Durham Symposium

Stochastic Dynamics, Nonlinear Probability, and Ergodicity

22-26 August 2022

Department of Mathematical Sciences

Organisers: *David Elworthy (Warwick), Chunrong Feng (Durham), Huaizhong Zhao (Durham)*

Scientific Advisory Board: *Martin Hairer (Imperial College), Kening Lu (Brigham Young), Terry Lyons (Oxford), Shige Peng (Shandong), Michael Scheutzow (TU Berlin)*

Durham Symposium

Stochastic Dynamics, Nonlinear Probability, and Ergodicity

22-26 August 2022

Department of Mathematical Sciences

Schedule

The Scott Logic Lecture Theatre, MCS 0001, Durham University

Zoom ID: 9293477645

Monday 22nd August

10:00-10:10 John Parker HoD welcome

10:10-11:00 Giuseppe Da Prato

11:00-11:30 Tea/Coffee

11:30-12:20 Xue-Mei Li

Collingwood College lunch

14:00-14:50 Christian Kuehn *

14:50-15:40 Nicolai Krylov *

15:40-16:00 Tea/Coffee

16:00-17:00 Martin Hairer (joint with Durham Pascal Lecture)

Drinks reception

18:30 Collingwood College dinner

Tuesday 23rd August

09:20-10:10 Zdzisław Brzeźniak

10:10-11:00 Michela Ottobre

11:00-11:30 Tea/Coffee

11:30-12:20 Mickaël Chekroun *

Collingwood College lunch

14:00-14:50 Kening Lu *

14:50-15:40 Zeng Lian *

15:40-16:10 Tea/Coffee

16:10-17:00 Tusheng Zhang *

17:00-17:30 Yu Liu

17:30-18:00 Baoyou Qu

18:30 Collingwood College dinner

Wednesday 24th August

09:20-10:10 Shige Peng *

10:10-11:00 Yongsheng Song *

11:00-11:30 Tea/Coffee

11:30-12:20 Matthias Troffaes

12:20-12:50 Hugo Chu

Collingwood College lunch

Poster session

18:30 Collingwood College dinner

Thursday 25th August

09:20-10:10 István Gyöngy

10:10-11:00 Michael Tretyakov

11:00-11:30 Tea/Coffee

11:30-12:20 Chenggui Yuan

Collingwood College lunch

14:00-14:50 Fengyu Wang *

14:50-15:40 Zhao Dong *

15:40-16:10 Tea/Coffee

16:10-17:00 Thomas Cass

17:00-17:50 Horatio Boedihardjo

19:00 Conference Dinner (Castle)

Friday 26th August

09:20-10:10 Weinan E *

10:10-11:00 Tadahisa Funaki *

11:00-11:30 Tea/Coffee

11:30-12:20 Alexander Veretennikov

12:20-12:50 Oana Lang

Collingwood College lunch

14:20-15:10 Szymon Peszat

15:10-16:00 Zhongmin Qian

(online talks *)

Durham Symposium
Stochastic Dynamics, Nonlinear Probability, and Ergodicity
22-26 August 2022
Department of Mathematical Sciences
Titles and abstracts of talks

Horatio BOEDIHARDJO
University of Warwick, E-mail: horatio.boedihardjo@warwick.ac.uk

Almost matching bounds for tail probabilities for integrals along fractional Brownian motion

Abstract: Consider a differential equation driven by fractional Brownian motion with smooth bounded vector fields. Cass-Hairer-Litterer-Tindel contained implicitly an upper bound for tail probability (made explicit by Baudoin-Nualart-Ouyang-Tindel). We are interested in the sharpness of this upper bound. In particular, we studied an equation where the solution can be explicitly expressed as an integral and showed that the tail probability matches with the known upper bound up to an arbitrarily small power in the exponential. Joint work with Xi Geng.

Zdzisław BRZEŹNIAK
TBA

Thomas CASS
Imperial College London, E-mail: thomas.cass@imperial.ac.uk

(Expected) signatures, weighted signature kernels and functions on unparameterised paths

Abstract: The signature is a non-commutative exponential that appeared in the foundational work of K-T Chen in the 1950s. It is also a fundamental object in the theory of rough paths (Lyons, 1998). More recently, it has been proposed and used as part of a practical methodology to give a way of summarising multimodal, possibly irregularly-sampled, time-ordered data in a way that is insensitive to its parameterisation. A key property underpinning this approach is the ability of linear functionals of the signature to approximate arbitrarily any compactly supported and continuous function on (unparameterised) path space. We present some new results on the properties of a selection of topologies on the space of unparameterised paths. Relatedly, we review some recent innovations in the theory of the signature kernel by introducing and analysing the properties of a family of so-called weighted signature kernels

The talk will draw on material from two recent papers; one is joint work with William F. Turner, the other is a joint work with Terry Lyons and Xingcheng Xu.

Mickaël CHEKROUN
TBA

Hugo CHU
Imperial College London, E-mail: hugo.chu17@imperial.ac.uk

The conditioned Lyapunov spectrum for random dynamical systems

Abstract: We establish the existence of a full spectrum of Lyapunov exponents for memoryless random dynamical systems with absorption. To this end, we crucially embed the process conditioned to never being absorbed, the Q-process, into the framework of random dynamical systems, allowing us to study multiplicative ergodic properties. We show that the finite-time Lyapunov exponents converge in conditional probability and apply our results to iterated function systems and stochastic differential equations.

This is joint work with Matheus De Castro, Jeroen Lamb, Martin Rasmussen (Imperial College London), Dennis Chemnitz and Maximilian Engel (Freie Universität Berlin).

Giuseppe DA PRATO
Scuola Normale Superiore, giuseppe.daprato@sns.it

An application of macroscopic fluctuation theory to reaction-diffusion equations

Abstract: We consider the Gibbs measure μ_ϵ in the Hilbert space $H = L^2(0,1)$ associated with a reaction–diffusion equation $dX = (\Delta X + p(X))dt + \sqrt{\epsilon}\, dW(t)$, Δ being the Laplace operator on $[0,1]$ equipped with Dirichlet boundary conditions, p a polynomial of odd degree having negative leading coefficient and W an H–valued cylindrical process. As well known, this Gibbs measure describes a reversible system. We perturb this system by a term $b(X)dt$ that is not of a potential form obtaining a system which is no more reversible and which possesses an invariant measure ν_ϵ. We give a characterisation of the generator of the adjoint transition semigroup and we show that in general it is not associated with a stochastic PDE (the adjoint dynamics). We denote by $\overline{X_\epsilon}$, a stationary process and by $\overline{X_\epsilon^*}$ its reversed process. Inspired by the recent paper *Macroscopic Fluctuation Theory* from L. Bertini, A. De Sole, D. Gabrielli, G. Jona Lasinio and C. Landim, we describe both the relaxation of a macroscopic fluctuation to equilibrium and the spontaneous emergence from the equilibrium. These results are achieved using large deviations, for the process $\overline{X_\epsilon}$ in the first case and for $\overline{X_\epsilon^*}$ in the second.

Work in progress with Stefano Bonaccorsi, Sandra Cerrai and Luciano Tubaro.

Zhao DONG
Academy of Mathematics and Systems Science, Chinese Academy of Sciences, E-mail:dzhao@amt.ac.cn

Large time behavior of solution for stochastic Burgers equation

Abstract: We consider the large time behavior of strong solutions to a kind of stochastic Burgers equationt, that is, the rarefaction wave is still stable under white noise perturbation and the viscous shock is not stable yet. Moreover, a time-convergence rate toward the rarefaction wave is obtained.

Weinan E
Peking University, E-mail: weinan@math.pku.edu.cn

The stochastic gradient descent algorithm for machine learning

Abstract: The stochastic gradient descent algorithm (SGD) is the most popular training algorithm in machine learning. In this lecture, we discuss some basic theoretical issues of this algorithm, including

- the convergence behavior
- the optimal learning rate and batch size
- in the over-parametrized regime, the selection of the particular global minimum that SGD converges to

Tadahisa FUNAKI
The University of Tokyo, E-mail: funaki@ms.u-tokyo.ac.jp

Convergence to stationary solutions in singular quasilinear stochastic PDEs

Abstract: A certain quasilinear PDE is derived from zero-range process (interacting random walks) in a regularized Sinai-type random environment via hydrodynamic limit; see Landim, Pacheco, Sethuraman and Xue (AAP, to appear). Then, in a general setting including this PDE, F, Hoshino, Sethuraman and Xie (AIHP, 2021) show that the PDE leads to a singular quasilinear stochastic PDE defined in a paracontrolled sense by removing the regularization.

For the singular quasilinear stochastic PDE obtained in this way, we discuss the global-in-time solvability and the convergence as time tends to infinity to stationary solutions, which are different for each conserved quantity. The equation has a striking character, the initial layer property of improving regularity, under a certain nonlinear transform. This is joint work with Bin Xie and appeared in Stoch. PDE: Anal. Comp., online, 2022.

István GYÖNGY
School of Mathematics, University of Edinburgh, E-mail: I.Gyongy@ed.ac.uk

Filtering of partially observed jump diffusions

Abstract: Partially observed jump diffusions, described by stochastic differential equations driven by Wiener processes and Poisson random measures are considered. In the first part of the talk the filtering equations, i.e., the equations for the conditional distribution $P_t(dx)$ and for the unnormalised conditional distribution of the unobserved component at time t, given the observations until t, are presented. These are (possibly) degenerate stochastic integro-differential equations. By the help of these equations new results on the existence and on the regularity properties of the conditional density $\pi_t = P_t(dx)/dx$ are established in the second part of the talk. The talk is based on a joint work with Fabian Germ and Alexander Davie in Edinburgh University.

Martin HAIRER
Imperial College London, E-mail: m.hairer@imperial.ac.uk

A mathematical journey through scales

Abstract: The tiny world of particles and atoms and the gigantic world of the entire universe are separated by about forty orders of magnitude. As we move from one to the other, the laws of nature can behave in drastically different ways, sometimes obeying quantum physics, general relativity, or Newton's classical mechanics, not to mention other intermediate theories. Understanding the transformations that take place from one scale to another is one of the great classical questions in mathematics and theoretical physics, one that still hasn't been fully resolved. In this lecture, we will explore how these questions still inform and motivate interesting problems in probability theory and why so-called toy models, despite their superficially playful character, can sometimes lead to certain quantitative predictions.

N.V. KRYLOV
University of Minnesota, USA, E-mail: nkrylov@umn.edu

On strong solutions of time inhomogeneous Itô's equations with Morrey diffusion and drift. A supercritical case

Abstract: We prove strong existence and uniqueness of solutions of Itô's stochastic time dependent equations with irregular diffusion and drift terms of Morrey class type.

Chris KUEHN
TBA

Oana LANG
Imperial College London, E-mail: o.lang15@ic.ac.uk

Analytical and numerical properties for a stochastic transport 2D Euler equation

Abstract: In this talk I will present a methodology for proving existence of a unique global strong solution for a stochastic two-dimensional Euler vorticity equation driven by noise of transport type. In particular, I will show that the initial smoothness of the solution is preserved, using an approach based on a liniarised approximating sequence. In the second part of the talk I will introduce a probabilistic pathwise approach to effectively calibrate the stochastic vorticity equation mentioned above. I will show that the driving stochastic transport parameters can be calibrated in an optimal way to match a set of given data, and the model is robust with respect to these parameters.

This work is based on:

[1] *Well-posedness for a stochastic 2D Euler equation with transport noise*, Stochastics and Partial Differential Equations: Analysis and Computations, 1-48 (2022), joint with Dan Crisan.

[2] *A pathwise parameterisation for stochastic transport*, to appear in the STUOD Springer Proceedings, joint with Wei Pan.

Xue-Mei LI
TBA

Zeng LIAN
Sichuan University, E-mail: lianzeng@scu.edu.cn

Random Horseshoe of Anosov systems driven by a quasi-periodic forcing

Abstract: Consider C^2 Anosov systems on a compact manifold driven by a quasi-periodic forcing. We study their dynamical complexity on various levels from both perspectives of path-wise dynamics and stochastic processes. In this talk, I will report the results on the existence of random horseshoe from two different viewpoints: topology and probability. This is joint with Wen Huang and Kening Lu.

Yu LIU
Durham University, E-mail: yu.liu3@durham.ac.uk

Numerical approximation to random periodicity of stochastic differential equations

Abstract: In this talk, I will introduce numerical approximation to periodic measure of a time periodic stochastic differential equations under weakly dissipative condition. For this we first study the existence of periodic measure ρ_t and the large time behaviour of $\mathcal{U}(t,s,x) := \mathbb{E}\phi(X_t^{s,x}) - \int \phi d\rho_t$, where $X_t^{s,x}$ is the solution of the SDEs and ϕ is a test function being smooth and of polynomial growth at infinity. With the existence and geometric ergodicity of the periodic measure of the discretized semi-flow from numerical approximation, we obtain weak convergence of order one for Euler-Marumaya scheme. Some numerical experiments will be presented to illustrate our theoretical results. This talk is based on a joint work with Chunrong Feng and Huaizhong Zhao.

Kening LU
TBA

Michela OTTOBRE
Heriot-Watt University, E-mail: M.Ottobre@hw.ac.uk

Non-mean-field interacting particle systems and uniform in time averaging

Abstract: We start by presenting results on Poisson equations on non-compact state spaces, with coefficients that can grow super-linearly; we then use such results to obtain a uniform in time averaging theorem for Stochastic Differential Equations (SDEs) with non-Lipschitz coefficients. Key to obtaining both our UiT averaging result and to enable dealing with the super-linear growth of the coefficients (both of the slow-fast system and of the associated Poisson equation) is conquering exponential decay in time of the space-derivatives of appropriate Markov semigroups. We refer to semigroups which enjoy this property as being Strongly Exponentially Stable. As an application we consider a population of N particles interacting with each other through a dynamical network. In turn, the evolution of the network is coupled to the particles' positions. In contrast with the mean-field regime, in which each particle interacts with every other particle, i.e. with $\mathcal{O}(N)$ particles, we consider the a priori more involved case of a sparse network; that is, each particle interacts, on average, with $\mathcal{O}(1)$ particles. We also assume that the network's dynamics is much faster than the particles' dynamics, with the time-scale of the network described by a parameter $\varepsilon > 0$. We combine the averaging ($\varepsilon \to 0$) and the many particles ($N \to \infty$) limits and show that the evolution of the particles' empirical density is described (after taking both limits) by a non-linear Fokker-Planck equation; we moreover give conditions under which such limits can be taken uniformly in time, hence providing a criterion under which the limiting non-linear Fokker-Planck equation is a good approximation of the original system uniformly in time. This is based on joint works with D. Crisan and Ewelina Zatorska (Imperial College), Paul Dobson, Ben Goddard and Iain Souttar (Maxwell Institute), Julien Barre (Orleans).

Shige PENG
TBA

Szymon PESZAT
Institute of Mathematics, Jagiellonian University, Kraków, Poland, E-mail: napeszat@cyf-kr.edu.pl

On Linear Stochastic Flows

Abstract: The talk is based on a joint work with Ben Goldys, University of Sydney. We study the existence of the stochastic flow associated to a linear stochastic evolution equation

$$dX = AXdt + \sum_k B_k X dW_k,$$

on a Hilbert space. Our first result covers the case where A is the generator of a C_0-semigroup, and (B_k) is a sequence of bounded linear operators such that $\sum_k \|B_k\| < +\infty$. We also provide sufficient conditions for the existence of stochastic flows in the Schatten classes beyond the space of Hilbert-Schmidt operators. Some new results and examples concerning the so-called commutative case are presented as well.

Zhongmin QIAN
University of Oxford, England, E-mail: qianz@maths.ox.ac.uk

Parabolic transport type equations arising from turbulence

Abstract: The main problem in the statistical theory of turbulence is to find a good description of distributions of turbulence dynamical variables, such as velocity, vorticity, pressure and so on. These fluid dynamics variables, according to Kolmogorov are random fields, with distributions unlikely being Gaussian. It is therefore a rather challenging scientific program to develop a theory of random fields arising from turbulence. In this talk I report some results about the singletime single-point probability density function (PDF) of the velocity and vorticity fields of a turbulent flow. The PDF PDE is a highly non-linear parabolic-transport equation, which depends on two conditional statistical numerics of important physical significance. The PDF PDE is a general form of the classical Reynolds mean flow equation, and is a precise formulation of the PDF transport equation. The PDF PDE provides us with a new method for modelling turbulence.

Baoyou QU
Durham University, E-mail: baoyou.qu@durham.ac.uk

Entrance measures of SDEs and the ergodicity through lifting

Abstract: We study the long time behaviour of the transition probabilities of time-inhomogeneous Markov processes. We extend Harris's "small set" method to the time-inhomogeneous situation with the help of Hairer-Mattingly's refinement of Harris's recurrence to a one-step contraction. For stochastic differential equations (SDEs for short) with locally Lipschitz, polynomial growth and one-sided linear growth coefficients, in order to establish the local Doeblin condition, we obtain a nontrivial lower bound estimates for the fundamental solution of the corresponding Fokker-Planck equation. The drift term is allowed to be possibly non-weakly-dissipative, but appear to be weakly dissipative over a large time average. As an application we obtain the existence and uniqueness of quasi-periodic measure. We then lift the Markovian semigroup to a cylinder on a torus and obtain unique invariant measure and its ergodicity. This talk is based on a joint work with Chunrong Feng and Huaizhong Zhao.

Yongsheng SONG
Academy of Mathematics and Systems Science, CAS, E-mail: yssong@amss.ac.cn

The Law of Large Numbers under Sublinear Expectations

Abstract: We first introduce Stein's method under sublinear expectations, by which we give the convergence rate for the (weak) law of large numbers under sublinear expectations ($\mathbf{LLN}^*$). Then we give a version of strong $\mathbf{LLN}^*$ for a sequence of i.i.d random variables under a sublinear expectation $\mathbf{E} = \sup_{P\in\Theta} E_P$ defined on a Polish space Ω with Θ being weakly compact.

M.V. TRETYAKOV
School of Mathematical Sciences, University of Nottingham, Nottingham, UK
E-mail: *Michael.Tretyakov@nottingham.ac.uk*

Computing ergodic limits of reflected diffusions

Abstract: A simple-to-implement weak-sense numerical method to approximate reflected stochastic differential equations (RSDEs) is proposed and analysed. Together with the Monte Carlo technique, it can be used to numerically solve linear parabolic and elliptic PDEs with Robin boundary condition. One of the key results presented is the use of the proposed method for computing ergodic limits, i.e. expectations with respect to the invariant law of RSDEs, both inside a domain and on its boundary. This allows to efficiently sample from distributions with compact support. Both time-averaging and ensemble-averaging estimators are considered and analysed. It is proved that the method has the first order of weak convergence, both at finite time and for approximating ergodic limits. A number of extensions are considered including a second-order weak approximation, the case of arbitrary oblique direction of reflection, and a new adaptive weak scheme to solve a Poisson PDE with Neumann boundary condition. The presented theoretical results are supported by several numerical experiments. Preliminary results on approximation of confined Langevin dynamics will be also discussed. The talk is based on joint works with Ben Leimkuhler (Edinburgh) and Akash Sharma (Nottingham).

Matthias C. M. TROFFAES
Durham University, UK, E-mail: matthias.troffaes@durham.ac.uk

A non-standard approach to non-linear expectation

KEY WORDS: non-linear expectation, non-standard analysis, imprecise probability, internal set theory, risk analysis

Abstract: Lower previsions use sets of probability measures, specified through non-linear bounds on expectations, to represent states of severe uncertainty. They have been successfully applied to a wide range of fields where risk under severe uncertainty is a concern. Following Walley's work from the 90's, the canonical interpretation of these bounds in the last 30 years has been through betting. However, in high-risk situations where the assessor themselves is at risk, various authors have argued that the betting interpretation of probability, and therefore also of lower previsions, cannot be applied. For this reason, in 2006, Lindley suggested an alternative interpretation of probability, based on urns, which mathematically leads to a theory of rational valued probabilities for finite possibility spaces. We revisit this interpretation in the context of non-linear expectations and lower previsions in particular.

In doing so, we (i) show how Lindley's interpretation can be generalized to infinite possibility spaces and arbitrary real-valued probabilities, effectively resulting in a finitely additive probability theory, and (ii) we provide an alternative interpretation of lower previsions, which leads to new expressions for consistency (called avoiding sure loss) and inference (called natural extension). We show that these expressions are mathematically equal to their canonical betting-based equivalents. We do this through a non-standard treatment of Lindley's urn interpretation based on internal set theory. This can be seen as an instance of Nelson's radically elementary probability approach.

As a side result, we establish a strong connection between Nelson's radically elementary non-standard probabilities and finitely additive probability measures.

References

[1] Dennis V. Lindley (2006). Understanding Uncertainty. Wiley. doi: 10.1002/0470055480.

[2] Edward Nelson (1977). "Internal Set Theory: A New Approach to Nonstandard Analysis". *Bulletin of the American Mathematical Society*, **83**, pp. 1165-1198.

[3] Matthias C. M. Troffaes and Gert de Cooman (2014). Lower Previsions. Wiley Series in Probability and Statistics. isbn: 978-0-470-72377-7.

Alexander VERETENNIKOV

University of Leeds, E-mail: alex.veretennikov2021@gmail.com

On 2-recurrence for an SDE with switching

Abstract: Consider an SDE with switching in $\mathbb{R}^d$ for the component X,

$$dX_t = b(X_t, Z_t)\,dt + dW_t, \quad t \geq 0, \quad X_0 = x,\ Z_0 = z, \tag{1}$$

while Z_t is a continuous-time Markov process on the state space $S = \{0, 1\}$ with constant positive intensities of respective transitions $\lambda_{01} =: \lambda_0$, & $\lambda_{10} =: \lambda_1$; the trajecotry of Z is independent of the d-dimensional Wiener process W. Denote $b(x, 0) = b_-(x), \quad b(x, 1) = b_+(x)$, The boundedness condition for the Borel function b suffices for the process (X_t, Z_t) to be well-defined as a strong solution of the equation. Assume that there exist $M, r_\pm, R_\pm$ such that

$$xb_-(x) \leq -r_-, \quad xb_+(x) \leq +r_+, \quad \forall\, |x| \geq M, \tag{2}$$

and

$$\lambda_1(4r_- - 6d) > \lambda_0(4r_+ + 6d), \tag{3}$$

and

$$xb_-(x) \geq -R_-, \quad xb_+(x) \geq +R_+, \quad \forall\, |x| \geq M. \tag{4}$$

with $R_+ \leq r_+$, $R_- \geq r_- > 0$.

Theorem 1 *Let b be bounded and conditions (2)–(4) be satisfied. Then the process (X, Z) is 2-recurrent; for any $\delta > 0$ there exists $C > 0$ such that for any M_1 large enough and all $x \in \mathbb{R}^d$ and for $z = 0, 1$*

$$\mathbb{E}_{x,z}\tau_{M_1}^2 \leq C(x^{4+\delta} + 1),$$

where $\tau_{M_1} := \inf(t \geq 0 :\ |X_t| \leq M_1)$.

This implies that this bound holds true for *any* $M_1 > 0$ with a new constant C; also, similar bounds may be obtained for higher moments of the stopping time τ_{M_1} as well under further restrictions of recurrence conditions on $r_\pm$.

Feng-Yu WANG

Tianjin University/Swansea University, E-mail: wangfy@tju.edu.cn

A General Framework for Solving Singular SPDEs

Abstract: We propose a general framework of *proper regularization* to solve singular nonlinear SPDEs. Besides singularities in drift, this framework also allows singular noise coefficients including high order pseudo-differential operators. As applications, the (local and global) well-posedness is presented for a broad class of fluid dynamics equations with singular noise, such as the stochastic magnetohydrodynamics (including Navier-Stokes/Euler) equation, stochastic Korteweg-De Vries equation, stochastic (modified) Camassa-Holm type equations, stochastic aggregation-diffusion type equations and stochastic surface quasi-geostrophic equation. Thus, some recent results derived in the literature are extended in a unified way to the singular noise case. This is a joint work with Hao Tang.

Chenggui YUAN
Swansea University, E-mail: C.Yuan@Swansea.ac.uk

The Harnack inequality of stochastic differential equations.

Abstract: In this talk, I will present the dimension-free Harnack inequality of stochastic differential equations and stochastic differential delay equations for regular coefficients. Moreover, I will also discuss the dimension-free Harnack inequalities for stochastic equations with Hölder continuous diffusion coefficient and singular drift term without regularity assumption.

Tusheng ZHANG
University of Science and Technology of China/University of Manchester, E-mail: tusheng.zhang@manchester.ac.uk

Stochastic partial differential equations with local monotone coefficients

Abstract: Considered in a Gelfand triple, the well posedness of stochastic partial differential equations with monotone or particular type of local monotone coefficients is now well understood. In this talk, we will report recent progresses on the well-posedness of stochastic partial differential equations which have fully local monotone coefficients. The results apply to many interesting models/examples. This is a joint work with Michael Rockner and Shijie Shang.

Durham Symposium

Stochastic Dynamics, Nonlinear Probability, and Ergodicity

22-26 August 2022

Department of Mathematical Sciences

Registered Participants

First name	Last name	Institution
Letizia	Angeli	Heriot-Watt University
Rui	Bai	Durham University
Bernat	Bassols Cornudella	Imperial College London
Horatio	Boedihardjo	University of Warwick
Athanasios	Bouganis	Durham University
Zdzisław	Brzeźniak	University of York
Thomas	Cass	Imperial College London
Georgy	Chargaziya	University of York
Mickaël	Chekroun	Weizmann Institute of Science
Slava	Cherepanov	University of Oxford
Sunil	Chhita	Durham University
Hugo	Chu	Imperial College London
Conrado	Da Costa	Durham University
Giuseppe	Da Prato	Scuola Normale Superiore di Pisa
Zhao	Dong	Chinese Academy of Sciences
Weinan	E	Princeton University/Peking University
David	Elworthy	University of Warwick
Chunrong	Feng	Durham University
Tadahisa	Funaki	University of Tokyo
István	Gyöngy	University of Edinburgh
Martin	Hairer	Imperial College London

Tyler	Helmuth	Durham University
Ruiqi	Hou	Shandong University
Ostap	Hryniv	Durham University
Yifan	Jiang	University of Oxford
Nicolai	Krylov	University of Minnesota
Christian	Kuehn	Technical University of Munich
Jeroen	Lamb	Imperial College London
Oana	Lang	Imperial College London
Xue-Mei	Li	Imperial College London
Ziyu	Li	Imperial College London
Zeng	Lian	Sichuan University
Fang Rui	Lim	University of Oxford
Yu	Liu	Durham University
Yujia	Liu	Shandong University
Chunlin	Liu	University of Science and Technology of China
Kening	Lu	Brigham Young University/Sichuan University
Tong	Lu	Shandong University
Yan	Luo	Shandong University
Jiaquan	Lv	Shandong University
Chenglin	Ma	Shandong University
Alpár	Mészáros	Durham University
Michela	Ottobre	Heriot-Watt University
John	Parker	Durham University
Peter	Paulovics	University of Warwick
Shige	Peng	Shandong University
Szymon	Peszat	Jagiellonian University, Poland
Zhongmin	Qian	University of Oxford
Baoyou	Qu	Durham University
Yongsheng	Song	Chinese Academy of Sciences

Iain	Souttar	Heriot-Watt University
Giuseppe	Tenaglia	Imperial College London
Debleena	Thacker	Durham University
Michael	Tretyakov	University of Nottingham
Matthias	Troffaes	Durham University
Will	Turner	Imperial College London
Alexander	Veretennikov	University of Leeds
Maria	Veretennikova	University of Warwick
Andrew	Wade	Durham University
Fengyu	Wang	Tianjin University/Swansea University
Djoko	Wirosoerisno	Durham University
Jinxiang	Yao	University of Science and Technology of China
Chenggui	Yuan	Swansea University
Tusheng	Zhang	University of Science and Technology of China/University of Manchester
Huaizhong	Zhao	Durham University
Danyang	Zhao	Shandong University
Bian	Zheng	Imperial College London
Yanpeng	Zhi	Southern University of Science and Technology

Information for participants staying at Collingwood College

If you have booked University accommodation, you will be accommodated at **Collingwood College**.

Collingwood College is one of the most modern of all Durham University's colleges and offers all the essential amenities for any event, from international conferences for hundreds of delegates to group trips exploring the riches of the area.

BEDROOM FACILITIES

The College has 200 en-suite bedrooms and 307 standard bedrooms.
All bedrooms have the following facilities:

- Tea and coffee making facilities refreshed daily
- Free internet connection Wi-Fi available in the bedrooms
- Hollow fibre filled pillows
- Bathrooms with shaver socket outlets
- Toiletry pack containing Shower gel/Shampoo, Soap, Body Lotion and a vanity kit, one per person per stay
- One hand towel and one bath towel per person
- Hairdryers, irons and ironing boards available from Reception
- Lift access in en-suite rooms but not in standard rooms

CHECK IN

Rooms are guaranteed to be ready by 2pm. The reception will be open from 8am-6pm**.** Outside these times, a porter will be available to show you to your room. Please use the internal telephone near to reception to call the porter if he is away from his post.

CHECK OUT

Check out is before 10am.

BREAKFAST

For participants resident in Collingwood College, breakfast will be served in the college's dining hall from 8.00 –9.00am. Early breakfasts can be arranged on request.

Guest information

SMOKING
Smoking is prohibited in all enclosed public places in the UK. A designated outdoor smoking area is provided at each College.

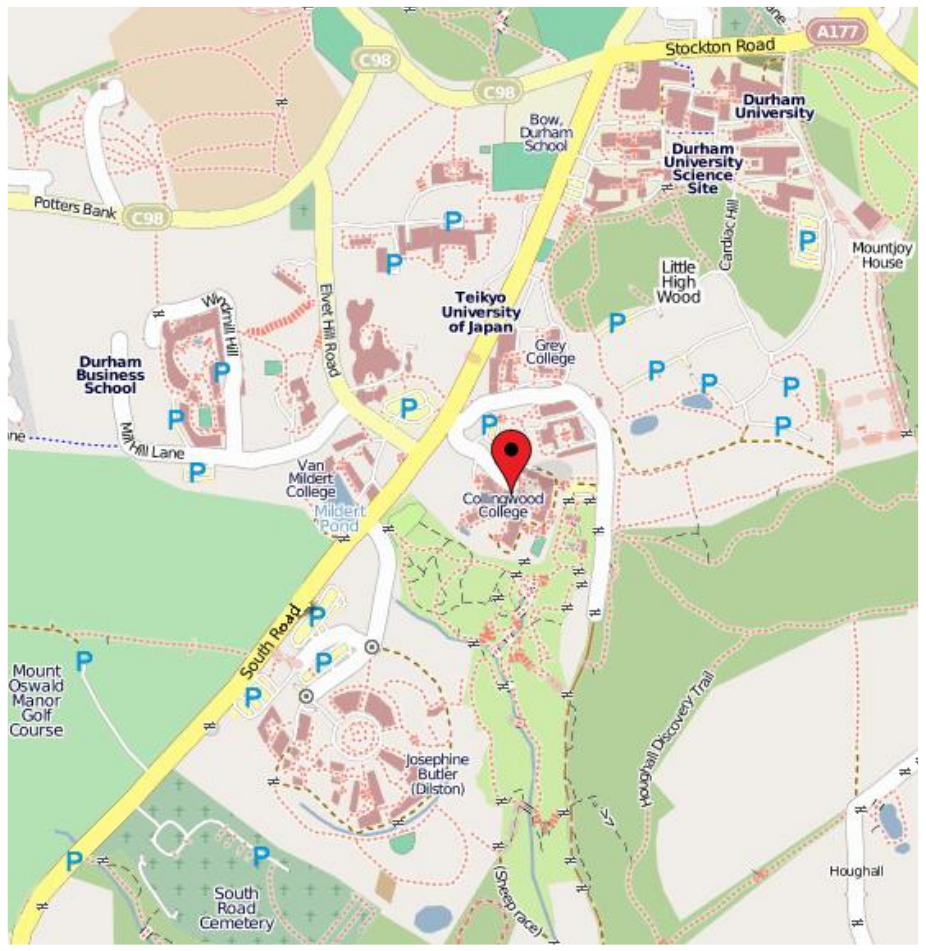
BUSINESS AND INTERNET FACILITIES
Free wireless internet access is available in college and all University buildings. Fax and photocopying facilities are available at the College, subject to a small charge.

ELECTRICAL APPLIANCES
Plugs and sockets in the UK have voltage between 220-240V. Please bring appropriate adaptors for your mobile phone recharger and other appliances.

EMERGENCY
In case of an emergency, to report any suspicious behaviour, accidents, if you require any medical attention or any other assistance please contact Reception.

PARKING
Car parking is available at the college, but very limited and strictly on a first come first serve basis. No spaces can be reserved. Car details will need to be registered on arrival at College Reception.

Directions to college



Collingwood College
South Road
Durham University
DH1 3LT
Tel: +44 (0) 191 334 5000

Set in tranquil woodland, Collingwood is close to the city centre, Durham Botanic Garden and the Oriental Museum.

Public Transport Directions
Durham Railway station is 2 miles away. From the city bus station - a short walk from the railway station – take the Arriva No 6 Bishop Auckland service which runs every 15 minutes past the Colleges on South Road.

Road Directions
Take the A690 from the A1 (M), turn left across Elvet Bridge over the traffic lights. Follow the road to New Inn crossroads, go straight over. Collingwood is the third turning on the left hand side.

For further information on how to get to Durham, please refer to the Travel section at the end of this brochure.

LOCAL INFORMATION

Taxis:	Paddy's	0191 3866662
	Pratts	0191 3860700
Banks:	Market Place:	Barclays, Lloyds
Post Office:	Market Place	Ground floor of W.H. Smith
Hospital:	University Hospital	0191 3332333

MATHS DEPARTMENT INFORMATION

If you have any questions please do not hesitate to contact the Maths Department via:

Telephone no: 0191 3343040 email: maths.office@durham.ac.uk

The Maths Office is in room MCS2093, Level 2, Mathematical Sciences and Computer Science Building, Upper Mountjoy, Stockton Road, DH1 3LE

TheCloud@Durham

Visitors and non-accademic guests should use 'TheCloud@Durham' to connect to the wireless service when visiting Durham University

About "TheCloud"

'TheCloud' is a free public access wireless service with thousands of hotspots and millions of registered users, it provides simple, fast and reliable wireless Internet access

'TheCloud' service is available for Android, iOS, Windows and Mac devices.

Get Connected

To connect to 'TheCloud@Durham' simply follow the steps below:

1. Switch on your smartphone, tablet or other Wi-Fi device and check that Wi-Fi is enabled.

2. Select 'TheCloud@Durham' from the available network list

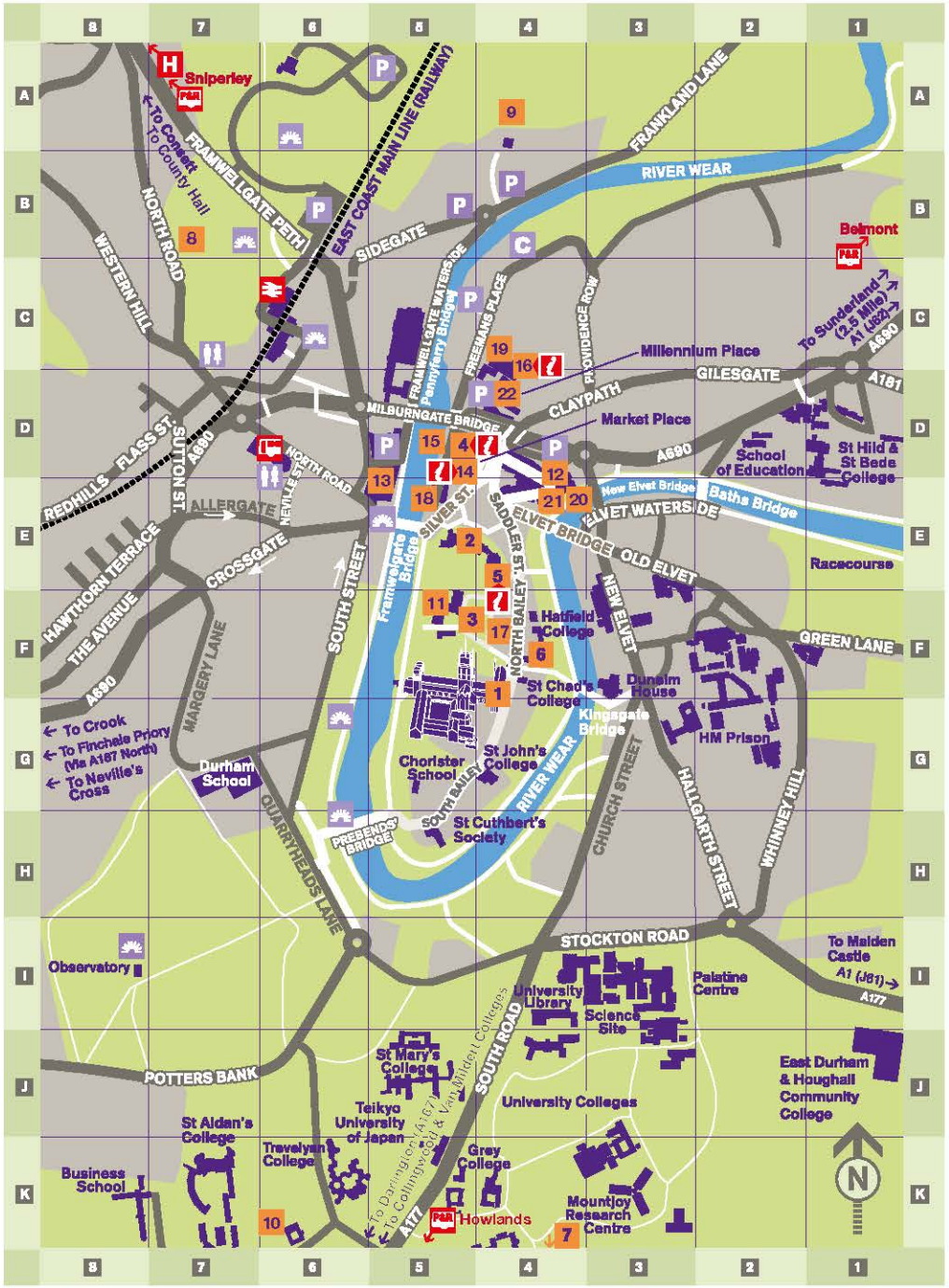
3. Open your Internet browser - 'TheCloud' landing page below will appear. Click 'Get Online'.
If the web page does not appear refresh the page

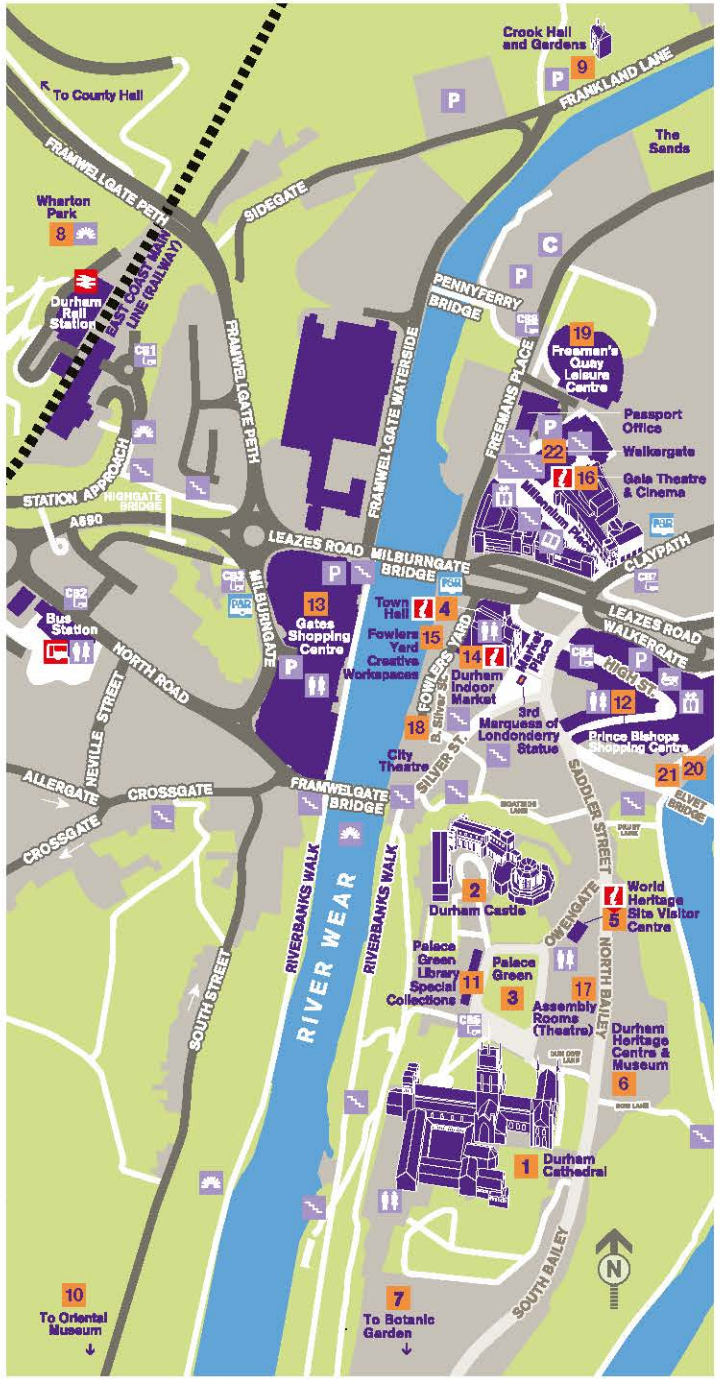
4. You will then see the service selection screen. Select 'The Cloud Wi-Fi'.

5. Once this is done you can either login with an existing 'TheCloud' account, or click on the 'Create Account' button to register for a free account.

6. Once you have logged in or registered you will be able to access the Internet using 'TheCloud@Durham'.

Durham City





- H A7 University Hospital
- R C6 Durham Rail Station
- B D6 North Road Bus Station
- i Visitor Information Points
- P Car Park
- C Coach Park
- Shopmobility
- Library
- Toilets
- Lifts
- Stairs
- View Point

Park & Ride Car Parks

- P&R A7 Sniperley
- P&R B1 Belmont
- P&R K6 Howlands

Heritage

- 1 F4 Durham Cathedral
- 2 E5 Durham Castle
- 3 F5 Palace Green
- 4 D5 Town Hall
- 5 E4 World Heritage Site Visitor Centre

Museums & Gardens

- 6 F4 Durham Heritage Centre & Museum
- 7 K4 Botanic Garden
- 8 B7 Wharton Park
- 9 A4 Crook Hall & Gardens
- 10 K6 Oriental Museum
- 11 F5 Palace Green Library, Special Collections

Shopping

- 12 E4 Prince Bishops Shopping Centre
- 13 E5 The Gates Shopping Centre
- 14 D5 Durham Indoor Market
- 15 D5 Fowlers Yard Creative Workspaces

Culture

- 16 D4 Gala Theatre & Cinema
- 17 F4 Assembly Rms (Theatre)
- 18 E5 City Theatre

Sport and Leisure

- 19 C4 Freeman's Quay Leisure Centre
- 20 E4 Prince Bishop River Cruises (Summer)
- 21 E4 Rowing Boat Hire (April - October)
- 22 D4 Walkergate

City Centre Map Symbols

- Park & Ride Bus Stops

Cathedral Bus Stops

- Rail Station
- Bus Station
- Milburngate
- Market Place
- Cathedral & Castle
- Car & Coach Park
- Claypath

TOURS WITH TASTE

For a sumptuous visit why not begin or finish your tour with refreshments served in the medieval Prior's Hall, originally the Prior's Dining Room when the Cathedral was a monastery.
Minimum numbers of 15 apply.

- **Morning Coffee & Tour £7.25**
- **Cream Cake & Tour £10.00**
- **Lunch & Tour £12.50**
- **Afternoon Tea & Tour £11.25**
- **Evening Dinner & Tour £bespoke – optional attendance at the service of Evensong followed by an evening guided tour and fine dining**

All refreshments are provided by the Undercroft Restaurant, winner of a Taste Durham award. It provides a range of high quality dishes using local produce whenever possible. Groups can visit the restaurant itself with group members purchasing refreshments on an individual basis, but booking ahead into Prior's Hall is highly recommended. Bespoke menus for special occasions can be arranged to suit. All dietary requirements can be catered for.

DURHAM CATHEDRAL SHOP

The shop is located off the Cathedral Cloisters close to the Undercroft Restaurant. It is the perfect place to buy souvenirs offering a wide range of postcards, gifts, books and CDs.

PHOTOGRAPHY

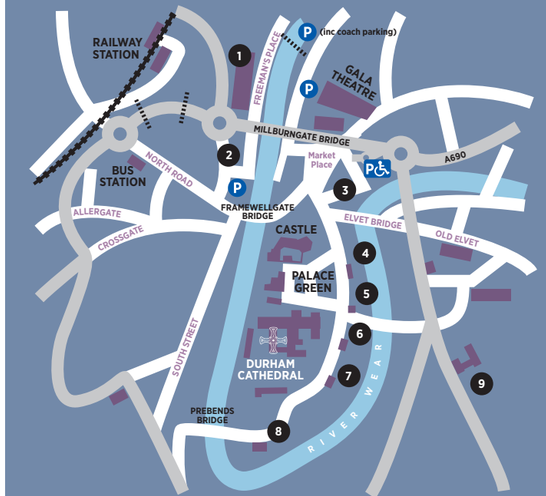
The Chapter does not permit photography within the Cathedral as it is a sacred place to which people come to pray and visit undisturbed. This includes the use of digital and video cameras and mobile phones. Photographs may be taken within the Precinct area including the Cloisters. There are many postcards and CDs of images available to purchase in the Gift Shop.

EXPERIENCES & PACKAGES

Durham Cathedral and St Chad's College
Residential packages available on selected dates. Guided tour of the Cathedral, optional attendance at the service of Evensong, refreshments and an evening Organ Recital.

Cathedral, Castle & World Heritage Site
Joint ticket for guided tour of the Cathedral, Castle and World Heritage Site on selected dates. Experience the magnificence one of Britain's first World Heritage Sites.

GETTING HERE



KEY
1 PASSPORT OFFICE
2 THE GATES DURHAM SHOPPING
3 PRINCE BISHOPS SHOPPING CENTRE
4 HATFIELD COLLEGE
5 DURHAM HERITAGE CENTRE
6 ST. CHAD'S COLLEGE
7 ST. JOHN'S COLLEGE
8 ST. CUTHBERT'S SOCIETY
9 JOB CENTRE

Transport
There is free coach parking at the City Centre Coach Park (the Sands). There is no parking at the Cathedral. Durham County Council provides a public shuttle bus service from the Coach Park and Durham Market Place to the Cathedral. An all-day ticket can be purchased on board. For timetable information please see www.durham.gov.uk/bustimetableinformation. The Sands Coach Park postcode is DH1 1SQ.

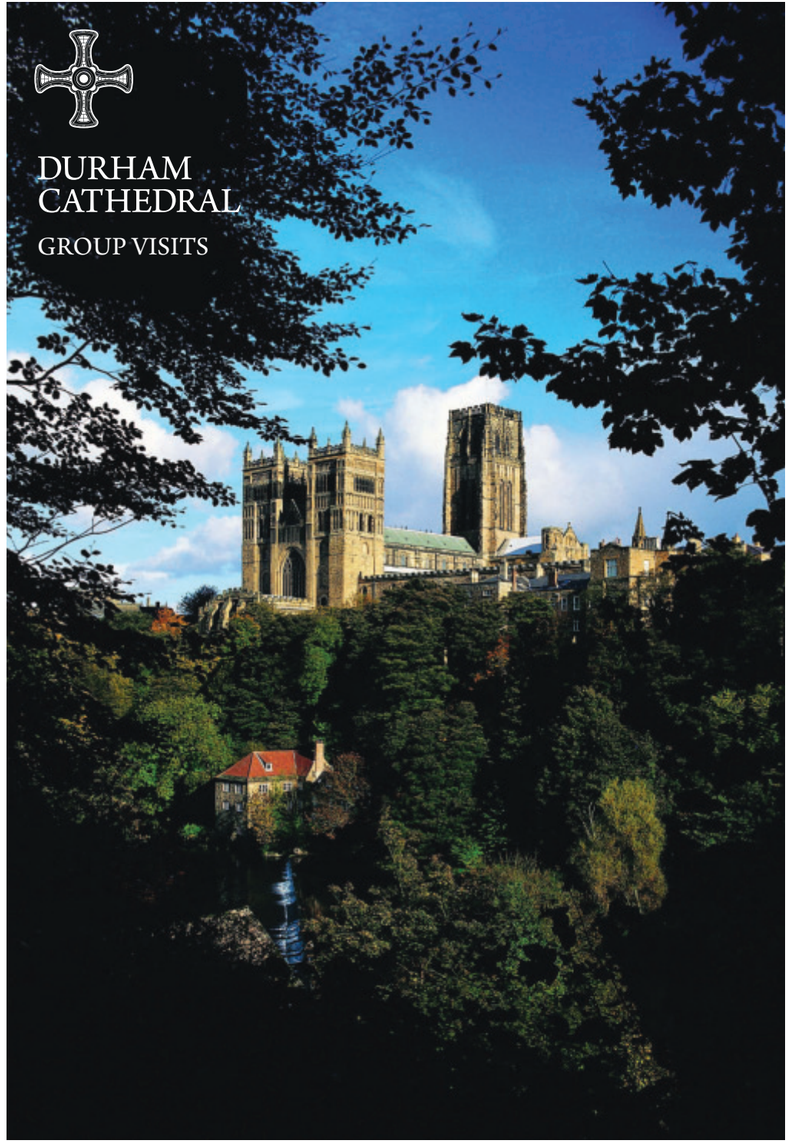
Access
Most of the Cathedral and Precinct is accessible; however as an historic building there are some uneven floors and certain areas are not accessible. For wheelchair users access is mostly via ramps; other services include accessible entrance, a stairclimber lift, large print guides, and an induction loop system. Wheelchairs are available on request. Assistance dogs welcome. If you have any access requirements or need any extra help or advice please do let us know in advance.

Further Information & Booking
Durham Cathedral wishes to provide a most enjoyable experience for all visitors, and understands that each group has its individual needs. To discuss your requirements further please contact our Group Travel Officer via
visits@durhamcathedral.co.uk
or **0191 374 4050**

DURHAM CATHEDRAL
Durham City
DH1 3EH
0191 386 4266
www.durhamcathedral.co.uk
www.facebook.com/durhamcathedral

DURHAM CATHEDRAL

GROUP VISITS



Durham has been a place of prayer and pilgrimage for a more than a millennium; the stunning Norman Cathedral was built in 1093 to replace a Saxon monastic church. It houses the shrine of St Cuthbert, the 7th century Bishop of Lindisfarne; and the tomb of the Venerable Bede, who is often called the Father of English History, as author of the early 8th century The Ecclesiastical History of the English People.

The Cathedral is one of the finest examples of Norman architecture in Europe, or as American writer Bill Bryson says, "the best Cathedral on planet Earth". The stone vaulting in the Nave marks a turning point in the history of architecture, as pointed arches were used successfully for the first time instead of Romanesque semi-circular arches. This allowed the building to reach a greater height, paving the way for the Gothic style. Durham Cathedral forms part of a UNESCO World Heritage Site and is a living place for Christian worship. Visitors come from around the world.

Durham Cathedral is open to pre-booked groups on:
Monday – Saturday 9.30am – 5.00pm
Sunday 1.00pm – 3.00pm

Pre-booked groups of 12 or more people receive a range of exclusive benefits with a group rate of £5.00* per person that includes:

- Private group guided tour available in various languages
- Free place for the group organiser or tour manager
- Free self-guide leaflets for unguided tours in various languages
- Free familiarisation visit for organiser ahead of any visit
- Free coach parking at Durham City Centre Coach Park
- Refreshment voucher for the coach driver

Supplementary benefits can be booked subject to an additional charge:

- Special interest talks & behind the scene tours
- Refreshment packages

Evening group visits can also be arranged and can include private dining.

Durham Cathedral is a working Church, booking for groups is essential as special services or other events may be scheduled to take place on the day of your intended visit.

*2012 price per person for group visits

GUIDED TOURS

General Tour
Trained guides provide a tour which last approximately 1¼ hours. It includes the history and development of the Cathedral, the Shrine of St Cuthbert, the Tomb of the Venerable Bede, the Galilee Chapel, the Chapel of the Nine Altars, the Nave and the Quire.

Highlights Tour
For groups that only have a short time to view the Cathedral, a brief 30 minute tour outlines the Cathedral's main points of interest.

BEHIND THE SCENE TOURS & SPECIALIST TALKS

Exclusive behind the scene tours and talks on specialist subjects can be arranged. These may include entry into areas not open to the general public. To ensure availability please book as early as possible.

- Northern Saints
- Pilgrimage Tour
- Architecture
- Stained Glass Windows
- Embroidery & Textiles*
- Cathedral Library & Manuscript Treasures*
- Monastic (Rites of Durham)*
- History of Cathedral Music
- Decorative Art in the Cathedral
- The Art of the Woodcarver
- Other subjects may be available by request.

Durham Cathedral regularly hosts special events and Durham itself has a busy programme of cultural festivals. At the time of your enquiry do ask about upcoming events. There may be something of interest to your group.

*Additional charges apply to some specialist tours.

HOW TO PAY

Payment can be made on arrival at the Information Desk at the back of the Cathedral. It must be made in one payment for the whole group by cash, debit card, credit card or cheque (made payable to Durham Cathedral). Alternatively, by prior arrangement only, the Cathedral can issue an invoice. Minimum numbers apply and will be charged for group bookings.

OPEN TREASURE

Durham Cathedral is reorganising its exhibition space as part of a project called Open Treasure. When complete the Cathedral will be able to display more of its internationally important collections in new exhibition space in some of the Claustral buildings (located off the Cathedral Cloisters). During 2012 the shop will move from the Great Kitchen to the Undercroft. Stunning exhibition space will be developed in the Great Kitchen and in the Monks' Dormitory, linked via a new glazed walkway and gallery. This work should be complete during 2013. At present the Treasures of St Cuthbert are not on display. The relics themselves are in suitable storage ahead of conservation work before they are returned to public view. Some elements of the Cathedral's collections can be seen as part of the specialist talks available to groups listed on this page, in particular the Cathedral Library & Manuscript Treasures talk.