THE UNIVERSITY OF MELBOURNE

Optics Group

School of Physics

Information for prospective students

Academic Staff

K.A. Nugent	**Professor & Federation Fellow 2002**
A. Roberts	**Senior Lecturer**
C. T. Chantler	**Senior Lecturer**
R. Scholten	**Senior Lecturer [sabbatical 2002]**
Z. Barnea	**Reader, retired [but active]**

Post-Docs

B. Dhal	**Atomic Form Factors**
A. Peele	**X-ray satellite and lithography**
D. Paterson	**X-ray Coherence diagnosis [Staff Scientist Chicago 2002]**
D. Paganin	**CSIRO – phase retrieval [Monash Uni lecturer 2002]**

Students

C. Q. Tran	**Ph.D.**	**L. Turner**	**Ph.D.**
M. de Jonge	**Ph.D.**	**I. Colton**	**Ph.D.**
T. Irving	**Ph.D.**	**C. Hawthorn**	**Ph.D.**
J. Lin	**Ph.D.**	**L. Maguire**	**Ph.D.**
E. Fallshaw	**Ph.D.**	**K. Weber**	**Ph.D.**
A. Mancuso	**Ph.D.**	**T. Mackin**	**Ph.D.**
G. Christodoulou	**Ph.D.**	**M. Michna**	**Ph.D.**
C. Bellair	**Ph.D.**	**E. Ampen-Lassen**	**Ph.D.**
M. Kinnane	**Ph.D. [Chicago 2003]**		

Contact information and further details:

E-mail: a.roberts@physics.unimelb.edu.au
chantler@physics.unimelb.edu.au
scholten@physics.unimelb.edu.au **[sabbatical 2002]**
k.nugent@physics.unimelb.edu.au
URL: http://optics.ph.unimelb.edu.au
Phone: +61-3-8344-5038 (Dr Ann Roberts)
+61-3-8344-5437 (Dr Chris Chantler)
+61-3-8344-5457 (Dr Robert Scholten)
Fax: +61-3-9347-4783 (International)

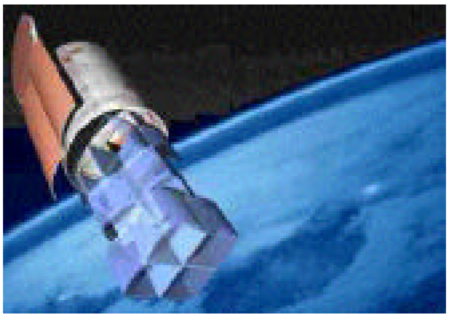
Research interests

The Optics group is one of the School's larger research groups. Its PhD graduates have obtained employment at prestigious international research institutions and a wide variety of industry employers. The group attracts substantial competitive research funding & pursues research in X-Ray optics & physics, visible optics, and atom optics; but within each area lies an array of diverse research topics. The group benefits from the strong synergies between the different research areas.

1. X-Ray Optics & Physics

The synchrotron announced in Melbourne brings a wealth of job opportunities for physics and engineering graduates, especially for our research group which has the highest profile in synchrotron physics in Australia. The local laboratories also allow development of tools and technology in-house, as well as asking fundamental questions about the universe and matter.

1.1 X-ray optics for astronomy



We are working on the development of "lobster-eye" optics. This is a novel form of optic that is based on an array of square channels that are configured in such a way that the x-rays from a wide range of angles may be brought to a focus on an x-ray detector. We have developed a detailed theoretical and experimental understanding of these devices and we are collaborating with a number of laboratories around the world to develop a satellite-based x-ray telescope utilising this concept. [1]

1.2 X-ray spectroscopy – experimental tests of theory, and applications

Quantum Electrodynamics is one of the two best-tested theories in physics and science. Yet certain problems in its formulation lead people like Roger Penrose to assume that there are fundamental flaws in the theory which may be revealed by an appropriate experiment. The type of experiment pursued by us may reveal such an inadequacy, by being more sensitive to higher order terms, two-electron QED and correlation interactions than other available tests. QED is the primary explanation of the interaction of light and charge, and is fundamental to much of the physics which we assume and rely on in the world today.

We have just made the highest precision tests of QED for Vanadium atoms (Z=23) using a new device called an Electron Beam Ion Trap.[2] Further research on X-ray photographic theory & experimental measurement has links with industry. Other projects have links with medicine (and patents in mammography).

1.3 Atomic Physics Theory: a particular area of theoretical investigation is the development of theory of atomic scattering of X-rays. A major form factor tabulation and theoretical basis have been published.[3] Despite many investigations, we still don't

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[1] W.C.Priedhorsky, A.G.Peele and K.A.Nugent, *X-Ray All-Sky Monitor with Extraordinary Sensitivity,* Mon.Not.Roy.Astron.Soc., **279**, 733-750, 1996.

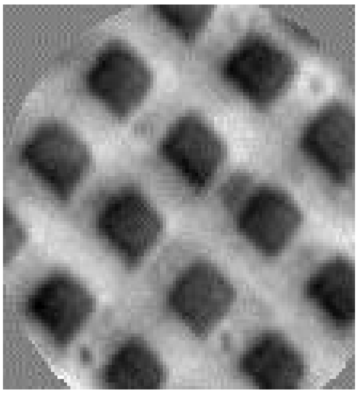
[2] J.D. Gillaspy, Y. Aglitskiy, E.W. Bell, C.M. Brown, C.T. Chantler, R.D. Deslattes, U. Feldman, L.T. Hudson, J.M. Laming, E.S. Meyer, C.A. Morgan, A.I. Pikin, J.R. Roberts, L.P. Ratliff, F.G. Serpa, J. Sugar, E. Takacs, *Overview of the EBIT Program at NIST*, Physica Scripta, **T59**, 392-395, 1995; C.T. Chantler, D. Paterson, L.T. Hudson, F.G. Serpa, J.D. Gillaspy, E. Takacs, *Absolute measurement of the resonance lines in heliumlike vanadium on an electon-beam ion trap*, Phys. Rev. A 29 (2000).

[3] C.T. Chantler, *Theoretical form factor, attenuation and scattering tabulation for Z=1-92 from E=1-10 eV to E=0.4-1.0 MeV*, J.Phys.Chem.Ref.Data 24, 71-643, 1995**;** C.T. Chantler, *Detailed new tabulation of atomic form factors and attenuation coefficients in the near-edge soft X-ray regime (Z=30-*

understand the computation & theory of atomic scattering and wavefunctions, particularly in the X-ray regime. Several problems of different theoretical approaches have been identified recently (by us), calling for further theoretical work on analytic and field theoretic approaches, together with theoretical computations of solid state contributions to X-ray absorption and scattering in the near-edge regime.

Critical tests of these important theories will have significant implications in understanding physics. Questions like 'How do X-rays diffract and scatter from crystals?', 'How much do we know about radial electron densities?', and 'Do we understand the fundamental forces between charges?' are addressed. Nuclear structure and relativistic corrections become important, so these fields tie together some of the main branches of physics. This work is done in-house and also in collaboration with NIST (Washington DC), the Clarendon Laboratory (University of Oxford), and at Synchrotrons (Japan, Chicago).

1.4 X-ray measurement of atomic form factors: Our techniques have surpassed the previous world's best result by some two orders of magnitude in accuracy and precision. This has opened up a new field of opportunities and initiated questions about relativistic, QED and other theoretical contributions to observed interactions.



1.5 X-ray coherence

We are investigating the role of coherence in x-ray sources and x-ray imaging. In particular we have developed models for describing the coherence of an x-ray laser and have used these models to measure their coherence properties.

We have developed some new approaches to hard x-ray phase imaging and tested them experimentally at the Photon Factory, Japan. The figure at left shows an x-ray phase image obtained from two intensity-only images using our algorithm. This work is expanding through our involvement with the Advanced Photon Source at the Argonne National Laboratory in the USA. We are exploring issues surrounding the emerging area of coherent x-ray optics, coherent x-ray sources and x-ray phase-contrast imaging.

2. Visible Optics

Farah Ajoudani and Magda Michna have been investigating the use of spatial light modulators in the production and study of optical wavefields.

Members of the group are interested in applications of phase retrieval to quantitative phase microscopy, adaptive optics and the characterisation of artwork. Our studies in phase imaging have also led to an interest in the production of optical wavefields containing phase dislocations using computer generated holograms and spatial light modulators. Members of the group have been conducting research over the last decade into near-field scanning optical microscopy (NSOM). Most recently, we have made significant advances in the characterisation of optical fibres and other photonic devices using NSOM in conjunction with atomic force microscopy (AFM). A newly formed collaboration with

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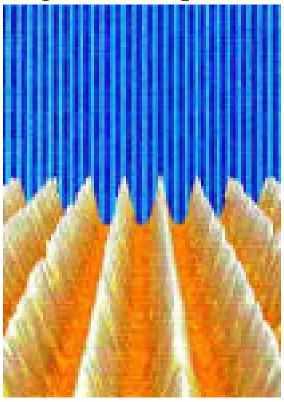
36, Z=60-89, E=0.1 keV – 8 keV), addressing convergence issues of earlier work, J. Phys. Chem. Ref. Data. 29 (2000) the Ian Potter Museum of Art has led to the exploration of the use of novel imaging techniques for the characterisation of works of art..[4,5]

3. Atom Optics

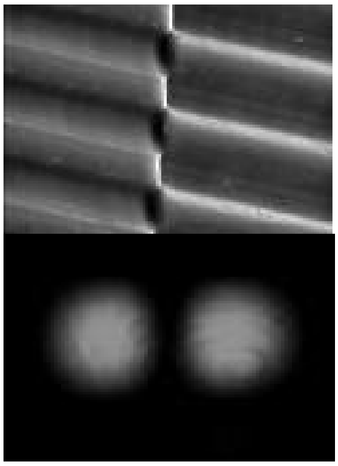
With conventional optics, material objects such as lenses and mirrors are used to control light. Turning this around, it is possible to control matter, in particular free atoms, using laser light. Manipulating atoms in this manner is called "atom optics", by analogy with light optics. Our atom optics group is working on theoretical and experimental aspects of three major projects that exploit several advantages offered by atom optics by comparison with photon optics.

Cooling and trapping of atoms is possible because they have internal degrees of freedom, which allows for the loss of kinetic energy via spontaneous emission. They are also heavy, and therefore generally have de Broglie wavelengths much shorter than typical of light, which permits focusing to much smaller spot sizes.



These two aspects of atom optics have made it possible to collimate a beam of atoms, and to then focus the beam down to nanoscopic dimensions, as the atoms deposit onto a surface.[6] A laser, tuned close to an atomic resonance, forms a standing wave intensity pattern immediately above the substrate. Due to the dipole interaction with the laser field, the atoms feel a force towards the nodes of the standing wave. Thus the standing wave acts like an array of many thousands of cylindrical lenses, each only a few hundred nanometres across, focusing the atomic beam into nanoscopic lines on the substrate (the figure at left shows 65nm lines of chromium on a silicon surface).

With the addition of a second orthogonal standing wave, the atoms can be focused into spots, typically 2.5 billion per square centimetre. This has potential applications in producing quantum well electronic devices or memory cells.



We are now working on atom optics with novel light fields constructed using computer-generated holograms. A complex intensity structure can be produced from a conventional gaussian laser beam using phase or amplitude holograms, calculated using diffraction theory, and manufactured by direct ablation of optical materials using an excimer laser. In collaboration with Errol Harvey's group at Swinburne, we have made holograms to produce TEM_{01} and TEM_{01}* propagating beams (see figure). Slow atoms are produced in a Zeeman slower and then focussed in the dark regions of the light field. Future work will explore the possibility of a neutral atom microscope, and electronic device fabrication by patterned deposition of neutral atoms.

In another project, we are investigating non-interferometric phase imaging with neutral atoms. Measurement of atomic phase shifts offers exciting prospects in many areas of physics, for example for detecting gravity gradients, gravity waves, electromagnetic fields and topological effects. Phase shifts are normally detected with interferometers, but interferometry with atoms in notoriously difficult due to the poor spatial and

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[4] D.J.Butler, K.A.Nugent and A.Roberts, *Characterization of Optical Fibres with a Near-Field Scanning Optical Microscope.* J.Appl.Phys., **75**, 2753-2756, 1994.

[5] D.J.Butler, A.Horsfall, K.A.Nugent, A.Roberts, I.M.Bassett and K.M.Lo, *Measurement of an Elliptical Fiber Mode-Field Using Near-Field Microscopy,* J.Appl.Phys, **77**, 5514-5517, 1995.

[6] Work done at NIST, Gaithersburg, MD, USA; see JJ McClelland, RE Scholten, EC Palm and RJ Celotta, *Science* **262** 877 (1993).

temporal resolution of conventional atomic sources. Non-interferometric propagation techniques have now been used to detect the electromagnetic field of a near-resonant laser.

Our experiments in atom optics require slow or stopped atoms, preferably with very narrow velocity spreads, in a well-collimated beam. Highly collimated atom beams are obtained by laser cooling transverse to the atomic beam direction. We are developing a new method for investigation of laser cooling by analysing the polarisation of fluorescence from atoms as they are cooled. A variation on a magneto-optic trap, using moving molasses to produce a slow beam of rubidium, will be used to cool the atoms along the beam, and hence produce a slow monochromatic source of atoms. This will be applied to patterned deposition of atoms and to measurement of gravitational and inertial phase shifts using non-interferometric methods.

Finally, we have developed new theoretical models for the calculation of atomic motion and the internal state of atoms in near-resonant laser fields. Our approach has been very successfully applied to the calculation of saturated absorption spectra and the calculation of atomic trajectories in complex light fields, and shows promise for predicting laser cooling of atoms.

Group facilities

The group has extensive experimental and computational facilities. These include well-equipped optics and laser laboratories with high power gas and diode lasers, near-field microscopy and conventional optical microscopes.

We also have high quality scientific grade x-ray and optical CCD cameras, soft x-ray sources with associated vacuum equipment and a high power rotating anode x-ray source. In addition, the department has a JEOL 4000EX high resolution TEM, a 100CS TEM and a Hitachi SEM.

The group is a major participant in the Advanced Photon Source (Chicago, USA) via the Synchrotron Radiation Instrumentation Collaborative Access Team (SRICAT), and has ready access to a state-of-the-art third generation synchrotron facility.

We also work with the School's Pelletron accelerator with a state-of-the-art proton microprobe installation.

Future directions

The group is currently participating in a proposal to fly an all-sky monitor x-ray satellite. The news that Australia will build a Synchrotron of its own in the near future, will lead to many more opportunities for research and development of Australian resources. In QED and atomic physics we look towards new tests of new physics and the development of new theoretical results.

In atom optics we will soon complete construction of our first rubidium atom beam apparatus for working with standing-wave and doughnut-mode lenses, and continue development of the computational models for laser/atom interactions using a quantum monte carlo approach.