

PHYSICS TSP PROJECTS: SECOND SEMESTER 2011

Here are outlines and contact emails for second semester TSP projects. This list is by no means exhaustive, and if there's a particular staff member or group you'd like to work with, you should contact them directly. It can be more efficient for supervisors if students work in pairs but this is not mandatory.

Dick Hunstead & Helen Johnston May 30, 2011
rwh@physics.usyd.edu.au, h.johnston@physics.usyd.edu.au

1. Hunting for intermediate-mass black holes

Sean Farrell
sean.farrell@sydney.edu.au

The existence of black holes is now well established from astronomical observations, with the known sample split clearly into two weight divisions: lightweight stellar-mass black holes ($\sim 3\text{--}30$ times the mass of the Sun), and heavyweight super-massive black holes ($\sim 10^6$ to 10^9 times the mass of the Sun). However, the existence of a middleweight 'intermediate mass' class of black holes has not yet been conclusively determined. Intermediate-mass black holes are possibly the building blocks of the super-massive black holes found in the centres of most galaxies, and may thus play an important role in the formation and evolution of galaxies. Matter falling into a black hole emits strongly in X-ray wavelengths, with the luminosity proportional to the black hole mass. The aim of this project will be to hunt for new intermediate-mass black hole candidates by identifying and studying extragalactic X-ray sources that have luminosities between the stellar mass and super-massive black holes. This project will make use of catalogues of X-ray sources compiled from observations performed with the XMM-Newton and Chandra X-ray space telescopes.

2. Exploring the extreme transient sky

Sean Farrell & Tara Murphy
sean.farrell@sydney.edu.au, tara.murphy@sydney.edu.au

Astrophysical objects that undergo rapid and violent physical processes produce transient behaviour over a range of timescales. Transient sources therefore provide excellent probes of the most extreme physical environments in the Universe such as intense magnetic fields, extraordinary gravitational fields, and extremely high temperatures. Astrophysical variability is closely tied to energetic processes, with the amplitude correlated with the energy produced. Thus, the most extreme transient phenomena produce emission in high-energy wavelengths such as X-rays. In this project you will exploit the enormous archive of unexplored data from the European Space Agency's XMM-Newton space telescope to search for new undiscovered transient X-ray sources. You will have the opportunity to discover and characterise new interesting objects such as black holes, magnetars (neutron stars with extremely strong magnetic fields), and tidal disruption events (flares produced when a star is ripped apart by a super-massive black hole). If you are computationally inclined, there is also the opportunity to develop automatic techniques to detect archival transients, which will also be used in surveys we conduct with future telescopes such as ASKAP and SKAMP.

3. How does the brain compute? Distributed dynamical computation in neural circuits

Pulin Gong & Peter Robinson
P.Gong@physics.usyd.edu.au

One of the most fundamental problems about the brain is how it computes. To answer this question, we have recently presented a concept of distributed dynamical computation in which computation is carried out by interacting, propagating brain activity patterns such as neural firing waves. The concept can merge dynamics and computation aspects of the brain, which used to have great gaps between each other. The project will involve making further links between dynamics and computation, including studying our current models of spiking neural networks with synaptic dynamics and quantifying distributed parallel computation capacities of interacting wave patterns.

4. Co-evolution of dynamics and structures of complex networks

Pulin Gong
P.Gong@physics.usyd.edu.au

Many networks including natural networks and human-made ones have small world, scale-free structures. We have presented a model with dynamical units to interpret how systems with dynamical behaviors can self-organize to such complex networks. In this project, we will study the physics of the dynamical evolution process, and determine how dynamics can evolve to a kind of edge of chaos behavior with structures eventually reaching small-world networks. We will be particularly interested in the underlying nonequilibrium phase transition and dynamical percolations of the evolving process.

5. Pattern dynamics of three-state neural networks

Pulin Gong & Prof. Peter Robinson
P.Gong@physics.usyd.edu.au

The three-state model of neurons has been introduced to capture three essential behaviors of neural activity, which are quiescent, activated, and refractory states. Given that the myriad details of neurons are only partially known, using models as simple as possible like this one is essential for us to firstly get some general principles of neural systems, and further generalize and test them in realistic models or even in real brains. The project will involve using the model to construct spatially-extended 2D and 3D networks to examine the principles of formation of dynamical patterns and their information processing abilities, and generalizing these principles to relevant neural field models. Due to the discrete nature of states of individual units, the networks share some similarity with other well-studied models in physics and mathematics, such as the models of self-organized criticality. This, therefore, will result in adapting methods developed in those models to study the formation of dynamical spatiotemporal patterns in our cases.

6. Conditions for frozen light in optical waveguides

Nadav Gutman & Martijn de Sterke
nadav@physics.usyd.edu.au

Optical waveguides confine light and control its directional propagation. For the last decade, optical waveguides have also designed to lower the (group) velocity of light traveling inside them. The reduced speed of light enhances the interaction of light with its surrounding. Applications of this enhanced interaction using slow light are diverse, ranging from optical memories to quantum electrodynamics. The aim of this project is to design optical waveguides with zero velocity, *ie.*, in which the light comes to a complete halt. Such light is referred to as *Frozen light*. Waveguides that support frozen light are quite rare. We showed earlier that optical fiber with periodic structures has this ability. In this project you will focus on defining the conditions for frozen light in optical fiber, using analytical methods and existing software.

7. Variability part I: radio sources from the AT20G survey

Paul Hancock
Paul.Hancock@sydney.edu.au

The AT20G is the largest high-frequency (20 GHz) radio survey of the southern skies. One of the outcomes of the survey was the identification of radio sources that vary in flux by more than a factor of two. Many radio sources are known to be variable, but a factor of two change in flux requires some rather energetic events to be taking place. Variability of astronomical sources is a fast growing field of interest and in the era of time-domain astronomy there exists a large amount of parameter space that is yet to be explored. In this project you will be investigating the multi-wavelength properties of these sources with the aim of identifying the cause of the variability. This project will be leveraging the large amount of information available online from many different observatories, including gamma-ray, X-ray, radio, and optical telescopes.

8. Finding your way in the cosmos

Dick Hunstead, Helen Johnston
rwh@physics.usyd.edu.au, h.johnston@physics.usyd.edu.au

Astrometry — the measurement of accurate positions on the sky — is fundamental to all observational astronomy. Up until the past two decades we relied on the positions of stars in our galaxy to define the cosmic reference frame. However, stars are not fixed and their positional accuracy degrades with time. Radio sources, on the other hand, are at much greater distances and their positions can now be determined using very long baseline interferometry with uncertainties <1 milliarcsecond. This project asks the question: how well do radio and optical positions agree over the whole sky? This is critical for identifying the optical counterparts of radio sources. Surprisingly, such a comparison has not been done using the latest data, so this is an opportunity to break new ground.

9. Nonlinear entrainment of neural activities in the brain

Jong-Won Kim & Peter A. Robinson
jwkim@physics.usyd.edu.au

Neurons in the brain fire in response to applied signals (e.g., visual/auditory inputs). This firing often shows oscillatory behaviors whose frequencies are associated with either neurons' intrinsic properties or harmonics of the applied stimuli. An extreme example of this entrainment is epileptic seizures. This projects will use the Brain Dynamics (in Complex Systems) Group's theory and computer codes to model this effect, with the aim of understanding the underlying dynamics of this entrainment. If successful, this will lead to a scientific publication.

10. Metamaterials: Making the invisible visible, and making the visible invisible (two projects)

Boris Kuhlmeiy, Alexander Argyros & Simon Fleming
boris.kuhlmeiy@sydney.edu.au

We offer two projects in the exciting field of metamaterials. The goal of the first, mostly experimental project is to turn state-of-the-art metamaterials into hyperlenses, which can form images of objects too small to be imaged by a standard optical microscope. The second, mostly numerical project will explore a practical scheme for invisibility cloaking that could be fabricated here at the School of Physics.

Metamaterials are novel artificially designed materials with unprecedented electromagnetic properties. It has been demonstrated that such metamaterials can be used for electromagnetic cloaking (the ability to make things invisible) or have negative refractive indices, which can be used to make perfect lenses with infinite resolution. Metamaterials are made of a more or less periodic set of electromagnetic resonators, which need to be smaller than the design wavelength. Metamaterials have been demonstrated at very long wavelengths (radio and microwaves) where the size of the resonators can be of the order of a centimetre, but also at optical wavelengths using appropriately arranged gold nanoparticles.

In both cases the fabrication of metamaterials is extremely time-consuming, and only small volumes can be made. We recently developed a technique to fabricate metamaterials in large volumes by drawing indium/polymer composite fibres. The first project will explore post-processing existing metamaterial fibres into a hyperlens, a lens capable which is of resolving details below the diffraction limit of conventional lenses. The second project's aim is to simulate metamaterial geometries we could actually fabricate to create invisibility cloaks.

11. Characterisation of novel micro-structured polymer fibres for bio-sensing

Boris Kuhlmeiy & Kwang Jo Lee
boris.kuhlmeiy@sydney.edu.au

Optical fibre-based refractive index (RI) sensors are one of the most effective and safe methods to measure biological substances in aqueous solution, in biology and medicine. We have recently demonstrated, with very promising results, a novel RI sensor based on optical fibres which have microscopic holes. However, it doesn't work for aqueous solutions. A major recent design development will allow us to improve the sensor dramatically in particular for aqueous solutions, and new required fibres have only just been drawn in the School of Physics fibre draw facility. This experimental project will measure the sensitivity of these new fibre sensors.

12. Variability part II: optical sources from the Carte du Ciel

Greg Madsen, Paul Hancock
Greg.Madsen@sydney.edu.au,Paul.Hancock@sydney.edu.au

The Carte du Ciel is part of the first all-sky map of the southern hemisphere, with contributions from telescopes in many countries. The Sydney Observatory participated in the Carte du Ciel, and catalogued 430,000 stars between 1892 and 1948. Until recently many of the photographic plates that went into making this catalogue have been under-utilized as the technology to accurately handle such a large amount of information has not been available. A subset of 700 of the original plates have been scanned into digital format. The scanned plates offer an historical reference for the study of long term variability, and contain overlapping regions from which short term variability can also be measured. In this project you will be working with the digitized images to characterize the incidence and magnitude of variability on different time scales and for different object types.

13. Optical sensing in solution

David McKenzie
d.mckenzie@physics.usyd.edu.au

We are using light to probe what is happening in solution near interfaces. This problem is of interest in the field of biosensing where antibodies and their binding partners combine. Optical methods of detecting this interaction are valuable as a fast and sensitive readouts for "lab on a chip" diagnostic methods in medicine. In this project we will use UV and infrared light to give information about the structures of the biological layers formed at interfaces using a new geometry in which the light only enters the solution as an evanescent wave.

14. Narcolepsy and microsleeps

Peter Robinson, Svetlana Postnova, Jong Won Kim

robinson@physics.usyd.edu.au, postnova@physics.usyd.edu.au, jwkim@physics.usyd.edu.au

Narcolepsy is a disorder characterized by excessive sleepiness and uncontrollable lapses into sleep, plus abnormal waking in what should be the sleep period. It is now known to be caused by a deficiency in a group of neurons in the hypothalamus. This project will involve modeling this pathology using our physiologically-based model of sleep dynamics. The effects of including noisy input to the system will be investigated, simulating the frequent napping behavior observed in narcolepsy, and possibly microsleeps of normal individuals. This will enable us to better understand and diagnose the disorder.

15. Dust charging in plasma crystals and clouds

Alex Samarian

samarian@physics.usyd.edu.au

Do the rings of Saturn have something in common with industrial reactors used to manufacture semiconductor microchips? Yes, since these are examples of systems containing charged dust particles. Then, what qualitatively new features appear if matter contains solid inclusions? How do the physical states of matter including the most chaotic and disordered one, a plasma, behave in the presence of charged solid 'dust' inclusions? The dust particles, strongly charged due to the ambient plasma, can form various ordered (crystals) or disordered (clouds) structures. This project involves the analysis of dust charging in plasma crystals and clouds formed in radio-frequency discharge plasmas.

16. Dynamics of microparticles in complex plasma

Alex Samarian

samarian@physics.usyd.edu.au

Plasma crystals consist of dust particles embedded in a discharge plasma. Particles in plasma acquire electric charge by collecting electrons and ions, and this charge can be extremely high (say up to a billion electron charges for a micron-sized particle). This high charge causes the particles to interact as strongly coupled plasma. The Coulomb interaction between the dust particles leads to the formation of ordered structures including liquid- and solid-like forms of matter, where the particles are arranged just like atoms in actual condensed matter. Such solid-like structures are called plasma or Coulomb crystals. This project involves the experimental observation of dynamics of charged particles in a plasma crystal consisting of several layers of dust particles trapped in sheath region of a planar radio-frequency discharge. The plasma crystals are illuminated by a laser and their positions are recorded by a CCD camera for later analysis.

17. Study of marginal stability in a complex plasma system

Alex Samarian, Sergey Vladimirov

samarian@physics.usyd.edu.au

Complex plasma systems have unique properties allowing experimental research of structural phenomena at the most fundamental kinetic level. The complex plasma is multi-component plasma with micrometre-sized particle inclusions. Experimentally, the structures are confined in the horizontal and vertical dimensions by the electrostatic field. The diagnostics of the structures is based on visualization of the particle positions and motions; it uses a laser beam and a CCD camera. This project involves the image analysis of the data from the direct experimental observation of nonlinear dynamics of the low-dimensional system of interacting individual particles near the marginal stability point.

18. Are my friends your friends too? Measuring hierarchy and overlaps in complex system community structures

Somwrita Sarkar & Peter Robinson

sarkar@physics.usyd.edu.au

Many physical, biological, and social complex systems perform their functions through system components self-organizing themselves into tightly knit clusters or communities. Investigating the hierarchical and overlapping organization of community structures is an exciting but unsolved question in complex systems research. We have developed a novel and successful community detection method that can identify hierarchical and overlapping clusters in such systems. In this project, we will develop rigorous measures to characterize hierarchy and overlaps between clusters. We will be particularly interested in domains where modular overlaps and hierarchy are known to exist, but are poorly understood (e.g. brain networks, protein interaction networks, communication networks, online community networks such as Facebook, the Internet and the WWW, etc).

19. Radiation propagation in fluctuating plasmas

Kunwar Pal Singh & Peter Robinson
kpsingh@physics.usyd.edu.au

Radiation propagation in fluctuating plasmas is important in space physics where plasma fluctuations are prevalent. Recently, the group has developed a numerical code to solve the kinetic equations to yield the distribution function of radiation quanta. This function enables calculation of radiation properties, such as intensity and polarization, as functions of time and space. The information about intensity and polarization can be used to obtain dynamic spectra and polarization properties of coronal and interplanetary type III solar radio bursts, emission from the vicinity of coronal mass ejections, and planetary radio emissions. The student will utilize this code to research on propagation of radiation by taking into account refraction, plasma anisotropy and mode structure in an ambient magnetic field, scattering of radiation by plasma nonuniformities, and mode conversion.

20. Laser driven electron acceleration

Kunwar Pal Singh & Peter Robinson
kpsingh@physics.usyd.edu.au

High energy electron beams find applications in inertial confinement fusion (which can solve energy problem of the world), production of X-rays, radiotherapy, biological imaging, high-energy physics, tunable radiations and particles. Traditional charged particle accelerators are huge in size, costly and produce low quality electron beams. Laser driven electron acceleration is a compact and low-cost alternative to the conventional accelerators, producing much higher energy and much better quality electron beams. The laser driven electron acceleration to obtain high energy quasimonoenergetic (nearly same energy), collimated (going in the nearly same direction) beams will be explored. The project will use existing ionization and acceleration simulation code available with the group to model electron acceleration during interaction of a laser pulse with low density gases. The student will get training in writing and using numerical code. The student will carry out numerical experiments to find out laser parameters and target properties to produce good quality high energy electron beams using the code. Our modeling results will be useful for the planning of the experiments to produce good quality electron beams.

21. Ion acceleration during laser-plasma interaction

Kunwar Pal Singh & Peter Robinson
kpsingh@physics.usyd.edu.au

The applications of good quality, high energy ion beams range from physics to medical and bio sciences such as inertial confinement fusion, production of X-rays, radiotherapy, biological imaging, high-energy physics, tunable radiations and particles. Traditional charged particle accelerators are huge in size. Ion acceleration during laser-plasma interaction is a compact and low-cost method to produce good quality, high energy ion beams. Laser accelerated ion beams show a large longitudinal emittance, with their energy spectrum exhibiting a quasi-exponential shape with a distinct cut-off energy. The mechanisms and characteristics of ion acceleration driven by the interaction of a short laser pulse with plasmas are of tremendous interest to understand the physics and for the success of the concept. The student will receive training about basics of Particle-In-Cell (PIC) simulation code available with the group and using the code for real laser-plasma interaction problems. The student will simulate ion acceleration during laser-plasma interaction using the code and will explore the effect of self-generated electric and magnetic fields on the ion acceleration. The student will find out laser parameters and target properties to obtain high energy quasimonoenergetic collimated ion beams using the code.

22. Asteroseismology: probing inside stars using stellar oscillations

Dennis Stello, Tim Bedding
bedding@physics.usyd.edu.au

Asteroseismology involves using the oscillation frequencies of a star to measure its internal properties. Measuring stellar oscillations is a beautiful physics experiment: a star is a gaseous sphere that will oscillate in many different modes when suitably excited. The frequencies of these oscillations depend on the sound speed inside the star, which in turn depends on density, temperature, gas motion and other properties of the stellar interior. This analysis, called asteroseismology, yields information such as composition, age, mixing and internal rotation that cannot be obtained in any other way and is completely analogous to the seismological study of the interior of the Earth. Many stars, including the Sun, are observed to oscillate. Asteroseismology is a new and rapidly developing field and we have a number of projects up for grabs.

23. Spontaneous symmetry breaking in nonlinear gratings

Martijn de Sterke & Irina Kabakova
martijn.desterke@sydney.edu.au

Spontaneous symmetry breaking is a very general phenomenon appearing in many branches of physics, such as fluid dynamics, high-energy physics, and ferromagnetism. It refers to symmetric systems with nonetheless have states which are neither symmetric nor antisymmetric. An example we are looking at is a nonlinear optical system with two defects: at low intensities, where nonlinear effects are negligible, it has a symmetric and an antisymmetric eigenstate, with different frequencies. When increasing the intensity, then by the nonlinear effect the refractive at a position changes in proportion to the local intensity. The effect of this is that initially the nature of both states is unchanged, with their frequencies merely shifting. However, at high intensities a new state, neither symmetric nor anti-symmetric becomes possible. The aim of this numerical project is to track how this nonlinear mode varies with intensity and to understand its stability to small external perturbations.

24. Interferometry for exoplanet science aboard the James Webb Space Telescope

Peter Tuthill
peter.tuthill@sydney.edu.au

We are leading a team developing an interferometric technology for NASA's JWST telescope (the successor to the Hubble) — a 6m infrared telescope to be launched in 2014. This project will explore the JWST space interferometer in terms of primary performance metrics, simulating real-world sources of error and imperfection. The ultimate goal will be the delivery of the most sensitive imager to reveal the presence of distant exoplanets ever devised.

25. Searching for bumps at hadron colliders

Kevin Varvell
kevin.varvell@sydney.edu.au

We live in interesting times for particle physics research. With the baton for the world's highest energy collider having passed from the Tevatron to the Large Hadron Collider, the search for new particles such as the Higgs boson and heavy vector bosons is gaining momentum. At hadron colliders this involves looking for a needle in a haystack. Sometimes the needle is found when in fact it may not be there, and bumps have been appearing on both sides of the Atlantic this year. In this project we will use a simple toy Monte Carlo technique to explore the phenomenon of bump hunting, in order to gain an appreciation of some of the pitfalls.

26. Surface waves in quantum plasmas

Sergey Vladimirov, Roman Kompaneets, Yuriy Tyshetskiy
S.Vladimirov@physics.usyd.edu.au

In a recent Nature paper entitled 'Lasers go nano' (October 2009), two experiments exploiting the collective wave-like motion of free electrons on a metal surface — surface plasmons, or plasma surface waves — were discussed that bring the science and technology of lasers into the nanoland. Despite being of great interest, surface plasmons have been mostly studied using classical linear or nonlinear theory. However, with current experiments and technologies approaching nanoscales, quantum plasma effects become important. We propose several analytical and computational projects to investigate the dispersion and other properties of plasma surface waves in situations where quantum effects are important. If successful, the results will lead to a publication in a refereed scientific journal. It is not expected that you will already be familiar with quantum plasma physics and numerical methods, but it is essential that you have good analytical mathematical or programming skills. More information (e.g. what you will learn by doing a project with us) can be found at: <http://sydney.edu.au/science/physics/research/complex/plasma>