# Chasing Tornadoes: Vorticity Above, Below, and in the Lab

**School of Mathematics, Statistics & Physics,
Newcastle University**

http://conferences.ncl.ac.uk/chasingtornadoes/

9-11 April 2018

Workshop Organisers:
Andrew Baggaley, Luca Galantucci, Nick Parker, George Stagg
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# Contents

# 1 Welcome

Carlo Ferruccio Barenghi is one of the leading figures in the field of quantum fluids, where he has pioneered the application of ideas from modern fluid mechanics in this exotic, low-temperature, realm. His scientific career began at the University of Milan where he obtained a degree in theoretical physics. He subsequently moved to the US where he was awarded a Ph.D. in experimental physics at the University of Oregon, working with one of the true pioneers of the science of cold, Russ Donnelly.

He moved to the UK in the early 1980s working with the father of quantum turbulence, Joe Vinen, in Birmingham. In 1986 Carlo moved to Newcastle, where he has remained for the past three decades. At Newcastle he has been responsible for establishing one of the world leading quantum fluids groups, and making numerous important breakthroughs in the field of quantum fluids. For all of Carlo's abilities (and achievements) as a scientist it is his infectious curiosity and entirely positive approach which have fired a passion for the cold and the "tangled" inside generations of scientists.

On the occasion of his $65^{\text{th}}$ birthday, we have the pleasure of hosting a workshop in Carlo's spirit, bringing together people belonging to the different scientific communities Carlo has worked in.

# 2 Useful Information

## 2.1 University Address

School of Mathematics, Statistics & Physics
Herschel Building
Newcastle University
Newcastle upon Tyne
NE1 7RU

## 2.2 Internet Access

Eduroam WiFi is available throughout the Herschel Building. Newcastle University also provides guest WiFi in partnership with Cloud Networks Ltd under the name "Wifi Guest". The service is provided free of charge.

## 2.3 Venues

### Herschel Building

- Ground Floor Foyer - Reception & Coffee Breaks
- LT3 - Ground Floor - Workshop talks
- LT1 - Ground Floor - Carlo & Keith's Lectures
- Penthouse - 7th Floor - Wine reception and poster sessions

### Dinner

- Monday - Buffet in the Herschel Penthouse
- Tuesday - As You Like It Restaurant, Jesmond

## 2.4 Hotel Information

### Osborne Hotel

URL: `http://www.theosbornehotel.co.uk`

13-15 Osborne Road,
Jesmond,
Newcastle Upon Tyne,
NE2 2AE

Tel: 0191 281 3385

### Holiday Inn Express

URL: `https://www.expressnewcastle.co.uk/`

Waterloo Square,
St James Boulevard,
Newcastle upon Tyne
NE1 4DN

Tel: 0871 902 1625 (Calls cost 13p per minute)
Alt. Tel: 0191 224 6850

### Dene Hotel

URL: `http://www.thedenehotel.co.uk/`

38-42 Grosvenor Road,
Jesmond,
Newcastle Upon Tyne,
NE2 2RP

Tel: 0191 281 1502

# 3 Support

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- Quantum Fluids Special Interest Group,
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- The Engineering and Physical Sciences Research Council,
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- School of Mathematics, Statistics & Physics – Newcastle University.

# 4 Workshop Schedule

## Monday 9th April

### 13:00-13:50 Registration

### 13:50-15:30 Session 1 Chair: Nick Proukakis

13:50 *Welcome/Introduction*

14:00 *Sixty years of quantum vortices*
**William (Joe) Vinen**

14:30 *Recent experiments on quantum turbulence in superfluid* $^4$He *in Prague*
**Ladislav Skrbek**

15:00 *Probing the quantum regime of vortex dynamics in superfluid* $^4$He
**Paul M. Walmsley**

15:15 *Local velocity measurements in superfluid* $^4$He
**Julien Salort**

### 15:30-16:00 Break

### 16:00-17:30 Session 2 Chair: Kali Wilson

16:00 *Turbulence on a far-of equilibrium BEC: new characterization*
**Vanderlei S. Bagnato**

16:30 *Phase transitions and Vortex Stripes in Two Component Bose Einstein Condensates*
**Amandine Aftalion**

17:00 *From the superfluid Taylor-Green vortex to the von Kármán liquid sodium flow*
**Caroline Nore**

### 17:30-17:45 Break

### 17:45-18:45 Lecture – Carlo F. Barenghi Chair: Yuri Sergeev

17:45 *Kolmogorov and Vinen regimes of quantum turbulence*
LT1, Herschel Building

### 18:45 Wine Reception & Buffet Venue: Hershel Penthouse

# Tuesday 10th April

## 09:00-10:30 Session 3 Chair: Andrew Baggaley

09:00 *Freeing a Trapped Superfluid Vortex*
**Rena J. Zieve**

09:30 *Cosmic vortex dynamics*
**Nils Anderson**

10:00 *Anelastic spherical dynamo models for Jupiter and Saturn*
**Chris Jones**

## 10:30-11:00 Break

## 11:00-13:00 Session 4 Chair: Luca Galantucci

11:00 *Vortex reconnections and rebounds in trapped atomic Bose-Einstein condensates*
**Gabriele Ferrari**

11:30 *Superfluidity in Bose-Einstein condensates beyond the standard azimuthal flow*
**Angela White**

12:00 *Filament dynamics and sound emission during vortex reconnections in superfluids*
**Davide Proment**

12:30 *Topological and statistical properties of superfluid vortex tangles*
**Giorgio Krstulovic**

## 13:00-14:15 Lunch

## 14:15-15:30 Session 5 Chair: Ladislav Skrbek

14:15 *Convection conundrum in the Sun*
**Katepalli R. Sreenivasan**

14:45 *Unsteady turbulence cascades and dissipation*
**Christos Vassilicos**

15:15 *Nonlinear solutions and turbulent transition in pipe flow*
**Ashley P. Willis**

## 15:30-16:00 Break

## 16:00-17:30 Session 6 Chair: Nick Parker

16:00 *A theory of turbulent counterflow energy spectra in superfluid* $^4$He
**Victor L'vov**

16:30 *Intermittency of turbulent He-II with superfluid fractions from 0% to 96%*
**Phillipe-E. Roche**

17:00 *The Cryogenic Lagrangian Exploration Module (CryoLEM) A rotating platform to study the dynamics of particles evolving in liquid Helium (HeI & HeII)*
**Mathieu Gibert**

17:15 *Heat transport in superfluid helium: some recent results.*
**Michele Sciacca**

## 17:45-18:45 Public Lecture – Keith Moffatt Chair: Andrew Wilmott

17:45 *The Navier-Stokes Singularity Problem*
LT1, Herschel Building

## 18:45 Conference Dinner Venue: As You Like It

# Wednesday 11th April

## 09:00-10:30 Session 7 Chair: Angela White

09:00 *Finite temperature effects in helical quantum turbulence*
**Marc E. Brachet**

09:30 *Numerical simulation of quantum turbulence*
**Makoto Tsubota**

10:00 *Quantitative Flow Visualization Measurement in Superfluid Helium-4*
**Wei Guo**

## 10:30-11:00 Break

## 11:00-12:30 Session 8 Chair: Paul Walmsley

11:00 *Chasing Microkelvin Vortices in Superfluid $^3$He*
**George R. Pickett**

11:30 *Rotating superfluid* $^3$He *at ultra-low temperatures*
**Vladimir B. Eltsov**

12:00 *Superfluid flow in the zero temperature limit*
**Richard P. Haley**

12:15 *Andreev reflection from quantum turbulence in* $^3$He-B: *Advantages and limitations of combined numerical/experimental study*
**Yuri Sergeev**

## 12:30-14:00 Lunch

## 14:00-15:00 Session 9 Chair: Carlo Barenghi

14:00 *Developing a Toolkit for Experimental Studies of Two-Dimensional Quantum Turbulence in Bose-Einstein Condensates*
**Kali Wilson**

14:30 *Motion of Electron Bubbles along Superfluid Vortices*
**Hayder Salman**

## 15:00 Departure

# 5 List of Talk Abstracts

**Phase transitions and Vortex Stripes in Two Component Bose Einstein Condensates**
*Amandine Aftalion*
The combined effect of rotation and spin orbit coupling in two component Bose Einstein condensates can lead to new vortex patterns, and in particular stripes or sheets. We will analyze this in the framework of the Gross Pitaevskii energy both from a numerical and analytical point of view.

**Cosmic vortex dynamics**
*Nils Anderson*
In this talk I will provide a brief overview of the role of superfluids and associated vortex dynamics for the observed spin-evolution of neutron stars. In particular, I will discuss the phenomenology of pulsar glitches and how we try to use observations to pin down the details of the superfluid (and superconducting) neutron star interior. I will also relate the problem to issues that can be probed in the laboratory setting.

**Turbulence on a far-of equilibrium BEC: new characterization**
*Vanderlei Bagnato*
TBC

**Kolmogorov and Vinen regimes of quantum turbulence**
*Carlo Barenghi*
Quantum fluids such as superfluid liquid helium and atomic Bose-Einstein condensates have two remarkable properties: superfluidity and the quantised nature of the vorticity. From the point of view of the hydrodynamics, the second property is perhaps the most striking, and it opens new geometrical and topological insights into turbulent motion. In this talk I shall review the evidence for two distinct regimes of quantum turbulence which have been observed in experiments and numerical simulations of liquid helium and cold atomic gases: the "Kolmogorov" regime and the "Vinen" regime. The first shares important properties with ordinary turbulence, the second is more like a random flow. Despite the great difference of length/time scales and experimental techniques, these systems are ruled by the same physics: the dynamics of vortex lines and their reconnections.

**Finite temperature effects in helical quantum turbulence**
*Marc Brachet*
We perform a study on the evolution of helical quantum turbulence at different temperatures by solving numerically the Gross-Pitaevskii and the Stochastic Ginzburg-Landau equations, using up to $4096^3$ grid points with a pseudospectral method. We show that

for temperatures close to the critical the fluid described by these equations can act as a classical viscous flow, with the decay of the incompressible kinetic energy and the helicity becoming exponential. The transition from this behavior to the one observed at zero temperature is smooth as a function of temperature. Moreover, the presence of strong thermal effects can inhibit the development of a proper turbulent cascade. We provide anzats for the effective viscosity and friction as a function of the temperature.

**Rotating superfluid $^3$He at ultra-low temperatures**
*Vladimir Eltsov*

While stationary rotation of superfluids is supported by a simple array of rectilinear vortex lines, the dynamic behaviour when rotation velocity changes can be very complicated and different from that of normal fluids. We have studied spin-up and spin-down processes in superfluid $^3$He-B at temperatures down to $0.12\,T_c$. In a smooth-walled cylindrical container the spin-up proceeds via propagation of a vortex front along the rotation axis. Two transitions in vortex dynamics are revealed on decreasing temperature [1]: First from the laminar to the turbulent motion in the front and then the decoupling of superfluid from the reference frame of the container. These transitions follow from the dual role of the rarefying normal component in superfluid dynamics: as a source of dissipation and as means of coupling to the walls. At the lowest temperatures quantum turbulence provides an internal route for finite energy dissipation, but it does not seem to affect substantially the transfer of momentum to the walls. In this regime superfluid dynamics cannot be described by a single effective friction parameter [2].

The spin-down, on the contrary, remains predominantly laminar in the whole studied temperature range. This allows for the first measurements of the mutual friction at ultra-low temperatures and reveals a new dissipation mechanism, which is a combination of the surface and bulk effects in vortex dynamics [3].

[1] V.B. Eltsov et al, Proc. Natl. Acad. Sci. USA 111, 4711 (2014)
[2] J.J. Hosio et al, Nature Commun. 4, 1614 (2013)
[3] J.T. Mäkinen and V.B. Eltsov, Phys. Rev. B 97, 014527 (2018)

**Vortex reconnections and rebounds in trapped atomic Bose-Einstein condensates**
*Gabriele Ferrari*

Quantized vortex interaction mechanisms in atomic condensates have been widely studied in rotating systems, with the self organization of alike vortices into a regular Abrikosov lattice, and also in flat quasi-2D systems, where vortex and antivortices coexist and affect their mutual dynamics. In both these kinds of systems vortices align (or anti align) along a single preferential direction. This is given by the rotation axis in the first case or by the confined direction in the second one. The interaction mechanism among vortices is hence mainly restricted to a 2D problem. We study the interaction mechanisms between vortices in an axially symmetric, elongated BEC. In such a geometry vortices tend to align in a radial plane and can therefore assume any orientation in such plane. Due to the asymmetric confinement the associated phase pattern varies substantially in a region not larger than the transverse Thomas Fermi radius, therefore initially far away vortices orbit around the center of the BEC unaffected by the presence of the other until they approach and start interacting, changing their relative velocity and their relative orientation. Depending on the approaching configuration the two vortices might bounce or reconnect. We combine experimental observations of real-time vortex dynamics and Gross-Pitaevskii simulations and provide a clear picture of 3D interaction mechanism between vortex filaments [Serafini et al., PRX 7, 021031 (2017)].

**The Cryogenic Lagrangian Exploration Module (CryoLEM) a rotating platform to study the dynamics of particles evolving in liquid Helium (HeI & HeII)**
*Mathieu Gibert*

We will present in details the CryoLEM which is a spinning cryostat with multiple optical access. We will describe Its performances and operation mode, especially when operating with H2 or D2 particles. The first results of counter flow turbulence under rotation will also be discussed.

**Quantitative Flow Visualization Measurement in Superfluid Helium-4**
*Wei Guo*

Flow field measurement in superfluid helium-4 (He II) is challenging yet crucial for attaining a detailed understanding of quantum turbulence. In recent years, there have been extensive efforts in developing quantitative flow visualization techniques applicable to He II. Two types of techniques, based on the use of either particle tracers (i.e. micron-sized frozen particles) or molecular tracers (i.e. He2 excimer molecules), have been developed and proven to be useful. I will first briefly summarize the contributions made from our cryogenics lab in these developments. Then, the applications of these two techniques in our study of thermal counteflow and grid turbulence in He II will be discussed. Some very recent Particle Tracking Velocimetry (PTV) data obtained in counterflow using frozen particles will be presented. These data allow us to resolve a long-standing discrepancy between typical PTV measurements and Particle Imaging Velocimetry (PIV) measurements in counterflow. Our analysis of the data also show that existing interpretations on particle velocity statistics in some early PTV counterflow experiments may not be appropriate. In the end, I will briefly introduce our on-going work in developing the next generation of flow visualization techniques.

**Superfluid flow in the zero temperature limit**
*Richard Haley*

A Lancaster specialty is the experimental study of flow around objects immersed in superfluid helium-3 in the pure condensate limit. At temperatures on the order of 100 microK, around 0.1Tc, the superfluid is in the regime of pure potential flow and broken Cooper pair quasiparticle excitations have mean free paths much longer than any length scale in the experimental cell. Over the years we have probed the dynamical properties of this ballistic superfluid by observing the behavior of various oscillating objects including vibrating wire resonators, quartz tuning forks and wire mesh grids. In general, measurement sensitivity has been improved by reducing the mass of the objects, while increasing resonant frequency and quality factor. However, recently we moved in the opposite direction by constructing the “floppy wire” resonator, the largest object we have ever moved through the superfluid at these low temperatures. It was deliberately made to have a low resonant frequency and low quality factor, so that we can use an active drive system to generate DC flows for the first time. We made the completely unexpected discovery that we can sustain DC flow at speeds far above the critical Landau velocity where the superfluid condensate is supposed to break down.

**Anelastic spherical dynamo models for Jupiter and Saturn**
*Chris Jones*

A series of numerical simulations of the dynamos of gas giant planets has been performed. We use an anelastic, fully nonlinear, three-dimensional, benchmarked MHD code to evolve the flow, entropy and magnetic field. Our models take into account the varying electrical conductivity, high in the ionised metallic hydrogen region, low in the molecular outer region. Our suite of electrical conductivity models ranges from Jupiter-like, where the outer hydrodynamic region is quite thin, to Saturn-like, where there is a thick non-conducting shell. The rapid rotation leads to two distinct dynamical regimes forming which are separated by a magnetic tangent cylinder - mTC. Outside the mTC there are strong zonal flows, where Reynolds stress balances turbulent viscosity, but inside the mTC Lorentz force reduces the zonal flow. We find a rich diversity of magnetic field morphologies. There are Jupiter-like steady dipolar fields, and a belt of quadrupolar dominated dynamos spanning the range of models between Jupiter-like and Saturn-like conductivity profiles. This diversity may be linked to the appearance of reversed sign helicity in the metallic regions of our dynamos. With Saturn-like conductivity profiles we find models with dipolar magnetic fields, whose axisymmetric components resemble those of Saturn, and which oscillate on a very long time-scale. However, the nonaxisymmetric field components of our models are at least ten times larger than those of Saturn, possibly due to the absence of any stably stratified layer.

**Topological and statistical properties of superfluid vortex tangles**
*Giorgio Krstulovic*

The development and decay of a turbulent vortex tangle driven by the Gross-Pitaevskii equation is studied. Using an accurate and robust tracking algorithm, all quantized vortices are extracted from the fields. The Vinen's decay law for the total vortex length with a coefficient that is in quantitative agreement with the values measured in helium II is observed. The topology of the tangle is then investigated showing that linked rings may appear during the evolution. The tracking also allows for determining the statistics of small-scale quantities of vortex lines, exhibiting large fluctuations of curvature and torsion. Finally, the temporal evolution of the Kelvin wave spectrum is obtained providing evidence of the development of a weak-wave turbulence cascade.

**A theory of turbulent counterflow energy spectra in superfluid $^4$He**
*Victor L'vov, Anna Pomyalov*

In the thermally driven superfluid $^4$He turbulence, the counterflow velocity $U_{ns}$ partially decouples the normal and superfluid turbulent velocities. Recently we suggested [J. Low Temp. Phys. **187** 497 (2017)] that this decoupling should tremendously increase the turbulent energy dissipation by mutual friction and significantly suppress the energy spectra. Comprehensive measurements of the $U_{ns}$- and temperature $T$-dependence of the apparent scaling exponent $n$ of the $2^{nd}$-order normal fluid velocity structure function $S_2(r) \propto r^n$ in the counterflow turbulence by Tallahassee group confirmed our scenario. Developing further this scenario we presented in this paper an analytical theory of the counterflow turbulence based on a two-fold mechanism of this phenomenon: i) a competition of the scale-dependent interplay of the turbulent velocity coupling by the mutual friction and the $U_{ns}$-induced turbulent velocity decoupling and ii) the turbulent energy dissipation by the mutual friction enhanced by the velocity decoupling. The suggested theory predicts the wavenumber dependence of the normal- and super-fluid turbulent energy spectra and explains the experimentally observed $U_{ns}$- and $T$-dependence of the apparent structure function exponents for relatively high Reynolds number.

**The Navier-Stokes Singularity Problem**
*Keith Moffatt*

Much interest attaches to the question of regularity of the Navier-Stokes equations: given smooth initial conditions of finite energy, does the solution remain smooth for all finite time, or alternatively is it possible for a singularity to develop within a finite time? We have addressed this problem by choosing a configuration which is widely favoured for the development of a singularity, and which lends itself to analytical investigation. Our detailed analysis shows that a finite-time singularity cannot occur for this configuration, but that an arbitrarily large amplification of vorticity can be realised within a finite time if the Reynolds number of the initial velocity field is sufficiently large. The manner in which viscosity suppresses the incipient singularity, as revealed by the analysis, will be described in the lecture.

This work is in collaboration with Yoshifumi Kimura, University of Nagoya.

**From the superfluid Taylor-Green vortex to the von Kármán liquid sodium flow**
*Caroline Nore, in collaboration with M. Abid, M.-E. Brachet, L. Cappanera, D. Castanon-Quiroz and J.-L. Guermond,*

Vortices are fascinating and ubiquitous. They exist as quantized vortices in the Nonlinear Schrödinger Equation and as multi-scale filaments in the turbulent von Kármán flow that can sustain a magnetic field when using liquid sodium. I will describe some contributions in these studies, all based on numerical simulations.

**Chasing Microkelvin Vortices in Superfluid $^3$He**
*George Pickett*

Superfluid $^3$He in the zero temperature limit is an ideal medium for imaging vortices. The naturally occurring tenuous normal fluid of quasiparticles provides the illumination, since flow fields around vortices are opaque to the excitations. This is one of the few fluids in which the velocity is directly 'visible', and without the introduction of any extraneous components. We discuss the processes involved and our progress with perfecting the cameras to make the videos.

**Filament dynamics and sound emission during vortex reconnections in superfluids**
*Davide Proment*

We will present recent numerical investigations of vortex reconnections in superfluids modelled using the Gross-Pitaevskii equation. We will specifically consider the decay of a vortex (Hopf) link into ring(s) and discuss if and how the geometry of the reconnecting filaments is related to the emission of phonons in the system.

**Intermittency of turbulent He-II with superfluid fractions from 0% to 96%**
*Philippe-E. Roche*

Puzzled by few numerical predictions in apparent contradiction, we perform a systematic experimental investigation of intermittency in He-II. The TOUPIE wind-tunnel is used, and the superfluid fraction is varied between 0% (He-I) up to 96% (He-II at 1.28 K). Velocity fluctuations are measured using a micro-machined cantilever anemometer positioned in far wake of the disc. Within accuracy, inertial-range intermittency was found independent of the superfluid fraction.

**Motion of Electron Bubbles along Superfluid Vortices**
*Hayder Salman*

Using a Gross-Pitaevskii model of a superfluid with suitably tuned parameters to provide the correct ratio of the radius of an electron bubble with respect to the healing length in superfluid Helium-4, we model the dynamics of the negative ion moving under the influence of an applied electric field. Full 3D simulations are performed to study the complex spatio-temporal dynamics. Our numerical simulations reveal the dynamical mechanisms that determine the limiting velocity of these ions. For an electron bubble moving along a vortex, we put forward a theory to explain the observed dynamics of the bubble-vortex system.

**Local velocity measurements in superfluid $^4$He**
*Julien Salort*

The use of miniature Pitot tube has been a successful means to perform local velocity measurements in superfluid helium and has allowed to evidence velocity distribution, power spectra, and statistics velocity increments in highly turbulent superfluid flows. However, they they cannot be made smaller than typically one millimetre, and they are only suited to co-flows where the fluctuations are small compared to the mean flow. An alternative approach is based on cantilever anemometer which is now well validated in turbulent co-flows. Recent measurements in co-flows will be shown, as well as encouraging preliminary measurements in counter-flows.

**Heat transport in superfluid helium: some recent results**
*Michele Sciacca*

The conference focuses the attention on the recent results obtained by means of the one-fluid model, which arises in the framework of the Extended Irreversible Thermodynamics. These results regard the following topics: a) transition from the laminar regime to the ballistic regime in thermal heat flow; b) thermal conductivity of superfluid helium through an array of heat-producing cylinders with and without mass flow.

**Andreev reflection from quantum turbulence in $^3$He-B: Advantages and limitations of combined numerical/experimental study**

*Yuri Sergeev*

Based on the recent results of numerical simulation combined with the experimental study of Andreev reflection of thermal quasiparticle excitations from quantum turbulence in 3He-B at ultralow temperatures, this talk will address the following question: Which properties of and processes in the zero-temperature quantum turbulence can (and which cannot) be revealed by the Andreev reflection from the turbulent vortex tangle?

**Recent experiments on quantum turbulence in superfluid $^4$He in Prague**

*Ladislav Skrbek*

TBC

**Convection conundrum in the Sun**

*Katepalli Sreenivasan*

In the outer 30% of Sun's radius, energy is transported primarily by convection. Given the enormous magnitude of length scales involved, one imagines the flow to be turbulent. Historically, the mixing length theory, which assumed the traditional turbulence structure to hold, provided the most basic estimate of the convection velocity. The later simulations using the anelastic spherical harmonic (ASH) code provided more detailed estimates. The two estimates agreed with each other — to the extent that comparisons could, in fact, be made. However, later estimates of these velocities by helioseismology have yielded velocities that are smaller by one to two orders of magnitude. Which estimate, if either, is right? If helioseismology results are indeed correct, what qualitative changes are needed in our understanding of transport mechanisms so that these much smaller velocities can accomplish the prescribed energy transport? This is the convection conundrum in the Sun. Naturally, this problem has attracted considerable attention since the helioseismology results became known, and more work has yielded a greater variety of results. The talk will first describe these various results and make an attempt to resolve the conundrum.

**Numerical simulation of quantum turbulence**

*Makoto Tsubota*

Quantum turbulence (QT) is highly nonlinear and nonequilibrium phenomena. Thus numerical simulation is indispensable for studying QT. In this talk, we discuss two important topics of QT in superfluid helium and atomic Bose-Einstein condensates (BECs). One is the three-dimensional coupled dynamics of two-fluid model in superfluid helium. Superfluid is described by the vortex filament model and normal-fluid obeys the Navier-Stokes equation, and they are coupled through the mutual friction. Superfluid turbulence makes the flow profile of normal fluid significantly, which is compared with the recent visualization experiments in thermal counterflow by the Tallahassee group. The other is the first confirmation of the turbulent cascade flux of BEC in a box potential. The experiments are done by the Cambridge group. Using a spatially-uniform time-dependent force, we inject energy at a large length scale and generate a turbulent cascade in a uniformly-trapped BEC. The adjustable trap depth provides a momentum cutoff, thereby realizing a tuneable dissipation scale. This new tool gives direct access to the particles flux, which is compared with the simulation of the Gross-Pitaevskii model. The author thanks S. Yui, H. Kobayashi, K. Fujimoto, C. Eigen, J. Zhang, R. Lopes, N. Navon, R. Smith, Z. Hadzibabic, for collaboration.

**Sixty years of quantum vortices**

*Joe Vinen*

That topological defects in the form of quantized vortices can exist in a superfluid was first recognized about sixty years ago. Since that time there has been a steady development of our understanding of these mini-tornados and of the important role that they play in behaviour of superfluids, a development to which Carlo Barenghi has himself contributed in important ways. As an introduction to this Workshop an account will be given of some of the highlights in this development, and of some of the challenging questions that remain unanswered, all from a personal perspective.

**Unsteady turbulence cascades and dissipation**

*Christos Vassilicos*

Turbulence energy transfer through length scales is arguably one of the most central and important processes in turbulent flows. Much of turbulence theory and modelling over the past 70 years has been based on the Kolmogorov (1941) stationary/equilibrium cascade which implies a particular well-known scaling of the turbulence dissipation rate. However, accumulating evidence from laboratory experiments and, more recently, numerical simulations is pointing at a very different, non-equilibrium, turbulence dissipation scaling in important extensive regions of various turbulent flows. There are consequences for turbulent shear flows such as self-similar turbulent wakes and jets because their growth rates are closely linked to the centreline turbulence dissipation scaling. These consequences include new turbulent mean flow scalings with streamwise distance. There are also consequences concerning entrainement and the local entrainment velocity of the turbulent/non-turbulent interface which there may not be time to mention. Direct numerical simulations of unsteady periodic turbulence show how non-equilibrium turbulence dissipation scalings are related to unsteady interscale energy transfer processes. Different dissipation scalings result from different types of unsteady interscale energy transfers. Large scale coherent structures seem to be playing an important role in the case where unsteady interscale energy transfers dictate an apparently universal dissipation scaling which has an explicit dependence on inlet conditions.

**Probing the quantum regime of vortex dynamics in superfluid $^4$He**

*Paul Walmsley, Andrei Golov*

We have used injected electrons to investigate the dynamics of quantized vortices at low temperatures. Firstly, we use time of flight spectroscopy to probe reconnections within turbulent vortex tangles. We find that below 0.6 K some charge arrives quickly due self-reconnections producing the emission of small vortex rings. Secondly, we have measured the mobility and limiting velocity of electrons as they travel along rectilinear vortices produced by steady rotation. One potential explanation is based on the creation of vortex solitons. This technique can also be used to probe perturbed vortex arrays (with inertial waves and Kelvin waves) and their subsequent relaxation.

**Superfluidity in Bose-Einstein condensates beyond the standard azimuthal flow**
*Angela White*

Superfluidity in Bose-Einstein condensates is a manifestation of long range correlations. A hallmark of superfluid flow is the existence of quantised vortices with a characteristic $1/r$ azimuthal velocity profile. In finite sized systems other flow patterns arise and we show that introducing short range correlations by introducing a second condensate component leads to surprising dynamics, such as classical solid body rotation of the domain wall in toroidal potentials and oscillation of the direction of superflow in elliptical traps. We show that the competition between long-range and short range correlations are also important out of equilibrium, where they dictate condensate dynamics.

**Nonlinear solutions and turbulent transition in pipe flow**
*Ashley Willis*

Osborne Reynolds demonstrated in 1883 that the transition to turbulence in a pipe depends not just on the flow rate (and physical parameters, establishing the Reynolds number) but also on the amplitude of initial disturbances. Given that transition therefore occurs in the absence of linear instability, theoretical progress did not advance significantly until the discovery of nonlinear solutions in 2003. These solutions take the form of a travelling wavy vortex, and many solutions have been shown to play an important role in transition. In this talk I will briefly describe how travelling wave solutions were discovered, and how we now understand how to find nonlinear solutions much more rapidly.

**Developing a Toolkit for Experimental Studies of Two-Dimensional Quantum Turbulence in Bose-Einstein Condensates**
*Kali Wilson*

Bose-Einstein condensates (BECs), with their superfluid behavior, quantized vortices, and high-level of control over trap geometry and other system parameters provide a compelling environment for studies of quantum fluid dynamics. Recently there has been an influx of theoretical, numerical and experimental progress in understanding the superfluid dynamics associated with two-dimensional quantum turbulence. In this talk I present efforts at the University of Arizona to develop an experimental toolkit that will enable further experimental studies. In particular, I will discuss a range of techniques for generating vortex distributions within a BEC, with varying degrees of control over vortex placement and winding number.

**Freeing a Trapped Superfluid Vortex**
*Rena Zieve*

We measure a superfluid vortex, initially trapped along the length of a thin straight wire. With the cryostat stationary, this vortex is metastable and heating the fluid can lead to depinning. While the temperature profiles that result in depinning are reproducible, the length of vortex that separates from the wire is not. A possible explanation is that counterflow velocity through the helium inlet hole enlarges vortices pinned at the cell wall until loops break free and subsequently interact with the vortex along the wire. I will present data supporting this model. I will also discuss an unusual training effect in which gradual heating increases the stability of the trapped vortex.

# 6 List of Posters

**A thermodynamic approach for the investigation of out of equilibrium systems**
*Vanderlei Bagnato*

**Quantum Ferrofluid Turbulence**
*Thomas Bland*

**BKT & Kibble-Zurek Scaling in Non-Equilibrium Condensates**
*Paolo Comaron*

**Topological complexity of superfluid turbulence**
*Robert Cooper*

**Vinen turbulence via the decay of multicharged vortices in trapped atomic Bose-Einstein condensates**
*André Cidrim*

**Vortex scattering by impurities in a Bose-Einstein condensate**
*Adam Griffin*

**Vortex Dynamics and Dynamical Equilibration Across a Quenched Phase Transition in a Trapped Quantum Gas**
*Nick Proukakis*

**Vortex reconnection in a nonlocal model of superfluid helium**
*Jason Reneuve*

**Diffusion of Quantum Vortices**
*Em Rickinson*

**Analysis of a superfluid vortex reconnection in the Gross-Pitaevskii model**
*Alberto Villois*

# 7 List of Participants with Accommodation

## 7.1 Holiday Inn Express

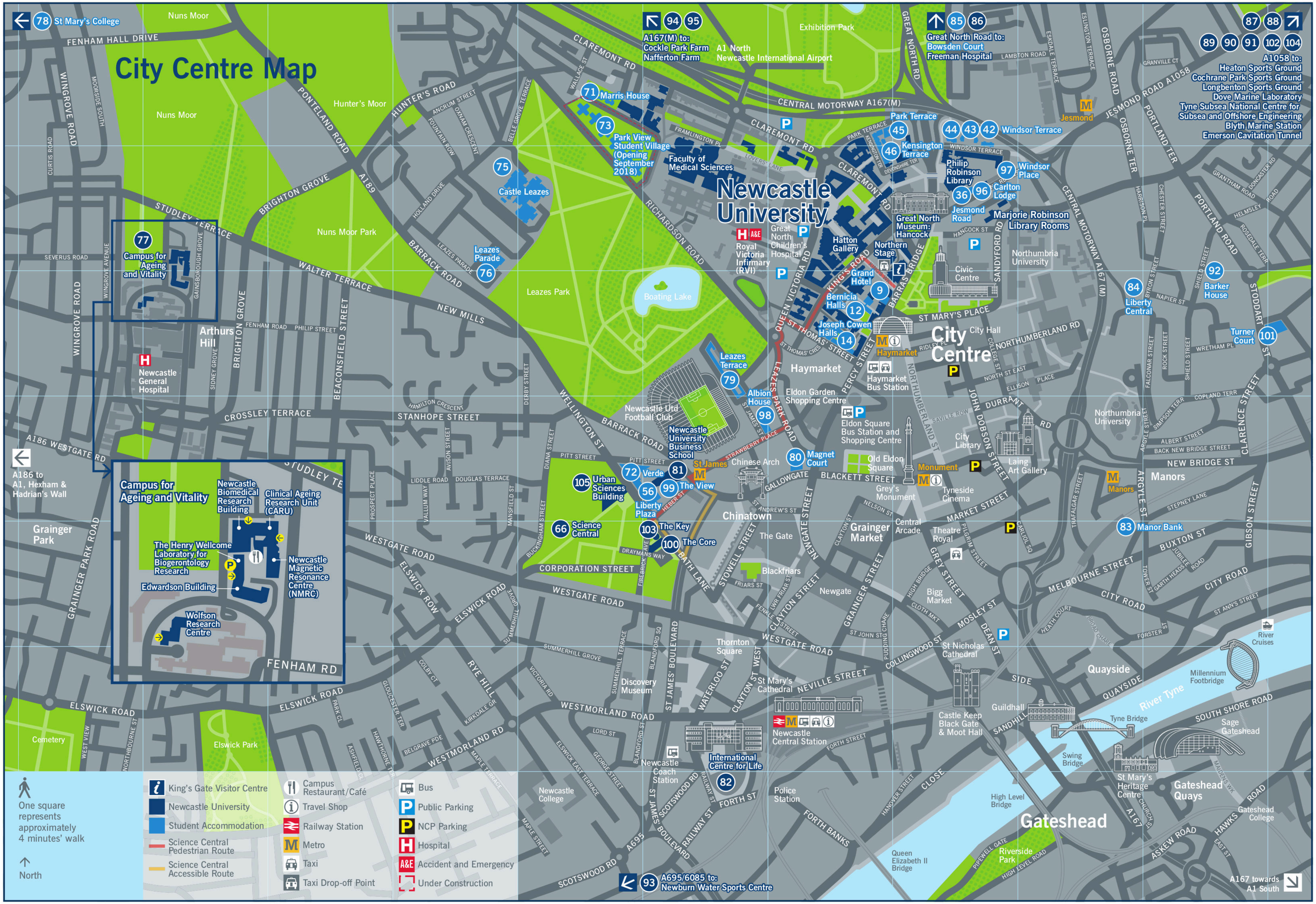
Amandine Aftalion
Vanderlei Bagnato
Marc Brachet
Gabriele Ferrari
Vladimi Eltsov
Wei Guo
Victor L'vov
Caroline Nore
Phillipe Roche
Michele Sciacca
Ladislav Skrbek
Katepalli Sreenivasan
Makoto Tsubota
Rena Zieve
Nils Anderson
Chris Jones
Keith Moffatt
George Pickett
Joe Vinen
Christos Vassilicos

## 7.2 Osborne Hotel

Mathieu Gibert
Rich Haley
David Proment
Hayder Salman
Paul Walmsley
Ashley Willis
Viktor Tsepelin
Andrei Golov

## 7.3 Dene Hotel

Ivan Skachko
Jason Reneuve
Theo Noble
Tom Wilcox
Adam Griffin
Andre Cidrim
Alberto Villois
Jonathan Skipp
Holly Middleton-Spencer
Kashmir Sami
Angela White
Cecilia Rorai
Giorgio Krstulovic
Julien Salort



City Centre Map
78 St Mary's College
94 95 A167(M) to: Cockle Park Farm Nafferton Farm
A1 North Newcastle International Airport
85 86 Great North Road to: Bowsden Court Freeman Hospital
87 88 89 90 91 102 104 A1058 to: Heaton Sports Ground Cochrane Park Sports Ground Longbenton Sports Ground Dove Marine Laboratory Tyne Subsea National Centre for Subsea and Offshore Engineering Blyth Marine Station Emerson Cavitation Tunnel
A186 to A1, Hexham & Hadrian's Wall
93 A695/6085 to: Newburn Water Sports Centre
A167 towards A1 South
Nuns Moor
Hunter's Moor
Exhibition Park
Nuns Moor Park
Leazes Park
Boating Lake
Grainger Park
Cemetery
Elswick Park
77 Campus for Ageing and Vitality
Arthurs Hill
Newcastle General Hospital
71 Marris House
73 Park View Student Village (Opening September 2018)
75 Castle Leazes
76 Leazes Parade
Faculty of Medical Sciences
Newcastle University
Royal Victoria Infirmary (RVI)
Great North Children's Hospital
45 Park Terrace
46 Kensington Terrace
44 43 42 Windsor Terrace
Philip Robinson Library
97 Windsor Place
36 96 Carlton Lodge
Jesmond Road
Marjorie Robinson Library Rooms
Great North Museum: Hancock
Hatton Gallery
Northern Stage
Grand Hotel
9
Bernicia Halls
12
Joseph Cowen Halls
14
Civic Centre
City Hall
City Centre
Northumbria University
84 Liberty Central
92 Barker House
Turner Court 101
Jesmond
Leazes Terrace 79
Albion House 98
Newcastle Utd Football Club
Newcastle University Business School
Haymarket
Haymarket Bus Station
Eldon Garden Shopping Centre
Eldon Square Bus Station and Shopping Centre
80 Magnet Court
St James
Chinese Arch
81
72 Verde
105 Urban Sciences Building
56
99 The View
Liberty Plaza
66 Science Central
103 The Key
100 The Core
Chinatown
The Gate
Old Eldon Square
Grey's Monument
Monument
City Library
Laing Art Gallery
Tyneside Cinema
Grainger Market
Central Arcade
Theatre Royal
Manors
83 Manor Bank
Blackfriars
Newgate
Bigg Market
St Nicholas Cathedral
Thornton Square
Discovery Museum
St Mary's Cathedral
Newcastle Central Station
International Centre for Life
82
Newcastle Coach Station
Police Station
Castle Keep Black Gate & Moot Hall
Guildhall
Quayside
River Tyne
Tyne Bridge
Swing Bridge
High Level Bridge
Queen Elizabeth II Bridge
Millennium Footbridge
River Cruises
Sage Gateshead
St Mary's Heritage Centre
Gateshead Quays
Gateshead
Gateshead College
Riverside Park
Newcastle College
Campus for Ageing and Vitality
Newcastle Biomedical Research Building
Clinical Ageing Research Unit (CARU)
The Henry Wellcome Laboratory for Biogerontology Research
Newcastle Magnetic Resonance Centre (NMRC)
Edwardson Building
Wolfson Research Centre
FENHAM RD
STUDLEY TE
One square represents approximately 4 minutes' walk
North
King's Gate Visitor Centre
Newcastle University
Student Accommodation
Science Central Pedestrian Route
Science Central Accessible Route
Campus Restaurant/Café
Travel Shop
Railway Station
Metro
Taxi
Taxi Drop-off Point
Bus
Public Parking
NCP Parking
Hospital
Accident and Emergency
Under Construction


University Campus Map
Newcastle University is a no-smoking campus
71 Marris House
70 Sports Centre
68
69
67
73 Park View Student Village (Opening September 2018)
63
60
62
61
64 Faculty of Medical Sciences
59
58
55 RVI: Leazes Wing
57
52
51
75 Castle Leazes
76 Leazes Parade
77 78 Barrack Road to: Campus for Ageing and Vitality, St Mary's College
Leazes Park
Boating Lake
Royal Victoria Infirmary (RVI)
Main Entrance
53 Great North Children's Hospital
74
54 RVI: Victoria Wing
79 Leazes Terrace
Newcastle United Football Club
98 Albion House
94 95 A167(M) to: Cockle Park Farm, Nafferton Farm
Exhibition Park
85 86 Great North Road to: Bowsden Court, Freeman Hospital
87 88 89 90 91 102 104 A1058 to: Heaton Sports Ground, Cochrane Park Sports Ground, Longbenton Sports Ground, Dove Marine Laboratory, Tyne Subsea National Centre for Subsea and Offshore Engineering, Blyth Marine Station, Emerson Cavitation Tunnel
84 92 101 Sandyford Road to: Barker House, Turner Court, Liberty Central
45 Park Terrace
46 Kensington Terrace
47
50
49
48
44
43
42 Windsor Terrace
37
38
40
41
97 Windsor Place
Robinson Place
35 Philip Robinson Library
96 Carlton Lodge
36 Jesmond Road
Marjorie Robinson Library Rooms
65
34 Great North Museum: Hancock
33
32
31
30
28
27
29 Hatton Gallery
26
25 Old Library Building
24
23
22 Armstrong Building
21 Bedson Building
20
19
18 Herschel Annex
17 Herschel Building
16
39
15 Joseph Cowen Halls
14
13 INTO Centre
12
11 Bernicia Halls
10
4 Hadrian Building (formerly King's Road Centre)
5 Students' Union
6
7
8
9 Grand Hotel
3 Northern Stage
2
1 King's Gate
Main pedestrian access to campus
Church of St Thomas the Martyr
Civic Centre
Northumbria University
City Centre
City Hall
Haymarket
Haymarket Bus Station
Eldon Garden Shopping Centre
Eldon Square Bus Station and Shopping Centre
80 Magnet Court
Old Eldon Square
Grey's Monument
Monument
City Library
Laing Art Gallery
Tyneside Cinema
Central Arcade
Grainger Market
Theatre Royal
The Gate
Chinatown
Chinese Arch
St James
72 Verde
81 Newcastle University Business School
105 Urban Sciences Building
56 Liberty Plaza
99 The View
66 Science Central
103 The Key
100 The Core
82 93 St James' Boulevard to: International Centre for Life, Newburn Water Sports Centre
83 A186 to: Manor Bank
CLAREMONT ROAD
FRAMLINGTON PLACE
RICHARDSON ROAD
QUEEN VICTORIA ROAD
KING'S ROAD
ST THOMAS' STREET
PERCY STREET
BARRAS BRIDGE
JESMOND ROAD WEST
SANDYFORD ROAD
CENTRAL MOTORWAY A167(M)
ST MARY'S PLACE
NORTHUMBERLAND ROAD
NORTHUMBERLAND STREET
JOHN DOBSON STREET
BLACKETT STREET
NEWGATE STREET
GALLOWGATE
STRAWBERRY PLACE
LEAZES PARK ROAD
BARRACK ROAD
WELLINGTON STREET
PITT STREET
STANHOPE STREET
HAMILTON CRESCENT
DERBY STREET
DIANA STREET
AVISON STREET
NEW MILLS
LEAZES PARADE
HOLLAND DRIVE
FOUNTAIN ROW
OXNAM CRESCENT
ANGRUM STREET
BELLE GROVE TERRACE
WALLACE ST
ST JAMES' BOULEVARD
ST ANDREW'S ST
STOWELL STREET
CLAYTON STREET
NELSON ST
MARKET STREET
PILGRIM STREET
CARLIOL SQ
DURRANT ROAD
FIREBRICK AVE
DRAYMANS WAY
HEBER ST
One square represents approximately 2 minutes' walk
North
Main pedestrian access to campus
Main pedestrian routes through campus
Newcastle University's campus is accessible except where marked
King's Gate Visitor Centre
University Information
Travel Shop
Hospital
Accident and Emergency
Public Toilets
Public Accessible Toilets
Changing Places Fully Accessible Toilets
Accessible Parking
Building Entrance (steps)
Accessible Entrance
Accessible Lift
Science Central Pedestrian Route
Science Central Accessible Route
Newcastle University
Student Accommodation
Campus Restaurant/Café
Under Construction
Green Flag Award
Metro
Bus
Taxi
Taxi Drop-off Point
Public Parking
NCP Parking
Smoking Shelter
Please note, Newcastle University is a no-smoking campus but designated smoking shelters are available

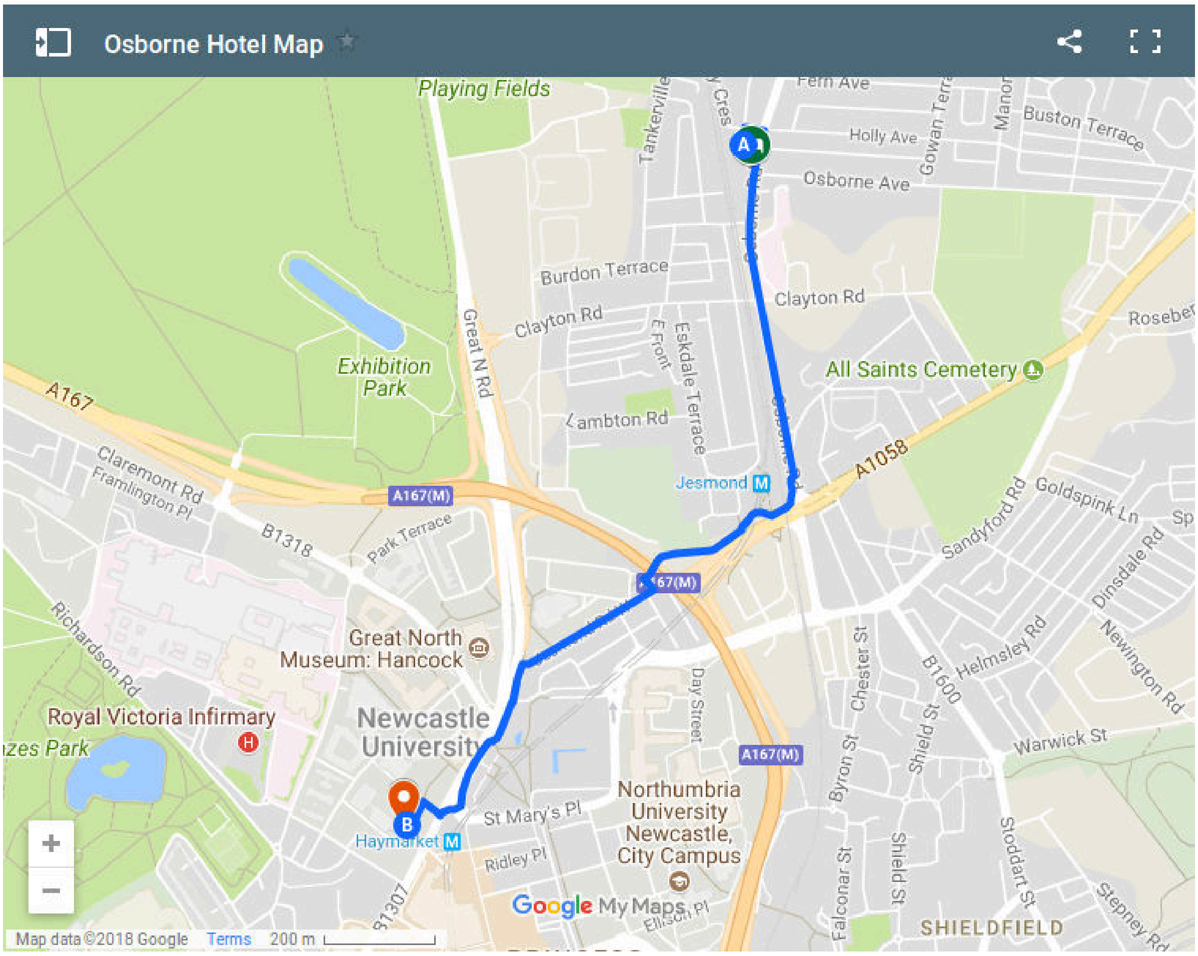
Newcastle University

## Numerical Key of Buildings/Services

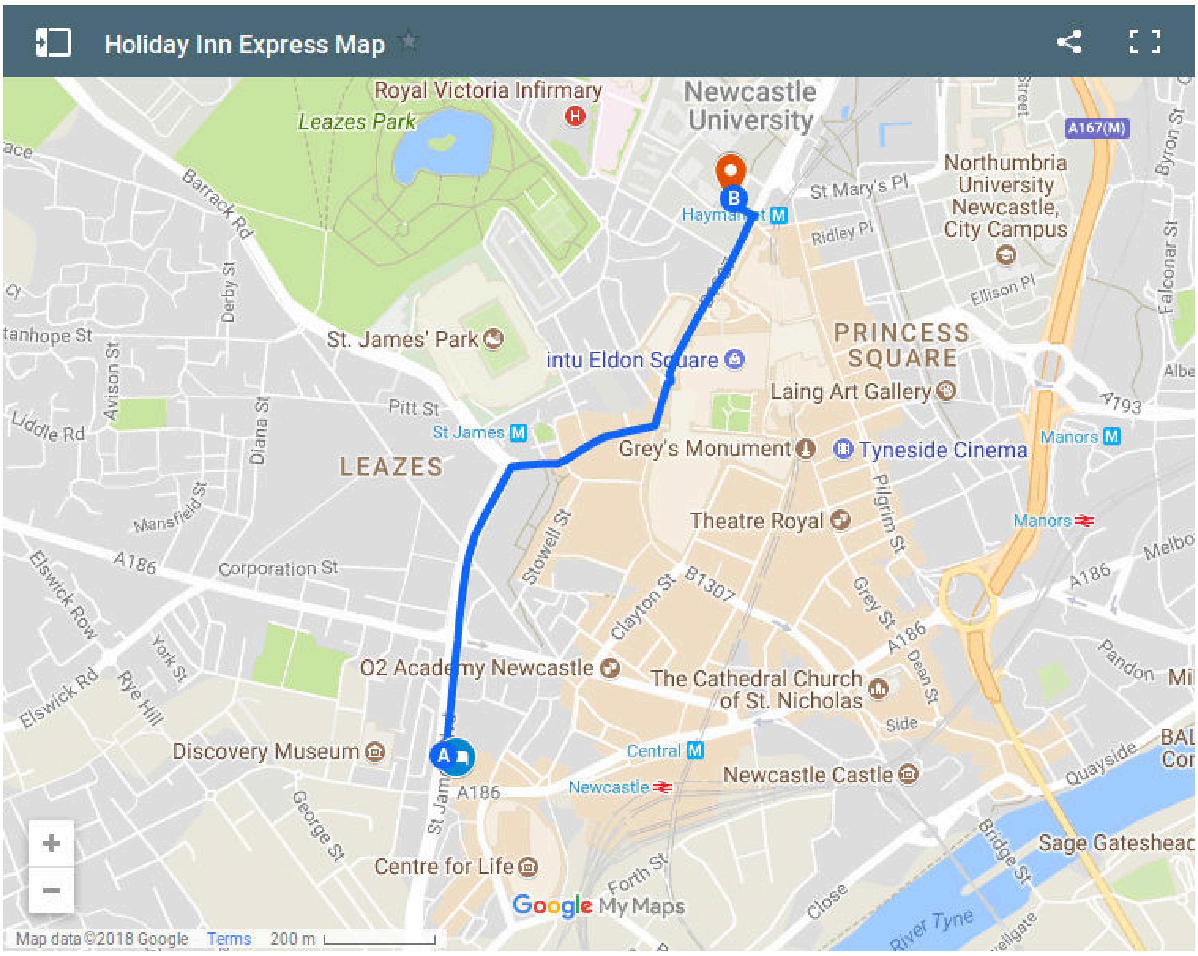
| | |
|---|---|
| King's Gate | 1 |
| Student Services: Accommodation Service; Careers Service; NU Advancement; Finance Office; Student Wellbeing; International Office | 1 |
| Barras/Claremont/Eldon Buildings | 2 |
| Security Control Centre | 2 |
| Northern Stage | 3 |
| Hadrian Building (formerly King's Road Centre) | 4 |
| Students' Union | 5 |
| Music Studios | 6 |
| Culture Lab | 7 |
| Campus Coffee | 8 |
| Grand Hotel | 9 |
| Boiler House | 10 |
| Bernicia Halls | 11, 12 |
| INTO Centre | 13 |
| Joseph Cowen Halls | 14, 15 |
| Agriculture Building | 16 |
| Estate Support Service | 16 |
| Curtis Auditorium | 17 |
| Herschel Building | 17 |
| Herschel Annex | 18 |
| King George VI Building | 19 |
| Bedson Building | 20, 21 |
| Barbara Strang Teaching Centre | 21 |
| Side Cluster | 21 |
| Armstrong Building | 22 |
| King's Hall | 22 |
| Robert Boyle Lecture Theatre | 22 |
| Percy Building | 23 |
| Merz Court | 24 |
| Beehive, Research | 25 |
| Courtyard Restaurant | 25 |
| Old Library Building | 25, 26 |
| IT Service Desk | 25, 26 |
| Language Resource Centre | 26 |
| Architecture Building | 27 |
| Building Science | 28 |
| Hatton Gallery | 29 |
| King Edward VII Building | 29, 30 |
| Daysh Building | 31 |
| Claremont Tower | 32 |
| Claremont Bridge | 33 |
| Great North Museum: Hancock | 34 |
| Philip Robinson Library | 35 |
| IT Service Desk | 35 |
| Jesmond Road | 36 |
| Politics Building | 37 |
| Newcastle Law School | 38 |
| Chaplain's Office | 39 |
| Windsor Terrace | 40, 41 |
| Windsor Terrace Accommodation | 42–44 |
| Park Terrace | 45 |
| Kensington Terrace | 46 |
| Drummond Building | 47 |
| Devonshire Building | 48 |
| Cassie Building | 49 |
| Stephenson Building | 50 |
| Ridley Building 1 | 51 |
| Ridley Building 2 | 52 |
| Royal Victoria Infirmary (RVI) | 53–55 |
| Liberty Plaza | 56 |
| Wolfson Building | 57 |
| William Leech Building | 58 |
| Catherine Cookson Building | 59 |
| Medical School | 60 |
| Walton Library | 60 |
| Henry Wellcome Building | 61 |
| David Shaw Lecture Theatre | 62 |
| School of Dental Sciences | 63 |
| Dental Hospital | 64 |
| Marjorie Robinson Library Rooms | 65 |
| IT Service Desk | 65 |
| Science Central | 66 |
| Claremont Terrace (1–4) | 67 |
| Paul O'Gorman Building | 68 |
| Baddiley-Clark Building | 69 |
| Sports Centre | 70 |
| Marris House | 71 |
| Verde | 72 |
| Park View Student Village | 73 |
| Sir James Spence Institute | 74 |
| Castle Leazes | 75 |
| Leazes Parade | 76 |
| Campus for Ageing and Vitality | 77 |
| St Mary's College | 78 |
| Leazes Terrace | 79 |
| Magnet Court | 80 |
| Newcastle University Business School | 81 |
| International Centre for Life | 82 |
| Manor Bank | 83 |
| Liberty Central | 84 |
| Bowsden Court | 85 |
| Freeman Hospital | 86 |
| Heaton Sports Ground | 87 |
| Cochrane Park Sports Ground | 88 |
| Emerson Cavitation Tunnel | 89 |
| Longbenton Sports Ground | 90 |
| Dove Marine Laboratory | 91 |
| Barker House | 92 |
| Newburn Water Sports Centre | 93 |
| Cockle Park Farm | 94 |
| Nafferton Farm | 95 |
| Carlton Lodge | 96 |
| Windsor Place Accommodation | 97 |
| Albion House | 98 |
| The View | 99 |
| The Core (Newcastle University Centre for Professional and Executive Development) | 100 |
| Organisational Development | 100 |
| Turner Court | 101 |
| Tyne Subsea National Centre for Subsea and Offshore Engineering | 102 |
| The Key | 103 |
| Blyth Marine Station | 104 |
| Urban Sciences Building | 105 |

## 8.2 Hotels

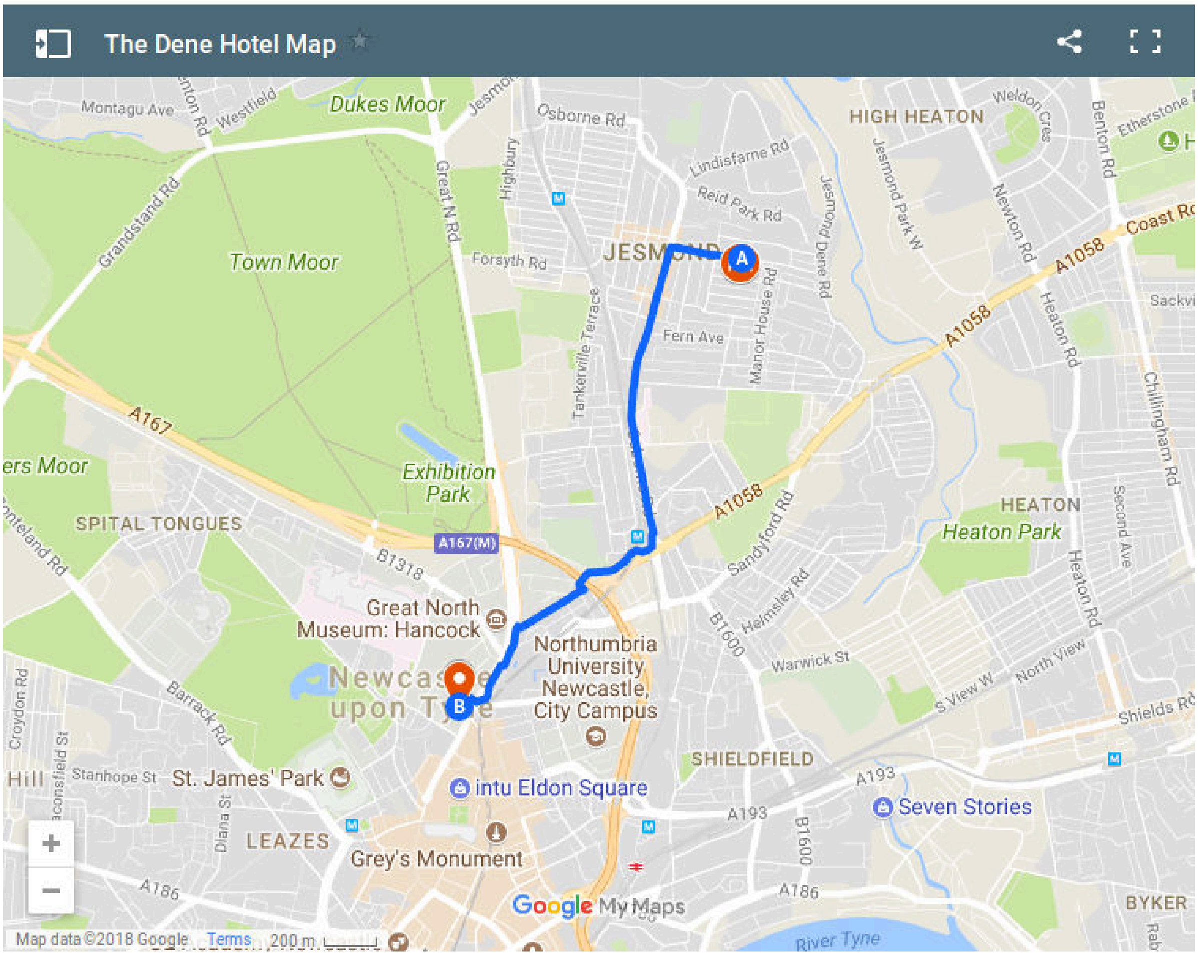
### Osborne Hotel



## Holiday Inn Express



### The Dene Hotel



## 8.3 As You Like It