Earth's magnetic field will be so high that the satellites will measure the tiny magnetic fields generated by electric currents flowing in the upper atmosphere and in the Earth's oceans. **Prof. Alan Aylward** and **Dr Tim Spain** used the UCL Coupled Thermosphere Ionosphere

Plasmasphere Model to gauge the magnitude of the ionospheric currents along the predicted paths of the Swarm satellites. These tiny magnetic fields will be subtracted from the satellite measurements to determine the pure magnetic field generated by the churning of the Earth's molten outer core. However, the study of ionospheric currents is also important because they distort and disrupt satellite signals. For example, landing a helicopter on an aircraft carrier requires a high precision from GPS navigation systems that rely on upper atmospheric modelling capabilities.

In parallel with modelling planetary atmospheres, the APL has a network of Fabry-Perot Interferometers in Arctic Scandinavia, including an innovative all-sky FPI called a Scanning Doppler Imager on the island of Spitsbergen in Svalbard. These have produced the longest continuous span of measurements of the Earth's upper atmosphere winds and temperatures, which now covers nearly 30 years. Regular field trips are taken to these Arctic observatories by the FPI team: **Dr Anasuya Aruliah**, **Dr Ian McWhirter**, **Dr Eoghan Griffin** and PhD student, **Iris Yiu**, to calibrate the FPIs and run EISCAT radar experiments.

From being remote, inhospitable territories, these Arctic locations have recently become chic tourist ports of call due to TV programs such as Joanna Lumley's trip to see the Northern Lights. However, few tourists venture there in the middle of winter with 24 hours of darkness, 2 metres of snow, and the prospect of meeting a hungry polar bear, which is when we take our observations of the aurora. We are currently investigating mechanisms to link Space Weather (i.e. due to the behaviour of the Sun and solar wind) with weather in the Earth's lower atmosphere. This is important for understanding how much climate change can be attributed to natural variations in the Sun.

This year the first ever comparison was made between Arctic and Antarctic FPI measurements to study how the Earth's

magnetic field lines connect the north and south Polar Regions to produce mirror image behaviour in the upper atmosphere. This is illustrated by figure 3 which shows a map of the Arctic region around Scandinavia. The Antarctic data is mapped onto the Arctic map by following magnetic field lines from South to North Pole. If the Earth's magnetic field was a perfect dipole, then the Arctic and Antarctic contours would match perfectly. In reality the magnetic field is a dipole that is shifted away from the centre of the Earth. This international multi-instrument study will allow us a unique opportunity to investigate the other causes of the asymmetry between the Arctic and Antarctic upper atmosphere such as differences in the ionospheric electrical conductivity and the merging of the Earth's and solar wind's magnetic fields.

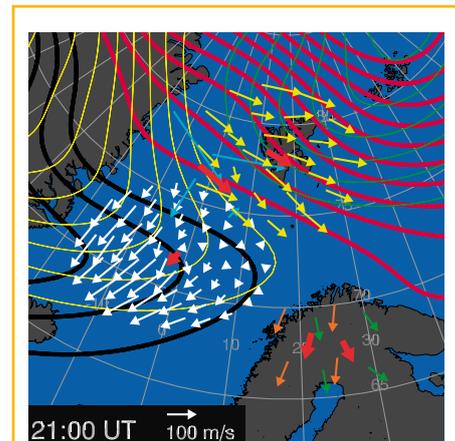


Fig 3: APL group members have been involved in the first ever comparison made between Arctic and Antarctic FPI measurements to study how the Earth's magnetic field lines connect the north and south Polar Regions to produce mirror image behaviour in the upper atmosphere.

Antarctic thermospheric winds (white and blue arrows) measured by La Trobe University, Australia, are superposed on a map of Arctic Scandinavia. The Arctic winds (red, orange, green and yellow arrows) were measured by APL FPIs and SDI. The contour lines indicate the ionospheric currents over the Arctic (black and red), and Antarctic (yellow and green), as measured by the SuperDARN radar network.

Biological Physics

“In many respects, we understand the structure of the universe better than the working of living cells. Stars may be 10^{43} times bigger, but cells are more complex, more intricately structured, and more astonishing products of the laws of physics and chemistry.” (B Alberts *et al.*, *Molecular Biology of the Cell*, 2008).

It may therefore not come as a surprise that physics has contributed and continues to contribute to answering key questions in the life sciences. Our knowledge of DNA structure, for example, is based on the use and interpretation of x-ray scattering, and is the foundation for modern molecular biology.

Biological research activities in the department have recently become more prominent via bio-(logical) physics sections of both the Atomic, Molecular, Optical and Positron Physics and the Condensed Matter & Material Physics groups. Biological physics at UCL is already in splendid shape as witnessed by the presence of a Doctoral Training Centre for interdisciplinary research in the life sciences (CoMPLEX), of a Biophysics Programme and Biophysics

Centre in the Institute of Structural and Molecular Biology (UCL & Birkbeck), of collaborations on cell physics between the London Centre for Nanotechnology and the Department of Cell & Developmental Biology, of life science modelling activities in the Thomas Young Centre (London Centre for Theory and Simulation of Materials), and of various biomedical imaging groups. In addition, a recent UCL-wide initiative on systems biology heavily relies on physical methods to disentangle the complexities of biological systems. UCL will host an international conference on the physical cell in June 2010, and will contribute to the new UK Centre for Medical Research and Innovation (UKCMRI) that aims to use interdisciplinary approaches to understand the biology underlying human health, planned at St Pancras.

The Department is currently in the process of establishing a Biological Physics Group, with the aim of providing a unified portal to biological physics activities at UCL and of further fostering and promoting interactions between physics and life sciences. It will identify common physics/life-sciences research themes at UCL, and use these to initiate and strengthen collaborations between physicists with an interest in life sciences and life scientists with an interest in physical methods. The group is not meant to replace existing departmental or other structures, but will primarily exist as a communication network, most visible via a dedicated web page that comprehensively links to the various research and teaching activities in this field. In addition, it will organise theme-specific dating events.

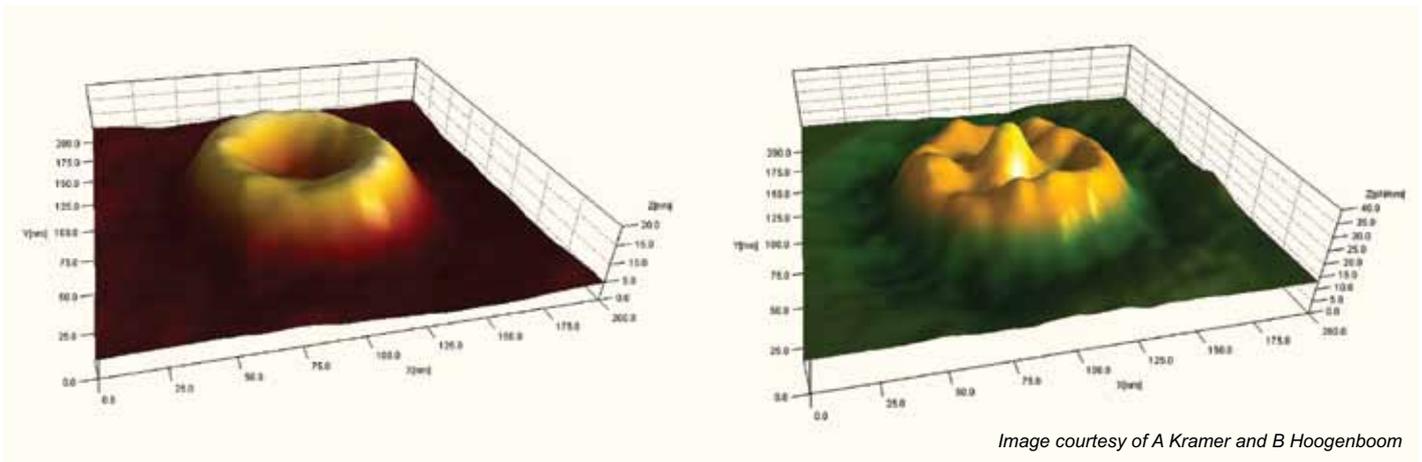


Image courtesy of A Kramer and B Hoogenboom

The image shows a topographic structure (left) and corresponding map of local stiffness (right) for a nuclear pore complex, the main gate for transport in and out of the cell nucleus.

Active Grants and Contracts

(Jan 2009 – Dec 2009)

Astrophysics

The next generation of cosmological surveys (Leverhulme Trust)
£42,000 PI: F Abdalla

University Research Fellowship: Design and exploitation of current and future cosmological surveys (Royal Society)
£464,594 PI: F Abdalla

Studies of the thermospheres and ionospheres: From the earth to the stars (STFC) £1,570,463 PI: A Aylward

Modelling and observations of planetary atmospheres: The solar system and beyond (STFC)
£266,136 PI: A Aylward

The dust enrichment of galaxies: supernovae and evolved stars (STFC)
£133,194 PI: M Barlow

Cosmic vision euclid bridging grant (STFC) £10,087 PI: S Bridle

Constraining and testing cosmological models (Royal Society)
£205,823 PI: S Bridle

Measuring cosmic shear (STFC)
£186,144 PI: S Bridle

University Research Fellowship – Renewal: Quantifying the dark universe using cosmic gravitational lensing (Royal Society) £135,482 PI: S Bridle

The mind of the universe: Series of school/public lectures communicating the excitement of cosmic discovery (STFC) £11,127 PI: F Diego

Smart X-ray optics (EPSRC)
£3,072,089 PI: P Doel

Dark energy survey design work (University of Chicago)
£10,072 PI: P Doel

Zonal biomorph deformable mirror feasibility study (STFC) £19,640 PI: P Doel

Large ultra-thin lightweight, carbon-fibre adaptive mirrors for ELTs (STFC)
£347,447 PI: P Doel

Large aperture telescope technology (ESA) £22,921 PI: P Doel

WFMOs Design Study (STFC)
£18,319 PI: P Doel

Astronomy in the classroom: School and observatory visits (STFC)
£13,354 PI: M M Dworetsky

Astronomy in the classroom: School and observatory visits (STFC)
£8,200 PI: M M Dworetsky

PATT Support (STFC)
£52,013 PI: I Howarth

KTP with Zeeko Ltd (KTP)
£188,667 PI: C King

Cosmology with the new generation of photometric redshift surveys (STFC)
£186,144 PI: O Lahav

Astrogrid 2 (STFC)
£22,113 PI: O Lahav

A wide-field corrector for the dark energy survey (STFC)
£1,762,660 PI: O Lahav

Cosmology: from galaxy surveys to dark matter and dark energy (STFC)
£839,172 PI: O Lahav

Wolfson Research Merit Award: Observing dark energy (Royal Society)
£100,000 PI: O Lahav

Dark energy survey collaboration (University of Nottingham)
£300,000 PI: O Lahav

Astrogrid 3 (STFC)
£12,298 PI: O Lahav

Comets as laboratories: observing and modelling cometary spectra (STFC)
£78,616 PI: S Miller

Europlanet: European planetary network research infrastructure (EU)
£218,024 PI: S Miller

Advanced Fellowship: Cosmic acceleration – connecting theory and observation (STFC) £304,205 PI: H Peiris

The e-MERLIN radio astronomy revolution: developing the science support tool (Leverhulme Trust)
£124,272 PI: R Prinja

UCL astrophysics short term visitor programme 2006-2009 (STFC)
£25,661 PI: R Prinja

Clusters, starbursts and feedback into the environments of galaxies (STFC)
£499,485 PI: J Smith

Exploring extra-solar worlds: from terrestrial planets to gas giants (Royal Society)
£413,232 PI: G Tinetti

Detecting biosignatures for extrasolar worlds (STFC)
£274,039 PI: G Tinetti

Mapping cosmic evolution with high-redshift clusters (STFC)
£251,250 PI: C Van Breukelen

Chemistry as a probe of physical evolution in the interstellar medium (Royal Society) £9,930 PI: S Viti

Clumpiness in star forming regions (STFC) £206,257 PI: S Viti

Chemistry in galaxies at high redshifts (Leverhulme Trust) £112,381 PI: S Viti

On-machine metrology for surface fabrication (STFC) £298,258 PI: D Walker

Integrated knowledge centre in ultra precision and structured surfaces (EPSRC) £391,853 PI: D Walker

Ultra-precision surfaces – translation grant (EPSRC) £681,546 PI: D Walker

High Energy Physics

Development and maintenance of ATLAS run time tester (CCLRC)
£45,000 PI: J Butterworth

MCnet – Monte Carlo event generators for high energy particle physics (European Commission)
£171,985 PI: J Butterworth

Wolfson Merit Award: Electroweak symmetry breaking and jet physics with ATLAS at the LHC (Royal Society)
£85,000 PI: J Butterworth

Probing the ultra-high energy universe with neutrinos as cosmic messengers (Royal Society)
£121,500 PI: A Connolly

ARTEMIS – Investigation of the electroweak symmetry breaking and the origin of mass using the first data of ATLAS detector at LHC (European Commission)
£228,959 PI: N Konstantinidis

Higgs-ZAP: Understanding the Origin of Mass with the ATLAS experiment at the Large Hadron Collider (EU) £33,750 PI: N Konstantinidis

Experimental particle physics at UCL (STFC) £1,288,506 PI: N Konstantinidis

Investigating neutrino oscillations with MINOS and neutrino astronomy with ANITA (Royal Society) £438,868 PI: R Nichol

Detection of ultra-high cosmic ray neutrinos with ANITA and investigation of future large scale detectors (STFC)
£281,290 PI: R Nichol

PNPAS knowledge exchange award: Cream tea – phase 1 (STFC) £100,000 PI: R Nichol

University Research Fellowship – Higgs physics at ATLAS (Royal Society)
£244,218 PI: E L Nurse

Measurement of the neutrino mass spectrum with oscillation and double beta decay experiments (STFC)
£236,269 PI: R Saakyan

Design study of the superNEMO experiment (STFC) £753,999 PI: R Saakyan

Studentship for superNEMO design study (STFC) £15,808 PI: R Saakyan

Signatures beyond the standard model (STFC) £65,792 PI: J Smillie

ILIAS – Integrated large infrastructures for astroparticle science (European Commission) £12,096 PI: J Thomas

Deputy chair of science board (STFC) £55,515 PI: J Thomas

Wolfson Merit Award: New frontiers in neutrino physics (Royal Society)
£75,000 PI: J Thomas

Global fits for parton distributions and implications for hadron collider physics (STFC) £150,675 PI: R Thorne

Theoretical particle physics rolling grant (STFC) £193,765 PI: R Thorne

Institute of Physics phenomenology associateship 2009-10 (IPPP) £4000 PI: R Thorne

GridPP Tier-2 support (STFC)
£42,244 PI: B Waugh

GridPP Tier- 2 support (STFC)
£128,479 PI: B Waugh

The development of acoustic detection, reconstruction and signal processing techniques and their application to the search for ultra-high energy cosmic ray neutrinos (Defence Science and Technology Laboratory) £12,930 PI: D Waters

Royal Society Fellowship: Electroweak physics and Higgs searches at the CDF experiment (Royal Society)
£159,768 PI: D Waters

CALICE: Calorimetry for the international linear collider (STFC)
£138,596 PI: M Wing

EUDET: Detector research and development towards the international linear collider (European Commission)
£207,685 PI: M Wing

LC-ABD Collaboration: Work package 9: Cavity BPM energy spectrometer (STFC) £203,957 PI: M Wing

Atomic, Molecular, Optical and Positron Physics

Dorothy Hodgkin Fellowship: Dynamics of information in quantum many-body systems (Royal Society) £374,692 PI: J Anders

Excited state photoengineering: Virtual crystallography – A new approach to spectroscopy, molecular dynamics and structure (EPSRC)
£625,471 PI: A Bain

Manipulating molecules with optical fields (EPSRC) £237,552 PI: P Barker

Creating ultra-cold molecules by sympathetic cooling (EPSRC)
£1,264,848 PI: P Barker

Spin chain connectors, entanglement by measurements and mesoscopic quantum coherence (EPSRC)
£783,478 PI: S Bose

Wolfson Research Merit Award: Quantum information uses of complex systems and limits of the quantum world (Royal Society) £75,000 PI: S Bose

Quantum information processing interdisciplinary research collaboration (EPSRC) £87,678 PI: S Bose

Developing coherent states as a resource in quantum technology (EPSRC)
£79,725 PI: S Bose

Quantum information processing interdisciplinary research collaboration (EPSRC) £91,493 PI: D Browne

Ionization of multi-electron atomic and molecular systems driven by intense and ultrashort laser pulses (EPSRC)
£812,136 PI: A Emmanouilidou

Alternative S-matrix approaches for matter in strong laser fields (EPSRC)
£310,014 PI: C Faria

Electron correlation in strong laser fields: a time-dependent density functional treatment (Daresbury Laboratory) £17,937 PI: C Faria

Nanofibre optical interfaces of ions, atoms and molecules (EPSRC) £202,297 PI: P Jones

Pairing and molecule formation in ultra cold atomic gases (Royal Society)
£261,740 PI: T Kohler

Pairing and molecule formation in cold atomic bose and fermi gases (EPSRC)
£855,268 PI: T Kohler

Positron reaction microscopy (EPSRC)
£604,297 PI: G Laricchia

Collaborative computational project 2 (EPSRC) £64,759 PI: T Monteiro

Postdoctoral Fellowship: Suppressing decoherence in solid-state quantum information processing (EPSRC) £258,549 PI: A Nazir

Exploiting quantum coherent energy transfer in light-harvesting systems: Career Acceleration Fellowship (EPSRC) £741,637 PI: A Olaya-Castro

Bridging the gaps across sustainable urban spaces (EPSRC) £6,352 PI: A Olaya-Castro

Brownian motors, disorder and synchronization an optical lattice (Leverhulme Trust) £21,600 PI: F Renzoni

Cooling of atoms in optical cavities by collective dynamics (EPSRC) £457,631 PI: F Renzoni

New rectification mechanisms in cold atom ratchets (Royal Society) £12,000 PI: F Renzoni

Metrology in cold atoms (British-Israeli Research and Academic Exchange Partnership) (British Council) £3,240 PI: F Renzoni

Newton International Fellowship: Quantum Network Dynamics (Royal Society) £56,000 PI: S Severini

Opacity functions for hot molecules (Royal Society) £12,000 PI: J Tennyson

QUASAAR – Quantitative spectroscopy for atmospheric and astrophysical research (European Commission) £126,788 PI: J Tennyson

Dynamic imaging of matter at the attosecond and angstrom scale (EPSRC) £101,769 PI: J Tennyson

An opacity function for ammonia (Leverhulme Trust) £59,480 PI: J Tennyson

Positron scattering from molecules at low energies using R-matrix method (Royal Society) £15,820 PI: J Tennyson

Electron initiated chemistry in biomolecules (EPSRC) £375,727 PI: J Tennyson

CAVIAR (NERC) £396,342 PI: J Tennyson

Detailed modelling of quantum electron molecule scattering in radioactive waste (EPSRC) £26,777 PI: J Tennyson

A Database for water transitions (NERC) £185,336 PI: J Tennyson

UK R-Matrix atomic and molecular physics HPC code development project (EPSRC) £315,419 PI: J Tennyson

The above dissociation spectrum of water (Royal Society) £4,162 PI: J Tennyson

Understanding the spectrum of ammonia (Royal Society) £12,000 PI: J Tennyson

Fundamental issues in the aerothermodynamics of planetary-atmosphere (Re)entry (ESA) £24,499 PI: J Tennyson

VAMDC – Virtual Atomic and Molecular Centre (EU) £402,390 PI: J Tennyson

Pathfinder – using simulations to reduce industrial costs and the environmental consequences of plasma etching (NERC) £7,603 PI: J Tennyson

CASE studentship for Stephen Harrison (STFC) £66,421 PI: J Tennyson

Dynamic imaging of matter at the attosecond and angstrom scales (EPSRC) £70,788 PI: J Underwood

The study and control of condensed phase molecular dynamics via femtosecond laser techniques (Royal Society) £14,138 PI: J Underwood

Condensed Matter and Materials Physics

Many CMMP grants are held through the London Centre for Nanotechnology

University Research Fellowship: Computer simulation of redox and hydrolysis reactions in enzymatic systems (Royal Society) £186,847 PI: J Blumberger

Modelling charge transport in conducting polymers and biological systems (IRC Cambridge University) £17,468 PI: D Bowler

Structure and conduction mechanisms of atomic-scale wires on surfaces (Royal Society) £172,260 PI: D Bowler

Bio-inspired materials for sustainable energy (University of Cambridge) £115,580 PI: D Bowler

THREADMILL – Threaded molecular wires as supramolecularly engineered materials (European Commission) £310,691 PI: F Cacialli

ONE-P – Organic nanomaterials for electronics and photonics: Design, synthesis, characterization, processing, fabrications and applications (EU) £289,501 PI: F Cacialli

SUPERIOR: Supramolecular functional nanoscale architectures for Organic electronics: a host-driven network (EU) £314,284 PI: F Cacialli

Exploring new graphitic superconductors: Charge transfer, excitations and dimensionality (EPSRC) £621,904 PI: M Ellerby

Monte Carlo and molecular dynamics approaches to cluster free energies (Royal Society) £900 PI: I Ford

Hyperthermia characterisation of magnetic nanoparticles (MNPs) for cancer treatment (Royal Society) £15,000 PI: T Nguyen

University Research Fellowship: Nanomaterials for biomolecular sciences and nanotechnology (Royal Society) £132,508 PI: T Nguyen

Bio-Functional magnetic nanoparticles: novel high-efficiency targeting agents for localised treatment of metastatic cancers (EPSRC) £13,069 PI: Q Pankhurst

Leadership Fellowship: Ex nihilo crystal structure discovery (EPSRC) £1,338,602 PI: C Pickard

Support for the UK Car-Parrinello consortium (EPSRC) £7,931 PI: C Pickard

Studentship - Laser materials interactions (PNNL) £31,000 PI: A Shluger

New Materials for hydrogen storage and large area solar cells (Wolfson Foundation grant) (Royal Society) £200,000 PI: N Skipper

Studentship: T Headon (Schlumberger Cambridge Research) £6,000 PI: N Skipper

Decommissioning, immobilisation and management of nuclear waste for disposal (EPSRC) £84,733 PI: N Skipper

University Research Fellowship: Electron gas in reduced ionic insulators and semiconductors (Royal Society) £470,269 PI: P Sushko

Publications 2009

Astrophysics

1. S. Thomas, F.B. Abdalla and O. Lahav, **Constraining modified gravity and growth with weak lensing**, *Monthly Notices of the Royal Astronomical Society (MNRAS)*, 395, 197-209 (2009)
2. G. Savini, P.A. Ade, J. House, G. Pisano, V. Haynes, P. Bastien, **Recovering the frequency dependent modulation function of the achromatic half-wave plate for POL-2: the SCUBA-2 polarimeter**, *Applied Optics*, 48, 11, 2006 (2009)
3. P.A.R. Ade, D.T. Chuss, S. Hanany, V. Haynes, B.G. Keating, A. Kogut, J.E. Ruhl, G. Pisano, G. Savini, E.J. Wollack, **Polarization modulators for CMBPol**, *J. Phys.: Conf. Series*, 155, 1, 012006 (2009)
4. T. Matthews, G. Savini, et al, **BLAST-pol: The Balloon-borne Large Aperture Submillimeter Telescope Plus Polarimeter**, *Bulletin of the American Astronomical Society*, 41, 437 (2009)
5. I.S. Konstantopoulos, N. Bastian, L.J. Smith, M.S. Westmoquette, G. Trancho, J.S. Gallagher, **A Spectroscopic Census of the M82 Stellar Cluster Population**, *The Astrophysical Journal (ApJ)*, 701, 1015 (2009)
6. I.S. Konstantopoulos, N. Bastian, L.J. Smith, M.S. Westmoquette, G. Trancho, J.S. Gallagher, **New results on the ages of star clusters in region B of M82**, *Astrophysics and Space Science*, 173 (2009)
7. C. Bertucci, B. Sinclair, N. Achilleos, P. Hunt, M. K. Dougherty, C.S. Arridge, **The variability of Titan's magnetic environment**, *Planetary and Space Science*, 57, 1813-1820 (2009)
8. A. Masters, N. Achilleos, C. Bertucci, M.K. Dougherty, S.J. Kanani, C.S. Arridge, H.J. McAndrews, A.J. Coates, **Surface waves on Saturn's dawn flank magnetopause driven by the Kelvin-Helmholtz instability**, *Planetary and Space Science*, 57, 1769-1778 (2009)
9. N. Achilleos, P. Guio, C.S. Arridge, **A model of force balance in Saturn's magnetodisc**, *MNRAS*, 1751A (2009)
10. P. Guio, N. Achilleos, **The VOISE algorithm: a versatile tool for automatic segmentation of astronomical images**, *MNRAS*, 398, 1254-1262 (2009)
11. N.M. Schneider, M.H. Burger, E.L. Schaller, M.E. Brown, R.E. Johnson, J.S. Kargel, M.K. Dougherty, N. Achilleos, **No sodium in the vapour plumes of Enceladus**, *Nature*, 459, 1102-1104 (2009)
12. B. Marty, and 56 colleagues (including N. Achilleos), **Kronos: exploring the depths of Saturn with probes and remote sensing through an international mission**, *Experimental Astronomy (EA)*, 23, 947-976 (2009)
13. A. Coustenis, and 155 colleagues (including N. Achilleos), **TandEM: Titan and Enceladus mission**, *EA*, 23, 893-946 (2009)
14. B. Ercolano, **Can X-rays provide a solution to the abundance discrepancy problem in photoionized nebulae?**, *MNRAS*, 397, 69 (2009)
15. J.J. Drake, B. Ercolano, E. Flaccomio, G. Micela, **X-ray photoevaporation-starved T tauri accretion**, *ApJ*, 699, 35 (2009)
16. B. Ercolano, C.J. Clarke, J.J. Drake, **X-Ray irradiated protoplanetary disk atmospheres. II. Predictions from models in hydrostatic equilibrium**, *ApJ*, 699, 1639 (2009)
17. R. Shetty, J. Kauffmann, S. Schnee, A.A. Goodman, B. Ercolano, **The effect of line-of-sight temperature variation and noise on dust continuum observations**, *ApJ*, 696, 2234 (2009)
18. B. Ercolano, C.J. Clarke, T.P. Robitaille, **The transition disc frequency in M stars**, *MNRAS Letters*, 394, 141 (2009)
19. B. Ercolano, J.J. Drake, C.J. Clarke, **Gas phase diagnostics of protoplanetary disc extension**, *Astronomy and Astrophysics (A&A)*, 496, 725 (2009)
20. N. Bastian, M. Gieles, B. Ercolano, R. Gutermuth, **The spatial evolution of stellar structures in the Large Magellanic Cloud**, *MNRAS*, 392, 868 (2009)
21. T.T. Koskinen, A.D. Aylward, S. Miller, **The upper atmosphere of HD17156b**, *ApJ*, 693, 868-885 (2009)
22. W.P. Nicholson, G. Gronoff, J. Liliensten, A.D. Aylward, C. Simon, **A fast computation of the secondary ion production in the ionosphere of Mars**, *MNRAS*, 400, 369-382 (2009)
23. S.E. Pryse, E.L. Whittick, A.D. Aylward, H.R. Middleton, D.S. Brown, M. Lester, J.A. Secan, **Modelling the Tongue-of-Ionisation using CTIP with SuperDARN electric potential input: verification by radiotomography**, *Annales Geophys. AG/2008196* (2009)
24. E. Yigit, A.S. Medvedev, A.D. Aylward, P. Hartogh, M.J. Harris, **Modelling the effects of gravity wave momentum deposition on the general circulation above the turbopause**, *J. Geophys. Research (JGR)*, 114, D07101 (2009)
25. C.G.A. Smith, A.D. Aylward, **Coupled rotational dynamics of Jupiter's thermosphere and magnetosphere**, *Annales Geophys.*, 27, 199-230 (2009)
26. E.L. Whittick, S.E. Pryse, H.R. Middleton, A.R. Loting, A.D. Aylward, **The CTIP Model with SuperDARN electric potential patterns as input: First comparison of modelled ion densities with radio tomography observations**, *Earth, Moon and Planets*, 104, 1, 45-60 (2009)
27. J. Watermann, P. Wintoft, B. Sanahuja, E. Saiz, S. Poedts, M. Palmroth, A. Millilo, F.A. Metallinou, C. Jacobs, N.Y. Ganushkina, I.A. Daglis, C. Cid, Y. Cerrato, G. Balasis, A.D. Aylward, A. Aran, **Models of solar wind structures and their interaction with the Earth's space environment**, *Space Sci. Rev.*, 147, 233-270 (2009)
28. R.J. Barber, S. Miller, N. Dello Russo, M.J. Mumma, J. Tennyson, P. Guio, **Water in the near-infrared spectrum of comet 8P/Tuttle**, *MNRAS*, 398, 1593 (2009)
29. J.R. Barnes, T.S. Barman, H.R.A. Jones, C.J. Leigh, A.C. Cameron, L. Prato, R.J. Barber, **Spectroscopic characterisation of close orbiting extrasolar giant planets**, *AIP Conf. Proc.*, 1094, 417 (2009)
30. R. Kisielius, P.J. Storey, G.J. Ferland, F.P. Keenan, **Electron-impact excitation of OII fine-structure levels**, *MNRAS*, 397, 903-912 (2009)
31. R.L. Porter, G.J. Ferland, K.B. MacAdam, P.J. Storey, **Uncertainties in theoretical Hel emissivities: HII regions, primordial abundance and cosmological recombination**, *MNRAS*, 393, L36-L40 (2009)
32. D.M. Kipping, S.J. Fossey, G. Campanella, **On the detectability of habitable exomoons with Kepler-class photometry**, *MNRAS*, 400, 398-405 (2009)
33. D.M. Kipping, **Transit timing effects due to an exomoon - II**, *MNRAS*, 396, 1797-1804 (2009)
34. D.M. Kipping, I. Ribas, A. Font-Ribera, **Eccentric planets & Transit time variation, Transiting Planets**, (*Proc. of the International Astronomical Union*), IAU Symposium, 253, 490-491 (2009)
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36. M. Matsuura, A.K. Speck, B.M. McHunu, I. Tanaka, N.J. Wright, M.D. Smith, A.A. Zijlstra, S. Viti, and R. Wesson, **A 'Firework' of H₂ Knots in the planetary nebula NGC 7293 (The Helix Nebula)**, *ApJ*, 700, 1067-1077 (2009)
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38. D.P. Caputo, A. Speck, K. Volk, M. Barlow, R. Wesson, **Pah formation: 3.3 and 11.3 μ m Data**, *American Astronomical Society (AAS)* 214, 402.11 (2009)
39. C. Gielen, H. Van Winckel, M. Matsuura, M. Min, P. Deroo, L.B.F.M. Waters, C. Dominik, **Analysis of the infrared spectra of the peculiar post-AGB stars EP Lyr and HD 52961**, *Applications and Applied Mathematics (A&AM)*, 503, 843 (2009)
40. J. Bernard-Salas, E. Peeters, G.C. Sloan, S. Gutenkunst, M. Matsuura, A.G.G.M. Tielens, A.A. Zijlstra, J.R. Houck, **Unusual dust emission from planetary nebulae in the Magellanic Clouds**, *ApJ*, 699, 1541 (2009)
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44. J. Cami, G.C. Sloan, A.J. Markwick-Kemper, A.A. Zijlstra, C.W.Jr Bauschlicher, M. Matsuura, L. Decin, S. Hony, **The detection of infrared SiS bands in spectra of S stars**, ApJ 690, L122 (2009)
45. D.J. Mortlock, H.V. Peiris, Z. Ivezić, **Photometric constraints on white dwarfs and the identification of extreme objects**, MNRAS, 399, 699-714 (2009)
46. S. Bird, H.V. Peiris, D. Baumann, **Brane inflation and the overshoot problem**, Phys. Rev. D, 80, 023534 (2009)
47. M.J. Mortonson, C. Dvorkin, H.V. Peiris, W. Hu, **CMB polarization features from inflation versus reionization**, Phys. Rev. D, 79, 103519 (2009)
48. A. Challinor, H.V. Peiris, **Lecture notes on the physics of cosmic microwave background anisotropies**, AIP Conf. Proc., 1132, 86-140 (2009)
49. D. Baumann, H.V. Peiris, **Cosmological inflation: Theory and observations (invited review)**, Adv. Sci. Lett., 2, 105-120 (2009)
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53. A.J. Hawken, S.L. Bridle, **Gravitational flexion by elliptical dark matter haloes**, MNRAS, 400, 1132-1138 (2009)
54. J. Kurihara, S. Oyama, S. Nozawa, T.T. Tsuda, R. Fujii, Y. Ogawa, H. Miyaoka, N. Iwagami, T. Abe, K.-I. Oyama, M. Kosch, A. Aruliah, E. Griffin, K. Kauristie, **Temperature enhancements and vertical winds in the lower thermosphere associated with auroral heating during the Dynamics and Energetics of the Lower Thermosphere in Aurora (DELTA) campaign**, JGR, 114, A12306 (2009)
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