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ASTRONOMY

Kenneth Duncan
Probing the first billion years of galaxy evolution

Answering the question of how galaxies grow over time is one of the fundamental problems in the study of galaxy evolution. With the installation of the Wide Field Camera 3 on the Hubble Space Telescope and the unprecedented depths in the near infrared it is able to probe, it has become possible to begin studying in detail the first billion years of galaxy evolution. The large samples of observable galaxies now available at redshifts of z~4-8 and beyond are allowing us to begin measuring the fundamental properties of galaxies in this epoch.

In this poster I present some of the techniques used to find these galaxies at the limits of our observational capabilities and the work i have done to find improved estimates of their stellar mass, results that can provide important constraints on theories of early galaxy evolution; tracing the integrated star formation and mass assembly over time.

Evelyn Johnston
Understanding the Formation of NGC 4550, a lenticular galaxy with counter-rotating stellar discs

NGC 4550 a peculiar disc galaxy in which about half of its stars orbit the centre of the galaxy in the opposite direction to the other half. Counter-rotating stellar discs such as these are only seen in about 10 % of lenticular galaxies, and even among these one disc is generally significantly more massive than the other. Therefore, to truly understand the evolution of lenticular galaxies, we need to understand how the more peculiar examples such as these are formed and therefore how they fit into all current theories.

By studying a spectrum of this galaxy, we have been able to determine for the first time that one of the stellar discs is significantly younger than the other. Simulations have shown that it is impossible for the observed properties of this galaxy to occur naturally and independently, and so we propose two possible theories for the formation of this galaxy through unusual interactions with another galaxy. Firstly, it is possible that the two galaxies underwent a carefully controlled merger event in which the structures of the two stellar discs were preserved and thus can be seen in the new galaxy we see today. Alternatively, the precursor lenticular galaxy accreted gas from the other galaxy into a counter-rotating gaseous disc, in which a star formation event later occurred to produce the new stellar disc. The unusual conditions required for either of these scenarios would explain the rarity of such galaxies in the universe.

'K+A' galaxies as an evolutionary link between Spiral galaxies and S0s
Bruno Rodriguez

Spiral galaxies are characterized by the presence of spiral arms in their disks, which is where new stars are being formed, and a central bulge, populated by old stars. Another type, the lenticular or S0 galaxies also have disks and bulges, but they are not forming stars. These similar properties can be indications of a possible evolutionary link between these two types of galaxies, with the S0s being the result of the cessation of the star

formation in the disk of the spiral galaxies. Galaxies that are a composite of a young (<1.5Gyr) and an old stellar populations, also known as 'K+A'
galaxies, can be the intermediate stage in this transformation and their properties are vital to understand this period of galaxy evolution.
In our study, we analyse a sample of disk 'K+A' galaxies in a cluster at redshift ~ 0.3 using the spectral information of the different regions of the galaxies, which can be achieved by the use of Integral Field Spectroscopy observations. We find that the distribution of the young population, which indicates where the last episode of star formation took place, is different for galaxies that are interacting from those that are isolated. The majority of the galaxies show signs of rotation, implying that their kinematics have not been strongly affected by the processes suppressing the star formation.

EXPERIMENTAL CONDENSED MATTER & NANOSCIENCE GROUP

Band-gap profiling by laser writing of hydrogen-containing III-N-Vs

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We describe a new physical process and a laser writing technique to pattern with nanoscale spatial resolution and high energy accuracy the electronic properties of hydrogen-containing semiconductors [1-2]. We show that the dissociation of the N-H complex in hydrogenated III-N-V dilute nitrides can be laser-activated due to a resonant photon absorption by the N-H complex. This phenomenon provides a mechanism for profiling the band-gap energy in the growth plane of the III-N-Vs; the profiles are erasable and the alloys can be re-hydrogenated making any nanoscale in-plane band gap profile rewritable. Since this direct laser writing technique does not require lithographic and etching techniques, it offers a new top-down approach to large-volume, cost-effective and fast fabrication techniques.

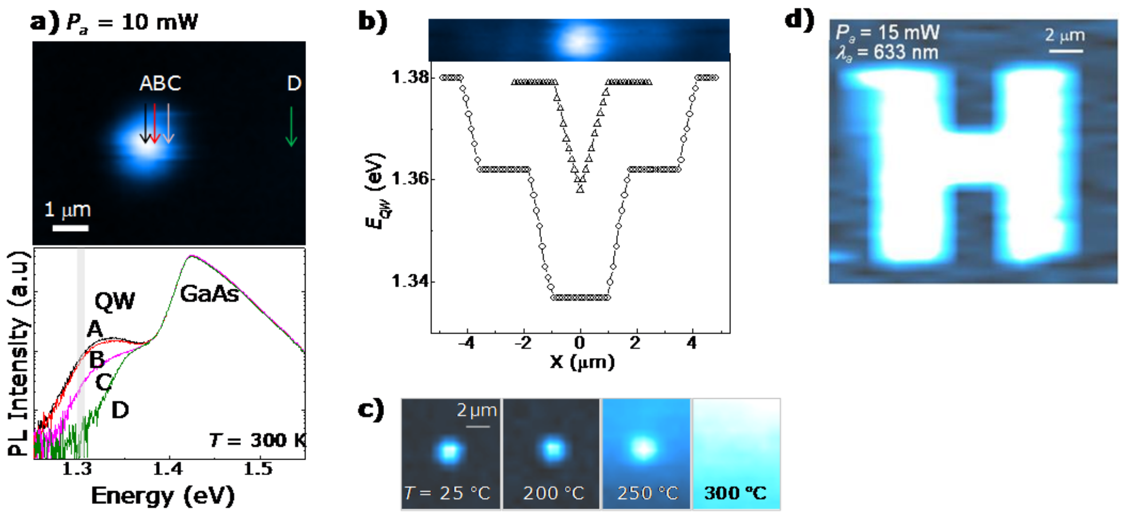

Figure 1. a) μPL maps at T = 300 K of an hydrogenated Ga(AsN) QW following exposure to a focussed laser beam. The μPL spectra at positions A, B, C, and D are shown on the bottom. b) Profiles of the QW PL peak energy, EQW, created by laser writing. The top figure is the μPL map corresponding to the triangular potential well. c) Light emitting spots created by laser writing and mapped following an annealing in a high temperature furnace at T = 200 °C, 250 °C, 300 °C for 1 hr. d) H-shaped emitting area written by a focused laser beam. All μPL maps are obtained by integrating the PL intensity around the peak energy of the QW emission in the as-grown sample (E = 1.30 eV).

[1] N. Balakrishnan et al, PRB, 86, 155307 (2012)
[2] N. Balakrishnan et al, APL, 99, 021105 (2011)

Duncan Parkes

Voltage control of magnetisation and magnetic domain configurations in magnetostrictive epitaxial $Fe_{1-x}Ga_x$ thin films

Moore's law (that computing power doubles every 18 months) has driven the computer industry for nearly 50 years. As the power of computers has increased, however, so has the amount of energy needed to run them. In the devices we use every day (laptops, smart-phones, tablets, etc.) we are not limited computing power, but rather how long we can use them before the battery runs out.

One solution to this power consumption problem is to use magnetic materials to produce non-volatile logic and memory devices, which, unlike conventional RAM or processors do not need an 'always on' energy supply. Unfortunately the conventional method of controlling magnetic materials is also inefficient: a current in a wire generates heat and a stray magnetic field, both of which are detrimental in large device arrays. The solution then is to use an electric *field*, rather than electric *current* to control the magnetisation.

This poster describes some of our contributions to solving this power-consumption problem. We use a piezoelectric transducer to convert a voltage into a strain which controls magnetisation in an alloy of iron, $Fe_{81}Ga_{19}$, whose magnetisation is particularly responsive to strain. We use electrical measurements and microscopy sensitive to magnetisation to show how we can control the magnetisation and magnetic domain configuration in micro-processed samples of $Fe_{81}Ga_{19}$.

Maria Wieland

Transfer of Covalent Networks from metal to Dielectric Surfaces

1- and 2-dimensional covalent organic networks are widely studied for possible applications as electronic materials and graphene analogues [1-3].Organic networks are commonly produced by on-surface coupling reactions leading to extended polymeric networks. Via modification of the building blocks the frameworks can be tailored to meet target requirements.
The formation of 2d covalent organic networks via radical covalent coupling typically requires specific substrates to catalyse the on-surface reaction. Metallic surfaces are commonly chosen particularly for schemes which require catalysts to enable dehalogenation of the molecules as a route to the formation of covalent bonds. However, the potentially interesting optical and/or electrical properties of the resulting networks cannot be investigated while the structures remain adsorbed on a metal substrate.
To overcome this problem, we have developed a method to transfer covalent networks from a metallic catalytic to a separate substrate, which can be dielectric or metallic. We demonstrate this using tetra(bromo phenyl)porphyrin networks that were formed on a gold substrate in UHV and subsequently transferred to a SiO2 surface. This process is facilitated through the use of a fullerene buffer layer in combination with an elastomer. The fullerene layer is shown to have adhesive properties and facilitates the removal of the Au film from the mica supporting substrate. The presence of the framework on the SiO2 substrate after the transfer can be verified by fluorescence spectroscopy.

1: Lafferentz et. al., Science 2009
2: Cai et. al., Nature 2010
3: Blunt et. al., Chemical Communications 2010

MAGNETIC RESONANCE IMAGING & SPECTROSCOPY

Quantifying the effect of blood oxygenation on MRI signal

P.L. Croal[1], E.L. Hall[1], I.D. Driver[1], S.T.Francis[1] and P.A.Gowland[1]
[1]Sir Peter Mansfield Magnetic Resonance Centre, University of Nottingham

Introduction: The power law (β) relating blood oxygenation and tissue R2*(representing MRI signal) is important in many contexts, in particular estimation of cerebral metabolic rate of oxygen consumption in calibrated BOLD fMRI [1]. This has generally been predicted from simulations or analytical models [2,3,4], however there have been few attempts to test these models experimentally.

Method: Data were collected across field strength in 6 healthy subjects. Scanning was performed on Philips Achieva 1.5/3/7T systems. A dual echo EPI acquisition was used (TR=3s, $2x2x3mm^3$) with TE1/TE2 =25/80, 22/60 and 16/47 ms at 1.5/3/7T respectively. Average R2* timecourses were calculated at each B_0, allowing the gradient between ΔR2* and oxygenation to be calculated. Monte-Carlo (MC) simulations (N=1000) were performed to assess the sensitivity of ΔR2*-oxygenation curves to β over range of Δω achievable using HO and on neuronal activation.

Results and discussion: At a given field, the R2*-oxygenation relationship appeared linear, in agreement with MC simulations which suggest limited sensitivity to β over this physiological range of Δω. However, by changing field strength, a much larger Δω is induced, and so β can be explored. Gradients differed significantly across field strength ($p = 0.009$), with the ratio between gradients, 1:0.31±0.05:0.37±0.06, only explained by a reduction in β between 1.5T and 3T and β > 1 at 3 and 7T. These results are in agreement with previous simulations that suggested β =1.5 for l.5T, falling to close to 1 at higher field [2,3,5,6].

References: [1] Davis et al., Proc. Natl. Acad. Sci.USA., 95:1834-1839(1998); [2] Boxerman et al., MRM, 34:555-566(1995); [3] Ogawa et al., Biophys.J. 64:803-812 (1993); [4] Yablonskiy et al., MRM,32:749-763(1994) [5] Van Der Zwaag., Neuroimage 47:1425-1434 (2009) [6] Driver et al., Neuroimage, 51:274-279 (2010); [7] Rossi et al., NMR Biomed. 25:1007-1014 (2012);

Improved characterisation of white matter lesions in multiple sclerosis patients using quantitative susceptibility mapping

Matthew Cronin

Multiple sclerosis (MS) is an autoimmune condition that currently affects approximately 100,000 people in the UK. MS causes the immune system to attack the myelin sheaths protecting the nerves in the brain causing lesions to form that disrupt the transmission and reception of nerve signals. Symptoms include numbness and tingling, blurring of vision, mobility and balance problems and weakness and tightness of muscles.

Magnetic Resonance Imaging (MRI) is a key non-invasive diagnostic tool in the treatment of and research into MS. Recent research has focussed on the in vivo measurement of iron levels in the brain using images based on the phase of the MRI signal. Being able to track these changes in iron levels could lead to a better understanding of MS progression. Making inferences from iron levels based upon the phase images is, however, flawed. Iron changes the bulk magnetic susceptibility of tissue and variations in the susceptibility cause perturbations in the magnetic field, which in turn affect the phase of the MRI signal. These field perturbations are non-local to the underlying susceptibility variation, and so a contrast can be seen outside of structures where iron levels are varying. This can lead to mistaken inferences about iron levels in the tissue so another approach is required

This work uses susceptibility mapping, a technique to exploit the relationship between susceptibility and phase, to demonstrate quantitatively that maps of magnetic susceptibility show variations consistent with physical features and underlying tissue composition, to effectively map changes of lesions in MS.

In situ Raman Spectroscopy to determine N_2 gas temperatures in spin exchange optical pumping cells for use in hyperpolarised noble gas NMR/MRI
Hayley Newton

Hyperpolarised noble gases have been used for a variety of applications, including MR imaging and spectroscopic measurements in the lungs; investigating host-guest interactions of molecules; as well as probing surfaces and porous media. Hyperpolarised gases are typically produced via spin exchange optical pumping (SEOP), where angular momentum is transferred from circularly polarised, resonant photons to the electronic spins of an alkali metal vapour (e.g. rubidium), and is subsequently imparted onto the noble gas nuclei (e.g. xenon-129). This creates a hyperpolarised gas with a nuclear spin polarisation many orders of magnitude greater than at thermal equilibrium, thus enabling its many applications across a wide range of scientific fields. Along with the rubidium and xenon-129, nitrogen is frequently added into the optical pumping vessel to both pressure broaden the rubidium absorption line and to collisionally de-excite the rubidium.

In this work, we attain Raman signals of N_2 gas during SEOP using both broadband lasers and high-powered frequency-narrowed lasers, and various gas mixtures. *In situ* Raman spectroscopy was collected using two contrasting methods which will be compared: an orthogonal excitation/detection method and an in-line module with filters to remove the 532 nm probe laser. We will compare the temperature of the gas under differing conditions, with corresponding *in situ* low field NMR signals and transmitted laser spectra to show how these values vary with optical pumping conditions. Measurement of the optical pumping cell surface temperature is often a poor indicator of internal gas temperature—necessitating the *in situ* Raman measurements explored here.

Magnetoencephalography – what is it, and how does it work?
Helen Smith, Darren Price, Elizabeth Liddle, Maddie Groom, Matt Brookes, Mary Stephenson, Emma Hall, George O'Neill, Peter Liddle & Peter Morris
The University of Nottingham Sir Peter Mansfield Magnetic Resonance Centre, Division of Psychiatry & School of Physics and Astronomy

Magnetoencephalography (MEG) is a powerful neuroimaging technique capable of *non-invasive assessment of brain electrophysiology.* The MEG scanner at The Sir Peter Mansfield Magnetic Resonance Centre, The University of Nottingham is pictured in Figure 1.
MEG uses super conducting quantum interference devices (SQUIDs) to measure the tiny magnetic fields at the scalp surface that are induced by electrical activity in the cortex of the brain. These magnetic fields originate largely from dendritic current flow in cortical pyramidal neurons.
With electroencephalography (EEG) we are able to record electric fields produced by the same current flow in pyramidal neurons. The recorded signals are, however, disrupted spatially by the presence of the skull and scalp, so attempting to localise brain activity may result in inaccuracies.

With functional magnetic resonance imaging (fMRI) we are able to measure haemodynamic responses to increased electrical activity. fMRI provides exquisite spatial resolution, but temporal resolution is limited to 2-6 seconds by the slow blood flow response.
With MEG, we not only bypass the haemodynamic response and capture brain activity with excellent temporal resolution, but we also obtain recorded signals that are not disrupted spatially by the presence of the skull and scalp. We are therefore able to locate sources with *high spatial and temporal resolution*.

Optimising Gas Composition for Hyperpolarisation of ^{129}Xe Using Simultaneous NMR and Raman Spectroscopy
Jason Smith

Hyperpolarised ^{129}Xe is capable of being used for diagnostic lung MRI, due to high image contrast in the gas phase and spectroscopic information in dissolved phase studies. Spin-exchange optical pumping is typically used to produce hyperpolarised gases; the process involves transferring angular momentum from resonant circularly polarised photons to the electronic spins of an alkali metal vapour and subsequently the nuclei of the noble gas. Buffer gases are often loaded into the optical pumping cell to both pressure broaden the alkali metal absorption line and to collisionally de-excite the alkali metal atoms.

This study presents experimental results of spin-exchange optical pumping of ^{129}Xe with various buffer gas compositions, along with simultaneous observations of low-field ^{129}Xe NMR signals and Raman nitrogen buffer gas temperatures under various experimental parameters: high laser powers (using frequency narrowed lasers), spectral offsets, and cell surface temperatures. Energy transport within the cell for xenon mixes with various buffer gases of different thermal conductivities is considered.

Preliminary studies indicate that the increased thermal conductivity of helium buffer gas allows greater heat dissipation, resulting in lower nitrogen rotational temperatures, greater thermal stability, and increased xenon polarisation when compared to gas mixtures excluding helium. These results may impact the design and operation of a next-generation clinical xenon polariser.

PARTICLE THEORY GROUP

Tests of the Equivalence Principle: A Window for Modified Gravity
Ana Avilez

According to General Relativity (GR) gravity accelerates all objects equally regardless of their mass or the materials from which they are made of. This is called the Equivalence Principle (EP), a cornerstone of modern physics. However, this principle may not be a fundamental physical law since there is no compelling reason to expect that coupling constants in physics should have an absolute character. Indeed, all Newtonian absolute structures should be replaced by dynamical entities, including coupling constants.

Although lunar laser ranging tests place strong limits on deviations from the EP, discovering even the slightest difference on how gravity acts on objects made up of different materials would have enormous implications for fundamental theory. In particular, violations of the EP would provide real evidence for theories that attempt to explain the observed cosmic acceleration by modifying general relativity.

In all known theories of modified gravity, a new scalar degree of freedom is introduced that is active on large scales but is screened on small scales to match experiments in the solar system (which agree with GR). It has been demonstrated that if such screening occurs via the chameleon mechanism then it is possible to have order unity violations of the EP. On the contrary, if the screening of the scalar occurs because it becomes strongly coupled, for instance as in the DGP braneworld model, EP violations occur at a much reduced level. These predictions suggest several observational tests for the chameleon mechanism, for example stars and gas in small galaxies should have different velocities, a difference in the size of voids defined by small galaxies compared to standard expectations, a difference in the lensing and mass estimates for small and large galaxies, etc.

The rich phenomenology of modified gravity motivates the need for improved tests of the EP. A planned mission called the Satellite Test of the Equivalence Principle (STEP) will be able to detect deviations from the EP as small as one part in a million trillion. That's 100,000 times more sensitive than the current best measurement. These tests would be probing new territories in physics that are related to deep and mysterious issues in fundamental physics.

Bradley J Kavanagh
Astronomy for WIMPs: the direct detection of dark matter

The standard model of cosmology predicts that roughly 84% of matter in the universe is 'dark' – emitting no light and being observed only through its gravitational effects. This 'dark matter' cannot be accounted for by ordinary baryonic matter and thus a new particle species is required to explain it. Weakly Interacting Massive Particles (WIMPs) are a popular class of candidates and typically have very weak but non-zero interactions with baryonic matter. This provides an opportunity to detect dark matter non-gravitationally in the laboratory by measuring WIMP-induced nuclear recoils in a detector.

Here, I discuss some of the astrophysical uncertainties associated with such direct detection experiments and illustrate what can go wrong when they are not properly taken into account. I also present techniques aimed at reconstructing the velocity distribution of WIMPs in the Milky Way from hypothetical data. These techniques are a necessary step in the development of 'WIMP astronomy' – the study of the nature and distribution of dark matter particles in the Milky Way halo.

Zong-Gang Mou
Baryogenesis Simulations with Low-cost Fermions

Quantum field theory can be simulated with copies classical fields. In the light of the method, quantum fermion properties can be mimicked with the supercomputer. One interesting application is the electroweak baryogenesis, which is believed to generate the present-day ordinary matter in our universe.

ULTRACOLD ATOMS

Using a BEC Microscope to detect Action Potentials
Rob Clay

BECs can be used as magnetic field sensors, with a combination of μm spatial resolution and nT sensitivity. A magnetic field changes the density profile of the atom cloud. The density profile can be imaged optically and then used to reconstruct the magnetic field profile.Here we outline a plan and model to test whether such a technique can be used to detect action potentials in neurons.

The behaviour of neurons has been described by the Hodgkin Huxley model which involves voltage dependent gated ion channels. A sufficiently large stimulus will cause the channels to behave in a nonlinear manner resulting in a positive feedback effect. This gives rise to a depolarisation of the cell membrane ~ 100mV which is known as an action potential.

A computational model will be required to determine whether the currents involved are large enough to be detected by a BEC. This involves modelling the concentration profiles in both the intracellular and extracellular space. The flux at the membrane will be regulated according to the Hodgkin-Huxley model.

Towards Ultracold Mixtures on a Chip
Matthew Jones, Sonali Warriar, **Asaf Paris Mandoki**, German Sinuco, Peter Krüger and Lucia Hackermüller

Ultracold mixtures hold the promise of understanding new phases of matter and collisions at very low energies. By combining the capabilities of the atom chip with optical dipole trapping, it will be possible to trap these mixtures in low dimensions and tune their scattering lengths via Feshbach resonances. In this way it will also be possible to realise experiments with additional magnetic potentials, position dependent interactions or impurity dynamics. Here we present the current status of our experiment. We detail the cooling schemes for both atom species, our experimental control system and include the recent development of implementing an optical dipole trap. The next steps, including implementation of Raman side-band cooling and introducing the atom chip to the setup are commented on.

The ground state of an inhomogeneous Rydberg lattice gas
Siyuan Ji, V. Sanghai, C. Ates and I. Lesanovsky

We consider a one-dimensional laser-driven Rydberg lattice gas with perfect nearest-neighbor blockade. The ground state of this system can be found analytically in certain parameter regimes even when the applied fields are inhomogeneous in space. This permits the systematic study of impurities and the role of inhomogeneous global fields that break the spatial symmetries, e.g. the sublattice symmetry. The latter enables the investigation of the effect of long-range interactions on the critical properties of the system.