CURRICULUM VITAE: D.S. Dean

PERSONAL DETAILS

Full name: David Stanley DEAN
Date of birth: 02/12/67
Place of birth: St. Asaph, Wales, UK.
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EDUCATION AND DEGREES

1990-93 PhD in Theoretical Physics: Department of Applied Mathematics and Theoretical Physics, University of Cambridge. Thesis title: **Stochastic Dynamics**, PhD supervisor: Professor I.T. Drummond.
1989-90 Part III Mathematics, Cambridge University: awarded Certificate of Advanced Studies in Mathematics (with distinction).
1986-89 BA Hons Mathematics: Girton College, Cambridge University (Class II.I).

Scientific Career

- October 1993- October 1995: NATO Postdoctoral Fellow, Service de Physique de l'Etat Condensé, CEA, Saclay, France.
- October 1995- October 1996: EU Postdoctoral Fellowship, Dipartimento di Fisica, Università di Roma I, Italy
- October 1996- December 1997: EU Postdoctoral Fellowship, Laboratoire de Physique Théorique, ENS, Paris France.
- January 1998- September 1998: CNRS Postdoctoral Fellowship, Division de Physique Théorique, Institut de Physique Nucléaire, Orsay.
- September 1998 -present : Professor of Statistical Physics, Laboratoire de Physique Théorique, IRSAMC, Université Paul Sabatier, Toulouse.

- September 2003 - September 2004: Sabbatical year, Department of Applied Mathematics and Theoretical Physics, University of Cambridge and Visiting Research Fellow at Sidney Sussex College, Cambridge.

Academic Honours

- **Rayleigh Prize, University of Cambridge 1992** - Prize for research conducted during first year of doctoral research.
- **Nommination at the Institut Universitaire de France 2006**- Junior member.

Research Activities

Areas of Research

- Applications of stochastic analysis to theoretical physics.
- Transport in random media.
- Out of equilibrium dynamics in complex and disordered systems.
- Statistical mechanics of spin glasses and disordered systems.
- Electrostatic effects in soft condensed matter physics.
- Thermodynamic approach to granular media.
- Applications of statistical mechanics in biology and computer science.

Referee for: Journal of Physics A, Journal de Physique, Zeitschrift für Physik B, Physical Review Letters, Europhysics Letters, European Physical Journal B, Chaos, Physical Review E, Advances in Complex Systems, Physics Letters B, Physica A, Physical Review B, Editions CNRS.

Invited conferences since 1999

- **Electrostatic Effects in Soap Films**, Foam Stability and Wetting, Amsterdam, Holland (1999).
- **Diffusion dans les Systèmes Complexes**, CNRS Colloque NOI, Bordeaux, France (2000).
- **Diffusion dans les Systèmes Biologiques** CNRS Program SVT, Montpellier, France (2001).
- **Tapping Spin Glasses and Ferromagnets**, SPHINX Conference Il Ciocco, Italy, (2001).

- **The Thermodynamics of the Tapped Ising Model**, Challenges in Granular Physics, Trieste, Italy, (2001).
- **Some applications of statistical physics for searching and sorting in computer science**, Aspects of Complexity and its Applications, Rome, Italy, (2002).
- **Some applications of statistical physics for searching and sorting in computer science**, Glassy States of Matter , KITP, Santa Barbara, U.S.A, (2003).
- **A possible experimental test of the thermodynamic approach to granular media**, Unifying Concepts in Granular Media and Glasses, Capri, Italy (2003).
- **The role of the interaction matrix in mean-field spin glass models**, Frustrated Magnetism and Slow Dynamics, Kyoto, Japan, (2004).
- **Thermodynamic approaches to granular media**, Granular Physics , KITP, Santa Barbara, U.S.A, (2005).
- **A physicist's perspective on optimization problems**, Stochastic Computation, Santander, Spain (2005).
- **The statistics of a slave estimator for response in Langevin systems**, Recent Progress in Glassy Physics, Paris, France (2005).
- **Field theoretic methods for transport in random media**, Conference in honour of Prof I.T. Drummond, Cambridge UK (2005).
- **The statistical mechanics of combinatorial optimization problems with site disorder**, ECCS'05 Cospico Satellite Meeting, Paris, France (2005).
- **Statistics of a slave estimator**, Relaxation Dynamics of Macroscopic Systems, Isaac Newton Institute, Cambridge UK (2006).
- **Phase transition in the Aldous Shields Growth Model**,First-Passage and Extreme Value Problems in Random Processes, Isaac Newton Institute, Cambridge UK (2006).
- **Extreme value statistics of maximal eigenvalues of random matrices** III BRUNEL Workshop on Random Matrix Theory, University of Brunel UK, (2007).
- **Growth models on trees** Interfaces between physics and computer science, Jacobs University, Allemagne (2007).
- **Diffusion in non-Gaussian potentials in one dimension**, Statistical Physics and Low Dimensional Systems, Nancy, France (2008).
- **Fluctuation induced interactions in one dimensional Coulomb gases** Fluctuate 08, Santa Barbara, USA (2008).

Invited Lectures

- **The Replica Method and Disordered Systems**, graduate course, TATA Institute for Fundamental Research, Bombay, India, (1999).
- **The Replica Method and Disordered Systems**, graduate course, University of Barcelona, Barcelona, Spain, (2001).
- **Slow Dynamics and Aging**, Session on Granular Matter, Institut Henri Poincaré, Paris, (2005).

Thesis direction

- R. Cherrier, 1999-2003, PhD Thesis, **Etude de systèmes de spins complexes où désordonnes: analogies avec la transition vitreuse structurelle**. *Dr Cherrier is now a university lecturer at the University of Bordeaux I, France.*
- A. Lefèvre, 2000-2003, PhD Thesis, **Etats métastables dans les systèmes vitreux: des verres de spins aux milieux granulaires**. *Dr Lefèvere is now a CNRS researcher at the Service de Physique Théorique, CEA, Saclay, France.*
- N. Destainville (Lecturer Université Paul Sabatier), 2005, *Habilitation Thesis*, **Dynamique de flips dans les pavages aléatoires et dynamique diffusionelle des recepteurs membranaires**.
- J. Sopik,2003-2006 **Dynamique de marcheurs aléatoires interagissant à longue portée**, in co-direction with C. Sire (LPT Toulouse).
- C. Touya, 2006-2009, working on the glass transition and diffusion in random media
- T. Portet, 2007-2010 in co-direction with M.-P. Rols (IPBS Toulouse), working on electropermeabilisation of artificial vesicles.

Teaching experience

Since 1998 I have taught at the University Paul Sabatier Toulouse. I have carried out the standard teaching load of 192 hours per year. I have given lecture courses in Statistical Mechanics for 3rd year and 5th year students and a Mathematical Physics course on Symmetries and Group Theory for 4th year students. For all these lecture courses I prepared the example sheets for the accompanying tutorials (24 hours). I have also set and marked the examinations for these courses. In addition I have given tutorials in these subjects (tutorial groups comprise of between 20 and 35 students) and I have also given numerical tutorials based on Matlab. I have also taught the Statistical Physics Course for the *Agrégation de Physique* (a national exam for prospective teachers at the level of the first 2 year of undergraduate study).

I have also given a series of lectures on Cosmology and Soft Condensed Matter for 5th year students, these lectures are given in English as part of their foreign language training.

Scientific administration

- Head of the Statistical Physics Group of the Laboratoire de Physique Théorique Toulouse (6 members).
- Member of the Recruitment Commission for Theoretical Physics at the University Paul Sabatier 1998-2006.
- President of the Recruitment Commission for Theoretical Physics at the University Paul Sabatier 2006-2008.
- Referee for the French Research Agency (ANR).
- Expert for the CNRS in the evaluation of CNRS Theoretical Physics Laboratories.
- Co-director of the 2nd year Masters Course (5th year of University study) in Condensed Matter Physics.

- Expert evaluator for the project EVERGROW (Complex Systems Cluster) Future and Emerging Technologies, EC Framework Program 6, 2006, 2007, 2008.
- President of AERES (Agence d'Evaluation de la Recherche et lÉnseignement Superieur) Committee for the Evaluation of the Scientifique activities of laboratories (nationally coordinated evaluation of research activities of individual laboratories). LPTMC Paris VI 2008; PLMC Paris XII (2008).
- Member of the Physics Committee for the ANR (French Research Funding Agency) 2008, 2009 (this committee is charged with the final selection of physics projects for about 17 million euros of funding).
- Member of the scientific steering committee of the Institut Henri Poincaré, 2007 - present.
- Consultant for the *Prix Le Monde* - this is a prize awarded for communication of a PhD thesis results to the wider public, the final article being published in the French national newspaper Le Monde.

PUBLICATIONS IN REFEREED JOURNALS

[1] D.S. Dean and K.M. Jansons, **A note on the integral of a brownian bridge**, *Proc. Roy. Soc. Lond. A* **437**, (1992).

[2] D.S. Dean and K.M. Jansons, **Brownian excursions on combs**, *J. Stat. Phys.* **70**, 5/6, (1993).

[3] T. Chan. D.S. Dean, K.M. Jansons and L.C.G. Rogers, **On polymer conformations in elongational flows**, *Comm. Math. Phys.* **160**, 2, (1994).

[4] D.S. Dean, I.T. Drummond and R.R. Horgan, **Perturbation schemes for flow in random media**, *J. Phys. A.* **27**, 15, (1994).

[5] D.S. Dean, **On the metastable states of the zero temperature SK model**, *J. Phys. A.* **27**, 23, (1994).

[6] J.P. Bouchaud and D.S. Dean, **Aging on Parisi's tree**, *J. Phys. I France* **5**, (1995).

[7] E. Vincent, J.P. Bouchaud, D.S.Dean and J. Hammann, **Aging in spin glasses as a random walk: Effect of a magnetic field**, *Phys. Rev. B* **52**, 2, (1995).

[8] D.S. Dean and K.M. Jansons, **Excursions for polymers in elongational flows**, *J. Stat. Phys.* **79**, 1/2, (1995).

[9] D.S. Dean, I.T. Drummond and R.R. Horgan, **Perturbation theory for effective diffusivity in random gradient flows**, *J. Phys. A.* **28**, 5, (1995).

[10] L.F. Cugliandolo and D.S. Dean, **Full dynamical solution for a spherical spin-glass model**, *J. Phys. A.* **28**, 15, (1995).

[11] D.S. Dean, I.T. Drummond and R.R. Horgan, **Effective diffusivity in nonisotropic gradient flows**, *J. Phys. A.* **28**, 6013, (1995)

[12] L.F. Cugliandolo and D.S. Dean, **On the dynamics of a spherical spin-glass in a magnetic field**, *J. Phys. A.* **28**, 17, (1995)

[13] D.S. Dean, I.T. Drummond and R.R. Horgan, **Renormalization of drift and diffusivity in random gradient flows**, *J. Phys. A.* **29**, 7867, (1996).

[14] D.S. Dean and D. Lancaster, **A field theory for finite dimensional site disordered spin systems**, *Phys. Rev. Lett.* **77**, 14, (1996).

[15] D.S. Dean and D. Lancaster, **Site disordered spin systems in the Gaussian variational approximation**, *J. Phys. A.* **30**, 37, (1997).

[16] D.S . Dean, **Langevin equation for the density of a system of interacting Langevin processes**, *J. Phys. A.* **29**, L613, (1996).

[17] D.S. Dean and D. Sentenac, **Surface charging mechanism for electrolytic soap films**, *Europhys. Lett.* **38**, 9, 645, (1997).

[18] D.S. Dean, I.T. Drummond and R.R. Horgan, **Continuum derrida approach to drift and diffusivity in random media**, *J. Phys. A.*, **30**, 385, (1997).

[19] D.S. Dean, R.R. Horgan and D. Sentenac, **Boundary effects in the one dimensional Coulomb gas**, *J. Stat. Phys.*, 90, 3/4, (1998).

[20] D. Sentenac and D.S. Dean, **Surface charging mechanism and disjoining pressure of electrolytic soap films**, *J. Colloid Interface Sci.*, **35**, 196(1), (1997).

[21] L. F. Cugliandolo, D.S. Dean and J. Kurchan, **Fluctuation-Dissipation theorems and entropy production in relaxational systems**, *Phys. Rev. Lett* **79**, 12, 2168, (1997).

[22] D.S. Dean and G. Parisi, **Statistical mechanics of a two-dimensional gas with long range interactions**, *J. Phys. A.* **31**, 3949, (1998).

[23] D.S. Dean, I.T. Drummond, R.R. Horgan and C.A. Da-Silvo-Santos, **Inertial effects in the short range toy model**, *Europhys. Lett.* **42**, 3, 241, (1998).

[24] A. Comtet and D.S. Dean, **Exact results on Sinai's diffusion**, *J. Phys. A.*, **31**, 8595, (1998).

[25] D.S. Dean, **Metastable states of spin glasses on random thin graphs**, *Eur. Phys. J. B* **15**, 493, (2000).

[26] S.N. Majumdar, D.S. Dean and P. Grassberger, **Coarsening in presence of kinetic disorders: Analogy to granular compaction**, *Phys. Rev. Lett.* **86**, 11, 2301, (2001).

[27] D.S. Dean, I.T. Drummond and R.R. Horgan, **Effect of helicity on the effective diffusivity for incompressible random flows**, *Phys. Rev. E* **63**, 061205, (2001).

[28] A. Lefevre and D.S. Dean, **Metastable states of a ferromagnet on random thin graphs**, *Eur. Phys. J. B* **21**, 121, (2001).

[29] D.S. Dean and A. Lefèvre, **Tapping spin glasses and ferromagnets on random graphs**, *Phys. Rev. Lett.* **86**, 25, 5639, (2001).

[30] A. Lefèvre and D.S. Dean, **Tapping thermodynamics of the one dimensional Ising model**, *J. Phys A* **34**, L213 (2001).

[31] D.S. Dean and S. N. Majumdar, **Extreme value Statistics of hierarchically correlated variables: violation of Gumbel statistics and anomalous persistence**, *Phys. Rev, E* **64**, 046121 (2001).

[32] D.S. Dean and A. Lefèvre, **Steady state behavior of mechanically perturbed spin glasses and ferromagnets**, *Phys. Rev E.* **64**, 046110 (2001).

[33] D.S. Dean and S. N. Majumdar, **The exact distribution of the oscillation period in the underdamped one dimensional Sinai model**, *J. Phys. A.* **34**, L697 (2001).

[34] D.S. Dean and A. Lefèvre, **The steady state of the tapped Ising model**, *Advances in Complex Systems* **4**, 333 (2001).

[35] D.S. Dean, **Approximation scheme for the density of states of the Laplacian on random graphs**, *J. Phys. A.* **35**, L153 (2002).

[36] F.Mila and D.S. Dean, **Dynamic spin-glass behavior in a disorder-free,two-component model of quantum frustrated magnets**, *Eur. Phys. J. B.* **26**, 301, (2002).

[37] D.S. Dean and F. Ritort, **The squared interaction matrix Sherrington-Kirkpatrick Model**, *Phys. Rev. B.* **65**, 224209 (2002).

[38] A. Lefèvre and D.S. Dean, **Phase transitions in the steady state behavior of mechanically perturbed spin glasses and ferromagnets**, *Phys. Rev. B* **65**, 220403, (2002).

[39] D.S. Dean and R.R. Horgan, **Electrostatic fluctuations in soap Films**, *Phys. Rev. E* **65**, 061603, (2002).

[40] S.N. Majumdar and D.S. Dean, **Exact solution of a drop-push model for percolation**, *Phys. Rev. Lett.* **89**, 115701 (2002).

[41] D.S. Dean and S.N. Majumdar, **Phase transition in a random fragmentation problem with applications to computer science**, *J. Phys. A.***35**, L501 (2002).

[42] S.N. Majumdar and D.S. Dean, **Exact occupation time distribution in a non-Markovian sequence and its relation to spin glass models**,*Phys. Rev. E* **66**, 041102 (2002).

[43] S.N. Majumdar and D.S. Dean, **Slow relaxation in a constrained Ising spin chain: a toy model for granular compaction**, *Phys. Rev. E* **66**, 056114 (2002).

[44] F. Daumas, N. Destainville, C. Millot, A. Lopez, D.S. Dean and L. Salomé, **Confined diffusion without fences of a G protein coupled receptor as revealed by single particle tracking**, *Biophys J.* **84**, 356 (2003).

[45] R. Cherrier, D.S. Dean and A. Lefèvre, **The statics of generalized random orthogonal model spin glasses**, *Phys. Rev. E* **67**,046112 (2003).

[46] R. Cherrier, D.S. Dean and A. Lefèvre, **The number of metastable states in generalized random orthogonal model**, *J. Phys. A* **36**, 3935 (2003).

[47] D.S. Dean and A. Lefèvre, **A possible test of the thermodynamic approach to granular media**, *Phys. Rev. Lett.* **90**, 198301 (2003).

[48] D.S. Dean and R.R. Horgan, **Weak non-linear surface charging effects in electrolytic films**, *Phys. Rev. E* **68**, 051104 (2003).

[49] D.S. Dean and R.R. Horgan, **The field theoretic derivation of the contact value theorem and its modification by the Casimir effect**, *Phys. Rev. E* **68**, 061106 (2003).

[50] D.S. Dean I.T. Drummond and R.R. Horgan, **Effective diffusion constant in a two dimensional medium of charged point scatterers**, *J. Phys. A.* **37**, 2039 (2004).

[51] D.S. Dean and R.R. Horgan, **Field theoretic calculation of the surface tension for a model electrolyte system**, *Phys. Rev. E* **69**, 061603 (2004).

[52] D.S. Dean and A. Lefèvre, **Self diffusion in a system of interacting Langevin particles** *Phys. Rev. E* **69**, 061111 (2004).

[53] D.S. Dean and R.R. Horgan, **Ressummed two loop calculation of the disjoining pressure of a symmetric electrolyte soap film**, *Phys. Rev. E*, **70** 011101 (2004).

[54] D.S. Dean, I.T. Drummond, R.R. Horgan and A. Lefèvre, **Perturbation theory for the effective diffusion constant in a medium of random scatterers**, *J. Phys. A.* **37** 10459 (2004).

[55] D.S. Dean, D.J. Lancaster and S.N. Majumdar, **The statistical mechanics of traveling salesman type problems**, *J. Stat. Mech.* L01001 (2005).

[56] D.S. Dean, I.T. Drummond, R.R. Horgan and S.N. Majumdar, **Equilibrium statistics of a slave estimator in Langevin processes** *Phys. Rev. E.* **71**, 031103, (2004).

[57]D.S. Dean and R.R. Horgan, **The thermal Casimir effect in lipid bilayer tubules**, *Phys. Rev. E* **71**, 041907, (2005).

[58] D.S. Dean and R.R. Horgan, **The field theory of symmetrical layered electrolytic systems and the thermal Casimir effect**, *J. Phys. C.* **17**, 3473, (2005).

[59]D.S. Dean, D.. Lancaster and S.N. Majumdar, **The statistical mechanics of combinatorial optimization problems with site disorder**, *Phys. Rev. E* **72**, 026125 (2005)

[60] D.S. Dean and R.R. Horgan, **Renormalization of membrane rigidity by long-range interactions**, *Phys. Rev. E* **73** , 011906 (2006).

[61] D.S. Dean, C. Sire and J. Sopik, **Distance traveled by random walkers before absorption in a random medium**, *Phys. Rev. E* **73**, 066130 (2006).

[62] C. Sire, S. N. Majumdar and D. S. Dean, **Exact solution of a model of time-dependent evolutionary dynamics in a rugged fitness landscape**, *J. Stat. Mech.*, L07001 (2006).

[63] D.S. Dean and M. Manghi, **Fluctuation induced interactions bewteen lipid domains in membranes**, *Phys. Rev. E* **74**, 021916 (2006).

[64] D.S. Dean and D. Lancaster **The statistical mechanics of multi-index matching problems with site disorder**, *Phys. Rev. E* **74** 041122 (2006).

[65] D.S. Dean and S.N. Majumdar, **Phase Transition in a Generalized Eden Growth Model on a Tree** , *J. Stat. Phys.* **124** 1351 (2006).

[66] D.S. Dean and S.N. Majumdar, **Large Deviations of Extreme Eigenvalues of Random Matrices**, *Phys. Rev. Lett.* **97** 160201 (2006).

[67] C. Touya and D.S. Dean, **Dynamical transition for a particle in a squared Gaussian potential** , *J. Phys. A* **40** 919, (2007).

[68] C. Favard, D.S. Dean and M.-P. Rols, **Electrotransfer as a non viral method of gene delivery**, *Curr. Gene Ther* **7**, 67 (2007).

[69] A.J. Bray and D.S. Dean **The statistics of critical points of Gaussian fields on large dimensional spaces** Phys. Rev. Lett., **98** 150201 (2007).

[70] L.F. Cugliandolo, D.S.Dean and H. Yoshino, **Non-linear susceptibilities of spherical models**, *J. Phys. A* **40**, 4285 (2007).

[71] D.S.Dean, I.T. Drummond and R.R. Horgan, **Effective transport properties for diffusion in random media**, *J. Stat. Mech.* **7**, P07013 (2007).

[72] J.-M. Escoffre, D.S. Dean, M. Hubert M.-P. Rols and C. Favard, **Membrane perturbation by an external electric field: a mechanism to permit molecular uptake** , *Eur. Biophys. J.* **36**, 973 (2007).

[73] D.S. Dean and R.R. Horgan **Path integrals for stiff polymers applied to membrane physics**, *Phys. Rev. E.* **76**, 041102 (2007).

[74] D.S. Dean and D. Lancaster, **Fluctuations in the site disordered traveling salesman problem**, *J. Phys. A* **40**, 13837 (2007).

[75] D.S. Dean and S.N. Majumdar, **Extreme value statistics of eigenvalues of Gaussian random matrices**, *Phys. Rev. E* **77**, 041108 (2008)

[76] D.S. Dean and C. Touya, **Self similar renormalization group applied to diffusion in non-Gaussian potentials**, *J. Phys. A* **41**, 335002 (2008).

[77] T. Portet, F. Camps Febrer, J.-M Escoffre, C. Favard, M.-P. Rols and D.S. Dean, **Visualization of membrane loss during the shrinkage of giant vesicles under electropulsation**, *Biophys. J.* **96**, 4109 (2009). (2009).

[78] J.-M. Escoffre, T. Portet, L. Wasungu, J. Tessié, D. Dean and M.-P. Rols, **What is (still not) known of the mechanism by which electroporation mediates gene transfer and expression in cells and tissues**, *Mol. Biotechnol.* **41**, 286 (2009).

[79] D.S. Dean, **Thermal Casimir effect with soft boundary condtions**, *Phys. Rev. E* **79**, 011108 (2009).

[80] D.S. Dean, R.R. Horgan, A. Naji and R. Podgornik, **One-dimensional counterion gas between charged surfaces: Exact results compared with weak- and strong-coupling analysis**, *J. Chem. Phys.* **130**, 094504 (2009).

[81] D.S. Dean, R.R. Horgan, A. Naji and R. Podgornik, **The thermal Casimir effect between random layered dielectrics**, *Phys. Rev. A* **79**, 040101 (2009).

[82] D.S. Dean and A. Gopinathan, **The non-equilibrium behavior of pseudo-Casimir forces**, *J. Stat Mech* L08001 (2009).

[83] C. Touya, D.S. Dean and C. Sire, **Dipole diffusion in a random electric field**, *J. Phys. A.* **42**, 375001,(2009).

[84] D.S. Dean, R.R. Horgan, A. Naji and R. Podgornik,**The effects of dielectric disorder on van der Waals interactions in slab geometries**, *submitted to Phys. Rev. E* (2009).

[85] A. Naji, D.S. Dean, J. Sarabadani, R.R. Horgan and R. Podgornik, **Thermal Casimir–van der Waals interaction between randomly charged dielectrics**, *submitted to Phys. Rev. Lett.* (2009).

[86] J.-M. Escoffre, T. Portet, C. Favard, C. Rosazza, J. Teissié, D. S. Dean and M.-P. Rols, **Why electro-mediated gene delivery works**, *submitted to PNAS* (2009).

[87] D.S. Dean and A.J. Gopinathan, **Nonequilibrium thermal Casimir effect**, *submitted to Phys. Rev. E.* (2009).

ARTICLES IN BOOKS AND PROCEEDINGS

[P1] L. Salomé. F. Daumas, N. Destainville, C. Millot, A. Lopez and D.S. Dean, **Receptor diffusion restricted to domains without compartimentalization as determined by single particle tracking**, *Biophys J.* **82**, 194 (2002).

[P2] D.S. Dean and A. Lefèvre, **The steady state of the tapped Ising model**, in *Challenges in Granular Physics*, eds T. Halsey et A. Mehta, *World Scientific* (2003).

[P3] F. Daumas, N. Destainville, C. Millot, A. Lopez, D.S. Dean and L. Salomé **Interprotein interactions are responsible for the confined diffusion of a G-protein-coupled receptor at the cell surface**, Biochemical Society Transactions **31**, 1001 (2003).

[P4] D.S. Dean and A. Lefèvre, **A possible experimental test of the thermodynamic approach to granular media** dans *Unifying Concepts in Granular Media and Glasses*, eds M. Nicodemi et al, *Elsevier Science B.V.* (2004).

[P5] S.N. Majumdar, D.S. Dean and P.L. Krapivsky, **Understanding search trees via statistical physics** , in *Proceedings of the 22nd IUPAP International Conference of Statistical Physics (STAT PHYS 22) Pramana* (2005).

DESCRIPTION OF RESEARCH ACTIVITIES

My general area of research is statistical mechanics. I have worked on fundamental aspects of statistical mechanics, including its more mathematical aspects, but also on applications of statistical mechanics. To give an idea of the spectrum of my research, I have worked on methods of stochastic analysis applied to the evaluation of path integrals arising in polymer physics but also on the direct physical modeling of trans-membrane protein dynamics in biological membranes. To give an idea of the scope involved here, former work was published in Communications in Mathematical Physics while the latter was published in Biophysical Journal.

Out of equilibrium dynamics in disordered systems

Complex and disordered systems have very complex free energy landscapes due to their inherent frustration. At low temperatures, the dynamics of these systems becomes very slow and they may not reach equilibrium even over huge time scales. These systems often exhibit aging phenomena where the system always retains a memory of its age or its history of preparation. Correlation functions and response functions show a nontrivial dependence on the age t_w (the waiting time of the system). The simplest model of a disordered system is the random energy model (REM), where the system is made up of an ensemble of interconnected states α of energy E_α, one can imagine the states as all being at the ends of the branches of a tree with a common root. One can introduce a simple dynamics for the transitions between the states based on the Arrhenius law. Below a certain temperature the system shows aging dynamics. Mean field models of spin glasses however suggest a more complex hierarchical organization of states within states, which corresponds to further subtrees within branches. This models is called the generalized random energy model (GREM) . With J.-P. Bouchaud at Saclay I solved the dynamics of the GREM [6], this full solution along with a supplementary local fluctuation dissipation allowed us to successfully fit the thermo-remnant magnetization decay is spin glass experiments with a one step GREM. The solution to the dynamics is rather involved and used a probabilistic analysis. There has been much subsequent interest in this work and our results have been applied to other out of equilibrium spin glasses. The paper [6] has been cited over 180 times in the physics literature.

The GREM model is a phenomenological model and relies on a predefined phase space. With L.F. Cugliandolo I studied the dynamics of the $p = 2$ spherical spin glass model [10]. We completely solved the dynamics of this microscopic model in what was the most complete study of the out of equilibrium dynamics of a microscopic model to date. It was shown how generic initial conditions lead to an out of equilibrium regime and we determined the aging behavior of the correlation and response functions in this system. We were also able to study the effect of temperature cycling in this system and compare it to that seen in experiments on spin glasses. The $p = 2$ spin glass model corresponds to what is generically called a droplet model, which basically has two pure states (as is the case in a ferromagnet). This is at variance with the picture coming from other more generic mean field models which exhibit an exponentially (in the system size) large number of pure states. By comparison of our results with experiments we found that certain aspects of temperature cycling experiments were not reproduced by this simple model and the decay of the thermo-remnant magnetization was too rapid by comparison with the experimental data. In a subsequent work [12] I also showed how aging was killed off by the presence of an applied magnetic field and equilibrium dynamics is restored by the presence of this field. We also determined at what time scale the crossover between the aging and equilibrium dynamics occurs. A nice point about this work is that we found an interpretation for the disappearance of aging in terms of the geometry of the energy landscape of the model. The presence of the field destroys all the metastable states or local stationary points of the energy landscape and so the system efficiently finds its equilibrium state via simple gradient descent.

A physical system which often shows a glass transition is a colloidal suspension. In systems where hydrodynamic interactions are negligible, the dynamics can be modeled as a system of Brownian particles interacting via a pairwise potential. One thus has a system of coupled Langevin equations. In a similar vain to that which inspired density functional theory, one may pose the question as to whether the dynamics of the system can be encoded in a dynamics of the density field $\rho(x,t)$ of the particles. I showed that the answer to this question is affirmative [16] and the relevant equation is

$$\frac{\partial \rho(x,t)}{\partial t} = \nabla \cdot \left(\rho(x,t) \nabla \frac{\delta F}{\delta \rho(x)} |_{\rho(x,t)} \right) + \nabla \cdot \left(\eta(x,t) \rho^{\frac{1}{2}}(x,t) \right).$$

Here η is a vectorial spatial white noise field and F is formally the mean field free energy for the system. The above dynamical equation is however exact; my derivation used the Ito formulation of the stochastic calculus and there have subsequently been a number of alternative derivations. Interestingly the same equation had been proposed by Kawasaki some years before as a purely phenomenological one. The study of the above equation has become increasingly popular in recent years, notably in the chemistry and physics literature (where it is sometimes called the Dean-Kawasaki equation) as a starting point to understand the glass transition.

Thermodynamic approach to granular media

Complex systems such as granular media possess a large number of metastable or blocked configurations. A blocked state is one of mechanical equilibrium and once in this state the thermal energy is insufficient to allow the system to leave it, the system can be made to evolve via shaking stirring or tapping. When a granular medium is shaken it quickly relaxes into a blocked configuration, a subsequent shake or tap will lead it to another blocked or jammed state and so on. If the driving mechanism is held constant one expects the system to enter into a quasi-equilibrium stationary state. The classification and understanding of these steady states is clearly of great fundamental and industrial importance. Various driving mechanisms can be investigated experimentally, for instance vertical tapping and horizontal shaking. In granular media and other complex systems, such as spin glasses, the entropy of these blocked states is extensive in the system size, and hence it has been proposed by S.F. Edwards that one may use a thermodynamic measure over blocked states to describe this steady state. The simplest proposition is that the system is characterized by a number of quantities which are fixed on average and then the measure on the steady state is obtained by maximizing the entropy (on blocked states) with the relevant macroscopic quantities fixed. Even if it is not expected to be exact, many systems may be described to a good engineering level by these measures. Given the difficulty of the analysis of the highly nonlocal dynamics in these systems this is an important step toward understanding their steady state regimes. There is no clear ergodicity in these systems and no detailed balance as in usual statistical mechanics. Edwards argued that a system might conceivably explore blocked configurations in a flat manner if the driving involved extensive manipulations, meaning the displacement of a macroscopic number of particles, for example shaking, stirring or pouring granular media.

One of the problems with this thermodynamics approach is that the entropy of blocked states is extremely difficult to compute. With my PhD student A. Lefèvre we tested this thermodynamic approach on spin glass systems where one may compute either numerically or analytically the *Edwards entropy*. Indeed I had already made a number of contributions in the problem of computing the entropy of blocked states in spin glasses, notably in dilute mean field models where I introduced the computational technique [25, 28]. We introduced a tapping algorithm in spin glass systems in which, starting from a blocked state, one flips each spin with probability p. This is the simplest algorithm possible, in a spin system when one decreases p, the strength of tapping, the average energy decreases. Here energy plays the role of free volume in a granular system, when you gently tap a box of cornflakes the packing becomes more compact. We showed that the Edwards measure could predict certain macroscopic observables in tapped spin glass systems such as the correlation functions and energy fluctuations to a precision that would certainly be acceptable for engineering applications [29, 30]. Also we showed how the Edward's measure could be used to explain phase transitions in tapped spin systems, both their order and more qualitative aspects [38]. As mentioned above, its is often difficult or impossible to calculate the Edwards entropy in real systems, however we proposed an experimental test of a weak form of the Edwards measure that needs no knowledge of this entropy [47]. It is based on the comparison of free volume fluctuations in granular systems which are tapped at slightly different strengths. The idea is very simple, but very general, and a number of experimental groups are currently investigating its utility in real systems. We showed in our paper how this test works in a mean field spin glass model.

Computer science and optimization

The statistical mechanical approach to the study of optimization problems has lead to progress in a number of ways. The approach is based on identifying the cost function, which needs to be minimized, with the energy of a physical system whose phase space is equivalent to the free adjustable parameters in the optimization problem. The zero temperature energy of the resulting physical system thus corresponds to the optimal solution. This formulation can be exploited in two ways. First, physically motivated minimization techniques such as simulated annealing can be applied to optimization problems, often leading to near optimal solutions. Secondly the statistical mechanical approach can also be used to carry out computations of average or typical values of optimal solutions, where the non-adjustable parameters (describing the realization of the instance) in the system are taken to be quenched random variables. One of the most famous of these combinatorial problems is the traveling salesman problem (TSP). Here the problem is to find the minimal circuit length to visit N cities or points where the distance between the points i and j is given by d_{ij}. The order in which the cites are visited is encoded in a permutation $\sigma \in \Sigma_N$ where Σ_N is the group of permutations of N objects. For a given permutation

$$D(\sigma) = \sum_i d_{\sigma_i,\sigma_{i+1}}, \tag{1}$$

is the corresponding total distance traveled. When the d_{ij}s are chosen from some quenched distribution the problem is referred to as the stochastic TSP. The most natural form of the TSP is the Euclidean TSP where the cities are points $\mathbf{r}_1, \mathbf{r}_2 \cdots \mathbf{r}_N$ in some connected domain $\mathcal{D}$ and each point is independently distributed from the others with the same probability density function $p_q(\mathbf{r})$. With D. Lancaster and S.N. Majumdar I showed how statistical mechanical methods may be used to compute the average optimal solution for the Maximal TSP or taxi cab ripoff problem where one wants to find the longest path visiting each city in the Euclidean case. This method is a new, and does not use the replica method which is often applied in systems with quenched disorder, and relies upon the technique of functional integration [55,59,64,74]. At zero temperature the ground state energy corresponds to the length of the optimal path. An intriguing point about this technique is that the saddle point equations we derive at zero temperature are rather complex functional equations. However we found a way of solving them inspired by guessing the optimal local heuristic for finding the optimal path. The method therefore does not just give information about the statistics of the optimal path length but also it suggests how one should search for it.

The methods of statistical mechanics can also be applied to the analysis of storing and searching for data in computer science. One of the most popular and efficient ways of storing data is in a search tree. In an m-ary search tree the tree has a branching ration of m and each node contains up to $m-1$ data elements. For example, for $m = 3$ a full node at the root of the tree may contain the numbers 3 and 8. If the next number that arrives in a data string is the number 1. then it move to the daughter node to the left as it is less than 3 and 8. The number 5 will move to the middle node and the number 10 to the right node. In this way the search tree is built up. When the incoming data string is random the search tree so constructed is random and it is of practical interest to understand the statistical properties of these random search trees. For instance in an m-ary search tree we studied the number of nodes M needed to store a data string of N elements. With S.N. Majumdar I showed that there is a phase transition at $m = 26$, the statistics of M are Gaussian below $m = 26$ but become non Gaussian with long tails for $m > 26$. The way we solved the model was by mapping it to a statistical model of fragmentation similar to those arising in nuclear physics and statistical models of turbulence. We also showed how the same method can be applied to quad-trees and more general tree structures used to stock vectorial data. As well as discovering a new type of phase transition of interest to the physics community, this work has attracted the interest of theoretical computer scientists and the transition we discovered is called the Dean-Majumdar transition in their literature. We have also studied a one dimensional percolation model, the drop push model, which arises in problems of hashing and sorting in computer science, this model actually turns out to be in difference university class to ordinary one dimensional percolation [40].

Soft condensed matter and biophysics

For a number of years I have been interested in soft condensed matter physics and especially the application of quantum field theoretic techniques to systems where the dominant effects are electrostatic. One of the most fascinating phenomena occurring in these systems is when two objects of the same charge attract each other in the presence of an electrolyte. This is a very subtle effect due to ion-ion correlations and cannot be explained by traditional mean field theory. An example of this phenomena can be seen in certain soap films which can collapse to form very thin films called Newton Black Films despite the fact that the two surfaces have the same charge. I developed a mean field theory which explains many features of these films [17,20], notably their disjoining pressure and the surface tension of bulk solutions which was confirmed by experiments carried out at Saclay. I many cases the collapse can be explained by van der Waals forces. However I showed that in a one dimensional soap film model [19], which I solved exactly by path integral techniques, that electrostatics alone could produce an effective attractive interaction and thus a collapse. Subsequently with Ron Horgan I have developed a path integral based method to calculate the fluctuations about mean field theories in certain cases. This method can also be applied to the calculation of the Casimir like manifestation of van der Waals forces in systems with dielectric discontinuities. The existing method was an eigenfunction method but the advantage of our method is that it is mathematically more elegant and more simple to apply. Very recently we used this method to compute the renormalization of the bending rigidity for tubes of a given dielectric constant in a solvent with another dielectric constant [57, 58]. The result we obtained was at variance with that obtained nearly 20 years ago with the eigenfunction expansion method which in fact predicted an increase of the stiffness and a dependence on the geometry. Van der Waals forces are attractive, at least in the pairwise, approximation and thus one clearly expects a reduction in bending rigidity. The problem with the eigenfunction expansion can be traced back to its renormalization with respect to the vacuum which is very difficult in a non-Cartesian coordinate system. We found that though the rigidity is reduced that it cannot be responsible for the formation of t-tubules seen in mammal muscle cells. However in a very recent work [60] we showed that, generically, attractive long-range interactions reduce the bending rigidity but increase the Gaussian rigidity. Concretely, this means that attractive inter-membrane forces favor the formation of cylinders but oppose the formation of spheres. This may partly explain how t-tubules are stable against the formation of buds in biological systems. Our general results were also obtained taking into account finite membrane thickness and we showed how our calculation for the van der Waals renormalization of the bending rigidity could be reproduced in the pairwise limit - a crucial confirmation given the extreme complexity of our full n-body calculation.

The Casimir effect can be resumed as the force experienced between objects immersed in quantum or classical fields. The classic example is the force of attraction between two conductors due to their effect on the fluctuations of the electromagnetic field. Mathematically similar effects arise for boundaries or objects subjected to the thermal fluctuations of classical fields such as those describing classical systems near critical points, the director fluctuations in liquid crystals and the fluctuations of lipid membranes. We have studied the effective interactions between regions of lipid membranes of varying elasticity and bending rigidity. In [63] we showed that regions of differing mechanical properties (due to differing lipid types) could have attractive or repulsive interactions between them. This means that the nature of the phase transition in membranes formed from lipid mixtures could be drastically modified by membrane height fluctuations. A thermal Casimir effect between large stripes membrane regions of differing mechanical properties was demonstrated in

[73] (analogous to the interaction between dielectric slabs) and the Pauli-van Vleck method for quadratic actions was generalised to quadratic actions with arbitrary time derivatives. This technical advance is needed in the study of membrane fluctuations as the bending energy depends on the second derivative of the height profile. The resulting action thus, using a dynamical analogy, contains acceleration, and not just velocity, terms. As the thermal Casimir effect occurs in soft matter systems where relaxation times can be large a it makes sense to ask how the Casimir effect evolves as a function of time. The problem is how to compute the out of equilibrium force. In equilibrium many methods exist but no rigorous method was available out of equilibrium. To solve this problem we considered a formulation of the Casimir effect where the energy of interaction of the fluctuating field with the boundaries or objects placed in the field is specified [79]. The usual formulation with boundary conditions can then be obtained by taking the appropriate limit (for instance introducing a large mass for a scalar field theory on a plate suppresses the fluctuations of the field and in the infinite mass limit imposes Dirichlet boundary conditions). Using a path integral method we were able to study the effect of these soft boundary conditions on systems of two and even three parallel plates. In the case of soft boundary conditions wether or not the fluctuate exists outside the two external plates drastically affects the force on the central plate and can even change its sign. In [82], using this energetic boundary formalism, we were able to unambiguously compute the force on objects and surfaces in fluctuating fields even out of equilibrium for a very general class of dissipative dynamics giving the first fully justified expressions for the evolution of the thermal Casimir effect towards its equilibrium value.

Bulk transport properties of complex systems

It is always difficult for theoretical physicists to point out how their work has aided society in an economic or industrial way. Often the practical benefits are realized many years after the initial theoretical breakthrough. However one area where my work has some direct practical importance is in the area of transport properties of complex systems. As oil supplies become scarcer a way of prolonging them is by better understanding the physics behind the oil extraction from existing reservoirs. In some systems, where the reservoir can be seen as a porous medium containing oil, the basic phenomenological equation describing stationary flow is Darcy's law:

$$\mathbf{u} = \kappa(\mathbf{x})\nabla P,$$

where $\mathbf{u}$ is the velocity field of the fluid, P is the pressure and κ is called the permeability which is a measure of how porous the rock is. The above equation is supplemented by the condition

$$\nabla \cdot \mathbf{u} = 0,$$

which comes from the fact that the flow is incompressible. Darcy's law is a description of the physics of flow through the rock at a length scale which is larger than the size of the pores of the rock and presents a considerable simplification. Actually implementing Darcy's law in a real system is impractical from the computational point of view, passing from a semi-phenomenological law at the scale of centimeters to a reservoir at the scale of kilometers requires vast computing power. In addition one cannot determine the permeability or porosity of the reservoir everywhere. A basic idea which has existed in geology for some time is that of up-scaling where one starts from a statistical description of the local permeability field and then computes the average or typical transport properties at larger length scales. It is these length scales which are important for engineering applications. For these applications it is often sufficient to know what the effective permeability κ_e for the system is, this is defined by

$$\overline{\mathbf{u}} = \kappa_e \overline{\nabla} P$$

here the over-line corresponds to a spatial average on the scale of the system size. The question is how does one compute the transport coefficient κ_e ? Remarkably exactly the same mathematical, and indeed physical, problem, occurs in particle physics. In particle physics energy scales correspond to length scales (the higher the energy the shorter the length scale). The renormalization group, which was developed in the context of particle physics and statistical physics, tells us how the physical parameters of a theory change, or are *renormalized*, as a function of the length scale over which they are observed. I showed how this idea could be used to compute the transport properties of porous media such as oil reservoirs and ground water reservoirs. The method, as in particle physics, must be implemented perturbatively or in the context of an approximation scheme. However I have shown that this scheme in fact reproduces exact results in some cases where they can be obtained. This technique has been adopted in the hydrology and geology communities where we are credited with its introduction in the field. The example of flow in oil fields is perhaps not the most ecological one that can be given. Other examples are the study of how pollutants diffuse in ground-water and the dielectric and conductive properties of random systems. An example is the effective conductivity of an alloy composed from two metals. The important of this problem is exemplified by an existence in the scientific literature dating back to the time of Maxwell.

With my PhD student C. Touya, we have study the problem of the computation of the effective diffusion constant of a Brownian particle diffusing in a random potential which is given by a function $V(\phi)$ of a Gaussian field ϕ. These systems are of interest because they can exhibit dynamical phase transitions where the behaviour of a tracer particle crosses over from a diffusive to anomalous (sub-diffusive) regime. This is the case for a quadratic potential $V(\phi) = -\phi^2/2$ [67] (a problem arising naturally for the diffusion of dipoles in random electric fields. A self similar renormalization group analysis was applied to a mathematically related problem of the effective permeability of a random porous medium (where the local permeability is taken to be an arbitrary function of a Gaussian potential). From this approach the diffusion constant of a random potential problem can be extracted using a very general result [71] due to myself and collaborators in Cambridge (U.K.). This renormalization group approach reproduces practically all known exact results in one and two dimensions [76]. The results are confronted with numerical simulations and we find that their accuracy is good up to points well beyond the expected perturbative regime. The results obtained are also tentatively applied to interacting particle systems without disorder and we obtain expressions for the self-diffusion constant in terms of the excess thermodynamic entropy. This result is of a form that has commonly been used to fit the self diffusion constant in molecular dynamics simulations and virtually no theoretical explanation of this result existed.