Projects update, errata and corrections to the *MPhys Projects Trinity Term 2021*

AO25 **Can a seasonal forecast model predict variations in the southern hemisphere jet stream?**

Variations in the southern hemisphere jet stream have a substantial effect on weather patterns over Australia, New Zealand and South America. This variability is typically well forecasted by models at timescales of around 10 days, but making predictions on monthly and longer timescales, known as seasonal forecasting, is a significant challenge. However, forecasting seasonal average weather is possible because of the slow evolution of sea surface temperatures which are a source of 'memory' in the system, affecting the atmosphere on longer timescales. The ability to make successful seasonal forecasts would provide important information for industries such as the energy and water sectors.

In this project, the student will analyse a set of weather model simulations to investigate the degree to which these have skill in predicting southern hemisphere jet variability at seasonal timescales. This will also involve exploring the physical mechanisms which give rise to predictability including forcing by the El Nino pattern of sea surface temperatures. Some basic programming skills in a high level language (such as Python or Matlab) are required.

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******WITHDRAWN***CMP21*** **Decoding the science of ultimate performance in perovskite solar cells: the beauty of interfacial engineering**

Following an unprecedented rise in power conversion efficiencies within the past few years, metal halide perovskites (MHPs) have surged as a new class of photovoltaic materials and hold great promise to revolutionise the solar industry in the next decade. However, many studies have suggested severe non-radiative recombination that exists at the imperfect interfaces between perovskite light absorbers and charge collection layers could hinder photo-carrier collection, hence limiting the ultimate photovoltaic performance using MHPs in solar energy harvesting applications. Taking these basic understanding forward, it seems natural to ask whether the photo-carriers dissociated within MHPs could be effectively collected through engineering preferential interface properties. This question provides the springboard for this project.

The specific approach that will be used here is to integrate various types of polymer electrets (i.e. dielectric polymers) in-between charge-collection layers and perovskite light absorbers. This work demands good experimental (solar cell fabrication) and electrical-characterisation (J-V measurement) skills. The main activities include that 1) understanding how the dipole-induced built-in electric-fields in polymeric materials could reduce non-radiative recombination losses; and 2) implementing selected polymer electrets into MHP cell structures, hence decoding what limits the ultimate cell performance both theoretically and experimentally.

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******WITHDRAWN***CMP22*** **"There's Plenty of Room at the Bottom" – Nanostructure-assembly towards high-performance perovskite solar cells**

Commenting on the possibility of directly manipulating individual atoms, more than half a century ago Nobel laureate Richard Feynman gave a lecture in Caltech, called "There's Plenty of Room at the Bottom". The idea conveyed in this lecture is believed to be the very first conceptual origin in the field of nanotechnology. In fact, the ability to control each individual photo-induced carrier in nanoscale/molecular-scale is particularly important for the applications of metal-halide perovskites (MHPs) in photovoltaics. This is because the non-radiative recombination loss that takes place at the interfaces between MHP and charge-collection layers plays a major role that limits perovskite solar cells (PSCs) from reaching their theoretical efficiency.

In this project, we will carry out our research in a nano-world. The specific approach will be used is to integrate various types of organic molecules into charge-collection layers through the means of nano-assembly. This project demands good experimental (solar cell fabrication) and electrical-characterisation (J-V measurement) skills. The main activities are to identify potential organic nanostructures that can facilitate charge transport as well as to design the processing routes to nano-assembling feasible organic molecules into PSCs, hence unlocking PSC's theoretical performance.

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*****WITHDRAWN**** *TP10* Topological Statistical Mechanics

Exactly solvable models have taught us an enormous amount about statistical physics and phase transitions. A new class of (classical) stat-mech models was recently proposed which can be solved exactly due to their having a special "crossing" symmetry. The simplest example of such a problem is counting the number of nets (branching tree structures) without ends on the honeycomb.

The objective of this project is to use the exact solvabiltiy of these models as a stepping off point for the analysis of models which are nearly, but not exactly, solvable. I.e., we will perturb these models with small terms that slightly ruin the crossing symmetry. We will use several tools to come to an understanding on the statistical physics of these systems — these tools include numerical simulation of several types, analytical perturbation theory, and renormalization group approaches.

The project is suitable for a mathematically strong student taking the Theoretical Physics option. This work will involve analytical calculations, and a large component of computer programming. Working knowledge of a computational programming language such as C, C++, or fortran will be required.

Some background reading: Steven H. Simon, Paul Fendley; J. Phys. A 46, 105002 (2013). M. Hermanns and S. Trebst http://arxiv.org/abs/1309.3793.

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TP20 Philosophical and practical applications of Occam's razor in machine learning

Since antiquity, the principle that parsimonious theories are better than more complex ones, which received the label Ockham's Razor, has played a pivotal role in countless scientific and philosophical arguments. But despite its popularity, its justification remains highly contested. In this project you will study some of the recent philosophical literature (Putnam, Sober, Swinburne, Sterkenberg) and connect it to a parallel discussion in the machine learning community (Mackay, Blumer, Domingos). A basic understanding of philosophy as well as excellent mathematical skills are needed for this project.

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AO12 Characterising recurrent climate cycles and teleconnections through atmospheric angular momentum fluctuations

The Earth's climate is observed to exhibit a variety of recurrent phenomena on timescales ranging from months to decades. Some of these phenomena occur as repeatable (albeit weakly or strongly chaotic) cycles that may either be localized to particular geographical locations or can act to couple fluctuations coherently between different parts of the planet. Such cycles may be apparent in different observed atmospheric variables, including atmospheric temperature, winds and angular momentum. They include phenomena such as the tropically-focused Madden-Julian oscillation (on timescales of 2-4 months), which affects patterns of tropical convection, the Arctic Oscillation (on timescales of 1-2 years) affecting the behaviour of storm tracks at high northern latitudes, and longer timescale climate cycles such as the El-Niño Southern Oscillation (with periods of 3-6 years) and the North Atlantic and Atlantic Interdecadal Oscillations (on timescales of up to 20-30 years).

In the present project we propose to explore the properties of fluctuations contained in a relatively novel time series of atmospheric axial angular momentum per unit mass, integrated in height from the surface to the lower stratosphere and covering an interval of more than 50 years of observations. The time series is unusual in partitioning angular momentum into a series of latitude bands covering the entire globe, allowing the possibility of detecting and characterizing recurrent phenomena that are coherent across different locations (so-called teleconnections). It is proposed to apply a variety of analysis methods, including those developed to analyse nonlinear oscillations and synchronization phenomena in chaotic dynamical systems. This project will require good computation skills and some background in the mathematics of nonlinear dynamics.

References

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Dickey, J. O., Ghil, M. & Marcus, S. L. (1991) Extratropical Aspects of the 40-50 Day Oscillation in Length-of-Day and Atmospheric Angular Momentum, J. Geophys. Res., 96(D12), 22,643-22,658

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AO13 **Quasi-geostrophic modeling of zonal jets, waves and vortex interactions on Jupiter and Saturn**

The visible atmospheres of Jupiter and Saturn are dominated by patterns of strong zonal (East-West) jet streams and bands of ammonia ice clouds, within which are observed a variety of wavy meanders and compact, coherent anticyclonic and cyclonic vortices. The latter includes features such as Jupiter's Great Red Spot (a huge anticyclone 3 x the size of Earth that has been present for at least 300 years) and similar smaller features on both Jupiter and Saturn, and a remarkably symmetric hexagonal wave near Saturn's north pole. The detailed mechanisms for the formation of these jets, waves and vortices are still not fully understood though some features are beginning to be reproduced in various types of numerical model.

In the present project we propose to explore a simplified numerical model capable of simulating some of these kinds of feature. The modelling approach is based on the quasi-geostrophic approximation, in which the horizontal flow is assumed to be close to a geostrophic balance between pressure gradient and Coriolis forces. This leads to a simplified mathematical form that is easier and quicker to solve than the full Navier-Stokes equations. We propose to use and extend an existing model code (such as the Python Quasigeostrophic Model - https://www.gfdatabase.com/2018/11/pyqg-python-quasigeostrophic-model/) to simulate flows that may emulate the dynamics of a set of eastward and westward zonal jets at mid-latitudes on Jupiter or Saturn. With suitable representations of forcing and dissipation the zonal jets can be sustained and the dynamics of embedded vortices and waves can be simulated. Possible scenarios to be investigated may include the interactions of the Great Red Spot with smaller vortices (e.g. as observed recently by the Juno spacecraft) or the formation of Saturn's north polar hexagon. This project requires good computational skills e.g. using Python or Fortran.

References

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Marcus, P. S. (1993) Jupiter's Great Red Spot and other vortices, Annu. Rev. Astron. Astrophys. 1993.31: 523-73

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