Project name: Bubbles, cavities, and prominences

Group: A&A

Supervisor: Nicolas Labrosse

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Backup supervisor: Lyndsay Fletcher

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

Solar prominences are intriguing features of the solar atmosphere, having densities and temperatures radically different from those of their coronal environment. They are one manifestation of the complex magnetic field which permeates the solar atmosphere. Spectroscopic observations are therefore a key tool for understanding these features.

Hinode/SOT observations indicate that prominences on the limb appear to consist of vertical dynamic structures. The Hα emitting plasma is constantly going up and down. Below these fine threads, "bubbles" with a semi-circular shape appear just above the limb. They are more or less empty of cool (6000 K) plasma emitting in Hα, and instead appear to be filled with hotter plasma according to SDO/AIA filters. Plumes rising through the prominence seem to form from these bubbles. Their material would be hotter and buoyant. The density, temperature, and velocity of the plasma within prominences, surrounding cavities, and bubbles all change with time and location, and can vary greatly.

The project will investigate the plasma parameters in and around solar prominences using data obtained with one or more spectrometers embarked on SOHO and/or on Hinode, in association with images obtained from other space-based instruments. The student will analyse images and line profiles to derive the conditions in the plasma inside and around prominences (e.g. in the surrounding cavity).

The analysis of the results will address one or more of the following areas:

- what are the characteristics of spectral lines in and around prominences over a large range of temperatures?
- what is the temperature of the so-called prominence 'bubbles'?
- can we constrain models of the transition region between the prominence and the corona?
- what is the relation between the prominence, its surrounding cavity, and the overall structure of the magnetic field?

Some relevant papers:

- Labrosse, Schmieder, Heinzel, & Watanabe, 2011, EUV lines observed with EIS/Hinode in a solar prominence, A&A, 531, A69
- Labrosse et al., 2010, Physics of Solar Prominences: I—Spectral Diagnostics and Non-LTE Modelling, SSRv, 151, 243

Two-dimensional radiative transfer models of solar prominences

Group: A&A

Supervisor: Dr Nicolas Labrosse

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Backup Supervisor: Dr Lyndsay Fletcher

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

Solar prominences are large magnetic structures in the solar atmosphere. The prominence plasma is roughly 100 times cooler and denser than the surrounding coronal plasma, which poses outstanding questions about origin and energy equilibrium. It is not clear how these cool objects can live for a long time within the hot solar corona. In addition, they are strongly sensitive to the radiation coming from the solar disc, which creates conditions far from Local Thermodynamic Equilibrium (LTE). They are also optically thick in several spectral lines. To model the emitted radiation it is necessary to use non-LTE radiative transfer codes.

This project aims at delivering new results which will yield more accurate information on the physical conditions inside solar prominences. This is a computational project which aims to produce a new set of data to help observers interpret their observations.

This is a computer-based project using a FORTRAN code. Previous experience with FORTRAN is recommended but not essential. The student will be given a FORTRAN 2D radiative transfer code co-developed by the supervisor with instructions on how to run it. The code will be run for different input parameters corresponding to different prominence atmosphere models, and the results will be analysed.

The analysis of the results will address one or more of the following areas:

- how H, He I, and He II spectral lines are formed?
- how does the emitted radiation change with the plasma parameters?
- how much does helium contribute to radiative losses compared to hydrogen?
- what are the spectral characteristics of filaments (horizontal structures) compared to those of prominences (vertical structures)?
- how to compile the results and make them available to observers?

Some relevant papers:

- Gouttebroze & Labrosse, 2009, Radiative transfer in cylindrical threads with incident radiation. VI. A hydrogen plus helium system, A&A, 503, 663
- Labrosse et al., 2010, Physics of Solar Prominences: I—Spectral Diagnostics and Non-LTE Modelling, SSRv, 151, 243

Project name:
Optically synchronized imaging in the beating heart

Group: **Imaging Concepts**
Supervisor: **Dr Jonathan Taylor**
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Backup supervisor: **Prof. Andy Harvey**

Project description: This project will investigate techniques for real-time optically synchronized imaging and intervention in the beating zebrafish heart. The zebrafish is an important animal model for studying heart regeneration, and we have already demonstrated a system for synchronized imaging and intervention in the living, beating heart of a zebrafish embryo [1, 2]. Images are acquired and analyzed in real time using a brightfield camera attached to a microscope, and information derived from this is used to determine the "phase" of the heart in its cycle, allowing trigger signals to be generated to acquire images or trigger some form of intervention at a precise position in the heart's cycle.

A significant challenge in the analysis is determining the heart's phase to a precision better than the camera framerate ("sub-frame resolution"). Crude interpolation techniques can be used, but these are sensitive to noise and make assumptions about the behaviour of the heart.

The aim of this project is to use and extend existing computer code and algorithms to evaluate ways of achieving more accurate synchronization. Depending on the interests of the student, the project would include some of the following aspects:

- Evaluation of simple image filtering/masking to improve the signal to noise ratio.
- Computer generation of simulated video of a model heart to validate the techniques against (and maybe even a physical model!).
- Experimental validation of the system using living fish, in conjunction with biologists at the Queens Medical Research Institute in Edinburgh.
- Development of adaptive signal interpolation techniques that respond to the current behaviour of the heart in order to improve accuracy.

There may be opportunities to visit the University of Edinburgh to work with medical and biological researchers and gain experience of the transfer of basic technological development into real-world application in biological research.

The project is suited to a student with an interest in practical application of imaging and image analysis techniques, and in particular an aptitude for writing computer software for data analysis. An interest in experimental research at the frontiers between physics and biology would be an advantage. It is essential that the student should be at ease programming in a high-level language such as Python, or alternatively in C.

[1] "Realtime Optical Gating for 3D Heart Imaging", J. M. Taylor, C. D. Saunter, B. Chaudhry, D. Henderson, G. D. Love, J. M. Girkin.
Journal of Biomedical Optics **16** 116021 (2011).

[2] "High-resolution 3D optical microscopy inside the beating zebrafish heart using prospective optical gating", J. M. Taylor, J. M. Girkin, G. D. Love.
Biomedical Optics Express **3** 3043-3053 (2012).

Project name: Demand-Side Control Techniques for Portable Electronic Devices

Group: IGR

Supervisor: Stefan Hild

Email address: Stefan.Hild@glasgow.ac.uk

Backup supervisor: Morag Casey

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

Climate change and decreasing reserves of fossil fuels will push us more and more to use renewable energy sources such as photovoltaics, wind or wave energy. One of the major drawbacks from such sources is their variability in time and limited predicatability due to weather. Therefore, huge effort is expected to go into building up energy storage and buffer capacity for times with low wind and no sunshine. Smart grids and Demand Side control techniques have been proposed to mitigate effects from the variability of renewable energy sources.

We have recently developed the first prototype of a smart charging laptop (http://arxiv.org/abs/1209.5931) that only charges the laptop battery when there is a surplus of electricity in the national grid and suspends the charging when the electricity demand outweighs the supply.

In this project the student will have the chance to contribute to the further development of smart charging techniques for portable electronic devices. Depending on the preferences of the student this project can focus either more on the hardware side (including analog electronics, micro-controller and digital electronics) or more on the software and simulation side (developing advanced charging algorithms and software based on for instance on adaptive filters and neural networks).

Project name: Interferometry below the Quantum Limit

Group: IGR

Supervisor: Stefan Hild

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Backup supervisor: Kenneth Strain

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

Gravitational wave detectors can measure the distance between 2 test masses to a precision of about a 1/1000 of a proton diameter. The next generation of these detectors, such as Advanced LIGO, will be limited entirely by quantum noise, which is a manifestation of the Heisenberg Uncertainty Principle. A novel interferometer configuration, a so-called 'Sagnac speedmeter' has the potential to increase the sensitivity of gravitational wave detectors even beyond the Heisenberg limit. The world's first Sagnac speedmeter is currently under construction in the IGR clean room labs.

The student will have the opportunity to work on the detailed design of the speedmeter interferometer. Depending on the preferences of the student this may include aspects of the seismic isolation system, the monolithic fused silica suspensions, the optical design of the core interferometer, ultra-low noise electronics, the control and locking scheme of the optical resonators and/or the interferometric readout concepts at the quantum level.

Project name: Network theory and artificial spin ice

Group: MCM (Materials and Condensed Matter)

Supervisor: Robert Stamps

Backup Supervisor:

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

Linus Pauling noted in 1935 that there should be a residual entropy in water ice at absolute zero due to bond frustration imposed by the geometry of crystalline ice. The problem can be represented easily using arrows to describe hydrogen position within bonds. The arrows can also represent spin magnetic moments, and materials exist with crystalline structure such that geometrical frustration prevents the simultaneous minimisation of all pairwise interactions between spins. As a result, there is a residual entropy at zero temperature as in water ice, and in some geometries, a classical analogy to a magnetic monopole.

We have found that it is possible to describe some aspects of spin ice using concepts and tools from network theory. In this project, a type of random network will be studied that can describe a two dimensional artificial spin ice. The goal will be to identify key "control nodes" that can be used to specify how the network evolves in time. A possible application may be encryption of data. The student will become familiar with basic concepts for computational simulation, and gain experience using python based computational tools.

Project name: Comparative Studies of TOF-PET

Group: NPE

Supervisor: Dr Bjoern Seitz

Email address: bjoern.seitz@glasgow.ac.uk

Backup supervisor: David Hamilton

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

TOF-PET, of Time-of-Flight Positron Emission Tomography, is a medical imaging modality making use of positron annihilation reactions inside tissue. Conventional PET scanners will image along a line of reference calculated from the impact point of the two decay photons on a ring of detectors. The photon energy and the geometrical hit position are used for the reconstruction. No information on the point of origin is obtained.
Adding the relative timing information will allow to constrain the point of origin along the line of reference, greatly enhancing the image contrast. In an ideal case, i.e.with a time resolution of 10 ps or better, this constraint will be comparable with the range of positrons in tissue and hence allow for a complete reconstruction of the image on an event-by-event basis. If this could be achieved, it would revolutionise the way PET images are formed.
GATE is a program library optimised to simulate nuclear medical imaging modalities. In the project, we will compare a conventional PET with a TOF-PET and a PET based on Cherenkov light, promising the ultimate time resolution.

Project name: Dose verification for radiotherapy using very highly energetic electrons

Group: NPE

Supervisor: Dr Bjoern Seitz

Email address: bjoern.seitz@glasgow.ac.uk

Backup supervisor: David Mahon

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

Conventional radio therapeutical treatments rely on high energetic photons to deposit a dose in cancerous tissue and thus prevent the proliferation of cancerous cells. In recent years, more treatment modalities are being studied to enhance the dose deposited in healthy tissue, improve tumour conformality and thus reduce the dose to healthy tissue and possible side effects.

High energetic electrons are one alternative, others include protons or heavy ions. A SUPA collaboration is investigating the use of laser accelerated electrons as a possible radio treatment modality. The aim of the project is to verify the deposited dose over a large range of electron energies by using measured data and Monte-Carlo simulations.

Project Name: Compressive Ghost Imaging

Group: Optics

Supervisors: Prof M. Padgett

Email address: Miles.Padgett@glasgow.ac.uk

Backup supervisor: Stephen Welch

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

Suited to Student interested in Computational Lab/Previous programming experience required

Computational Ghost Imaging is a technique which projects a random but known light field onto a test object and measures the back reflected signal. This acts as a weighting signal for that pattern, (an estimate of correlation between light field 'pattern' and object). After many patterns have been projected and measured one can reconstruct the original object. This Project is a computational based project working with real experimental data in firstly learning how to construct a ghost imaging algorithm, and then apply this knowledge to write a compressive algorithm in either Labview calling a necessary function using Mathscript or similar in Python. Prospective students should have some degree of previous experience and/or enthusiasm for programming as this project is about constructing a pre-existing algorithm in an entirely different programming language to the one that it current uses and so with be computationally intensive, also may include some computer modelling for the algorithm and using real data if successful.

Project Name: Optical Tweezers

Group: Optics

Supervisors: Prof M. Padgett

Email address: Miles.Padgett@glasgow.ac.uk

Backup supervisor: Maria Dienerowitz

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

Optical tweezers use tightly focused beams of light to trap hold and move micron sized objects. In Glasgow we have pioneered such systems and our designs are now sold commercially.

We are now exploring the use of optical tweezers for the study of nano particles in several situations. These range from their significance within biofilm, their potential to guide light in optical circuits and to act as tiny light emitter in their own right.

Prospective students should have a strong desire to pursue challenging optical experiments which will require careful optimisation if they are to give the results we hope for. However if successful such results will lead to publications of significance.

Project name: Raytracing in metamaterials

Group: Optics

Supervisor: Johannes Courtial

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Backup supervisor: tbd

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

One of the recent hot topics in optics has been metamaterials research. This research often requires raytracing through continuously-varying optical materials.

We now want to add code that allows raytracing through continuously-varying metamaterials into our marvellous in-house Java raytracer, TIM. We will use the techniques outlined in Ref. [1] to trace such rays, and perhaps also to calculate the material properties that perform a desired coordinate transformation. This is then "transformation optics", a new optical design paradigm that allows optical researchers to make use of the freedom offered by new, nano-structured, materials ("metamaterials") [2].

Experience with Java programming and with the numerical solution of differential equations (e.g. the Runge-Kutta method), as well as fearlessness in the face of differential equations that involve tensors, desirable.

References:

[1] D. Schurig, J. B. Pendry, and D. R. Smith, *Calculation of material properties and ray tracing in transformation media*, Opt. Express **14**, 9794-9804 (2006)

[2] H. Chen, C. T. Chan and P. Sheng, *Transformation optics and metamaterials*, Nature Materials **9**, 387-396 (2010)

Project name: Superchiral light

Group: Optics

Supervisor: Johannes Courtial

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Backup supervisor: tbd

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

Light normally oscillates once per optical wavelength. It is well understood that, sometimes, light can also oscillate faster than once per optical wavelength. Such light is called "superoscillatory".

In circularly polarised light, the polarisation vector rotates once per wavelength. It was recently found that it can also twist faster than once per optical wavelength [1]. Such light is called "superchiral"; it has applications for chemical sensing.

Currently, researchers go to great lengths to prepare superchiral light. We want to calculate (probably numerically) how much superchiral light there is in "natural light", i.e. random speckle fields that have not been prepared in any special way other than by simply shining a laser beam onto a rough surface. We do not do this in order to annoy those who carefully prepare superchiral light, but to greatly simplify experiments involving superchiral light.

References:

[1] Y. Tang and A. E. Cohen, *Enhanced Enantioselectivity in Excitation of Chiral Molecules by Superchiral Light*, Science **332**, 333-336 (2011)

Project name: The infrared limit of Quantum Chromodynamics

Group: PPT

Supervisor: Chris White

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Backup supervisor: David Miller

Project description (include published papers if relevant; the length should not exceed the remainder of this page):

Quantum Chromodynamics (QCD) is the theory of quarks and gluons, constituents of the proton, and is a type of quantum field theory. Calculations in QCD are of direct relevance to particle accelerator experiments such as the Large Hadron Collider in CERN. Typically these calculations use perturbation theory, an expansion in the "coupling constant" which describes the magnitude of the strong interaction. For many observables, perturbation theory becomes unstable, a problem which can be traced to the emission of multiple "soft" (low-momentum) gluons. Whilst it is already known how to deal with this problem to some extent, new mathematical insights are needed in order to extend the precision of calculations. Furthermore, the study of soft gluons is related to a number of unproven conjectures in QCD and other field theories, and may have something to say about the relationship between QCD and (quantum) gravity.

This project will study soft gluons in detail. There is a lot of flexibility regarding which questions to look at, and possible avenues include:

* How does one calculate soft gluon effects (using Feynman diagrams) at higher orders in the coupling constant?

* What is the structure of soft gluon corrections in scattering processes involving many quarks and gluons? This is related to so-called "web diagrams", whose study involves interesting combinatoric structures.

* What dualities exist between QCD and the quantum theory of gravity?

* What similarities exist between QCD and theories with more supersymmetry (e.g. N=4 Super-Yang-Mills theory)?

I expect that the emphasis will be on analytical calculations, although there is also some scope for computational work (for which programming experience in e.g. C++, Fortran or Java would be mandatory).