Neutron Scattering Studies of Classical and Quantum Fluids in Porous Media DE-FG02-03ER46038 (ER46680)

Final Report
February 15, 2003 – November 15, 2016

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Executive Summary

This is the Final report on DE-FG02-03ER46038 (ER46680) which opened 15 February 2003 and closed 15 November 2016. The Principal Investigator is Henry R. Glyde, Department of Physics and Astronomy, University of Delaware, Newark, DE 19716 (email: glyde@udel.edu). The Administrative Point of Contact is Dale S. Weiss Tel: 302 831 3634 dsweiss@udel.edu. The DOE Program is the Office of Basic Energy Sciences, Program manager is Dr. P. Thiyagarajan, Neutron Scattering SC-22.2/ Germantown Bldg., <Thiyagarajan@Science.DOE.GOV>. The chief activity was conducting neutron scattering experiments to reveal the dynamics of quantum liquids confined to nanoscales. The confinement to nanoscales creates new physical quantum properties. Experiments were conducted at DOE supported national neutron facilities. The chief product is (1) scientific articles published in peer-reviewed scientific journals, (2) scientific papers presented at national and international conferences and (3) education of PhD graduate students by providing a research experience in neutron scattering. Fifty (50) scientific papers were published in peer-reviewed journals, (110) papers were presented at national or international conferences and 12 PhD graduate students were supported wholly or in part in the scientific topic of this award. This report summarizes the activity, the productivity, lists highlights, publications and conference presentations, graduate students and collaborators. At close a balance of $ 7,000 remained which will be returned to DOE.

Neutron Scattering Studies of Classical and Quantum Fluids in Porous Media

1 Introduction and Summary

This is the final report on DE-FG02-03ER46038 (ER46680) following a no cost extension of DE-FG02-03ER46038 from February 16, 2016 to November 15, 2016. The report period is 15 February, 2003 to 15 November, 2016. DE-FG02-03ER46038 (ER46680) was closed on November 15, 2016. The contract institution is the University of Delaware, address: Room 210, Hullihen Hall, University of Delaware, Newark, DE 19716. The Principal Investigator is Henry R. Glyde, Department of Physics and Astronomy, University of Delaware, Newark, DE 19716 (email: glyde@udel.edu). The Administrative Point of Contact is Dale S. Weiss Tel: 302 831 3634 dsweiss@udel.edu. The DOE Program is the Office of Basic Energy Sciences, U.S. Department of Energy, Germantown Building, 1000 Independence Ave., SW Washington, DC 20585. The program manager is Dr. P. Thiyagarajan, Neutron Scattering SC-22.2/ Germantown Bldg., Tel: 301-903-9706, email: P. Thiyagarajan@Science.DOE.GOV.

The chief scientific goal is to determine the structure and dynamics of classical and quantum systems both in bulk and confined in nanoporous media and on surfaces (two and one dimension). Neutron scattering experiments are conducted at the Spallation Neutron Source (SNS) at ORNL, at the Institut Laue Langevin (ILL), Grenoble, and at the ISIS Facility, Rutherford Appleton Laboratory, UK, all world class facilities. A second goal is to develop methods to better reveal and understand motional mean square displacements (MSD) and diffusion of hydrogen in proteins, in lipid membranes and in interfacial (hydration) water as observed with neutrons.

Most experiments are conducted within national and international collaborations. The neutron scattering data obtained is generally analyzed at the University of Delaware by the PI and participating graduate students. Some modeling and theoretical calculation are undertaken to support interpretation of data and to advance scientific understanding. The activity made possible by ER4660 is summarized in section 2.1. The scientific productivity in terms of scientific papers published, conference presentations given and graduate students involved is listed in section 2.2. Some scientific highlights of the project are presented in sections 2.3, recent highlights in 2.4. Community service to the American Physical Society (APS) and the Neutron Scattering Society of America (NSSA) is noted in section 3. The graduate students involved are identified in section 4. Collaborators are list in section 5. Expenditures and Cost Status is given in section 6. DOE funds are highly leveraged by neutron beam time, instrumentation, technical support and hospitality at neutron scattering facilities where experiments are conducted and some data analysis is conducted. The report closes with a list of publications and conference presentations.

2 Progress Report: 15 Feb 2003 to 15 Nov 2016

2.1 Activities

In this section we state the chief scientific activity of DOE funded research between the start date of 15 February, 15 2003 and the close date of 15 November 2016. The chief scientific activity

is conducting neutron scattering experiments to determine the dynamics of quantum liquids. The dynamics (e.g. collective phonon-roton modes), Bose-Einstein condensation (BEC) and the atomic momentum distributions of quantum liquids (and solids) are uniquely observed using neutron scattering measurements. Neutron scattering is the only technique available to observe these fundamental properties of quantum fluids.

Many of the measurements were made at DOE supported neutron scattering facilities, such as the spallation Neutron Source (SNS) at Oak Ridge National lab (ORNL). Measurements were also made at international facilities. The chief goal was: (1) accurate determination of the Bose-Einstein condensate fraction in liquid ^{4}He, of the shape of the atomic momentum distribution and of the phonon-roton modes as a function pressure and temperature and (2) revealing and exploring these properties for the first time in nanoscale quantum liquids in disorder. The nanoscale quantum liquids are created when the liquid is confined to nanoporous media such as aerogels, MCM-41 and FSM-16. In project (2) we have revealed the interdependence of BEC, well defined modes and superfluidity at nanoscales. Quantum solids were also investigated since superfluidity in the solid was reported and possible supersolidity in soild helium was investigated for some years, but subsequently withdrawn. Some measurements on semiclassical liquids were also made. This project began on 15 February 2003 and continued until closing on November 15, 2016..

In 2010, the PI initiated a new research program in biophysics also related to neutron scattering. The motional dynamics of proteins, particularly of hydrogen (H) in proteins, has been and continues to be extensively investigated using neutron scattering methods. The goal is to develop improved methods to analyze neutron scattering measurements of the dynamics of proteins, methods that also apply to other soft matter. The goal was to extract more precise and well-defined information on the dynamics. It is also to extract more complete dynamical information such as the distribution of motional displacements in the proteins from existing measurements and molecular dynamics simulations. Much of this work, particularly the MD simulations, was done in collaboration with scientists at ORNL.

Both of these DOE funded research projects are continuing beyond the end date, 15 November 2016, of DOE grant.

2.2 Productivity

The productivity or deliverable of the project is chiefly (1) scientific publication in peer-reviewed scientific journals and (2) scientific and technical papers presented at conferences. Another goal is to (2) support graduate students to develop the scientific community, particularly the community that uses facilities at DOE supported labs. To demonstrate productivity, we provide:

(1) A list of scientific publications and conference presentations below in section . Between 15 February 2003 and 15 November 2016 ? scientific papers were published in peer-reviewed journals. These journals include the most prestigious journals such as Physical Review Letters, Nature, Physical Review, Euro Physics Letters and many others. In this perioid, scientific papers were presented at conferences, at national laboratories and at universities. The conferences include the American Physical Society Annual Meeting, the American Conference on Neutron Scattering, the European Conference on Neutron Scattering, European Physical Society Meetings, the International conference on Quantum Fluids and Solids, the Spallation neutron source, the ISIS Facility, Rutherford Appleton lab., UK, Institut Laue-Langevin, France, the US-China Workshop on Neutron Scattering, Pekin and many others.

(2) A list of graduate students supported during this period appears below in section ?. Some of these students received a Ph D in this DOE support research program. Others were supported for shorter periods, obtained a research experience in neutron scattering and received their PhD in other topics.

2.3 Scientific Highlights

Since 2003, highlights of this DOE-supported research are:

1. New high precision measurements of the Bose-Einstein condensate fraction and the atomic momentum distribution in quantum liquids have been made. The condensate fraction is smaller than previously believed, especially in the liquid under higher pressure near the solidification pressure. The temperature dependence of the condensate fraction depends on pressure. These measurements provide benchmark data and test fundamental theory of quantum fluids.

2. Measurements of BEC in liquid ^{4}He at nanoscales confined in porous media have been made. These show that BEC exists at temperatures above the superfluid phase (BEC but no superflow) in disorder.

3. Well-defined phonon-roton collective modes in liquid ^{4}He exist when there is BEC, but do not when there is no BEC. When the liquid is in disorder, well-defined modes and BEC can exist together at temperatures above the superfluid phase.

4. We have observed phonon-roton modes in the liquid at high pressure (above the bulk freezing pressure) and at negative pressures in liquid 4he. The liquid phase can be extended to higher pressures and to negative pressures when it is confined to nanoscales in porous media.

5. In solid helium, we showed that the condensate fraction was unobservable, much smaller than that in the liquid, suggesting no superflow in the solid. Other test using neutrons were made.

6. Developed methods to extract the intrinsic (long time) atomic mean square displacements in proteins and the distribution of displacements from neutron scattering experiments. Recent Highlights

2.4 Recent Scientific Highlights

(1) A comprehensive review of measurements of the elementary excitations of liquid ^{4}He made in the past 25 years and their interpretation has been 2016-7. Previous reviews and books appeared in the early 1990s. The review considers both collective excitations at low energy and long wavelength and single particle excitations at high energy and short wavelength from which Bose-Einstein condensation can be observed. These measurements are made using neutron scattering techniques, many at DOE supported facilities. The review (45 journal pages) includes advances made in the theory and understanding of these excitations as well as their implications for other dramatic phenomena of quantum liquids such as superfluidity. Many of the measurements were made by the PI and his collaborators, measurements made with the support of Office of Basic Energy Sciences, under contract DE-FG02-03ER46038. In this sense the review reports the scientific advances in quantum liquids made possible with the support of the DOE at DOE facilities.

The review was solicited by the scientific journal *Reports of Progress in Physics* (Impact factor 15). The review was submitted to *Rep. Prog. Phys.* mid January 2017. The front page of the review is reproduced below.

Excitations in Quantum Liquids

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Progress made in measuring and interpreting the elementary excitations of superfluid and normal liquid ^{4}He in the past 25 years is reviewed. The goal is to bring up to date the data, calculations and our understanding of the excitations since the books and reviews of the early 1990s. Only bulk liquid ^{4}He is considered. Reference to liquid ^{3}He, mixtures, reduced dimensions (films and confined helium) is made where useful to enhance interpretation. The focus is on the excitations as measured by inelastic neutron scattering methods. The unique collective excitations at low energy and long wavelength (e.g. P-Rmodes) as well as single particle response at high energy from which the atomic momentum distribution and Bose-Einstein condensate fraction are determined are reviewed. A goal is to show the interplay of these excitations with other spectacular properties such as superfluidity and the test of fundamental calculations of quantum liquids that is possible. The role of Bose-Einstein condensation in determining the nature of the P-R mode and particularly it's temperature dependence is emphasized. The similarity of normal liquid ^{4}He with other quantum and classical liquids is discussed.

1. INTRODUCTION

A. In the beginning and why liquid ^{4}He

Helium was first liquefied by H. Kamerlingh Onnes (1908) in Leiden. With this breakthrough, liquid ^{4}He became the most accessible quantum fluid in nature for the study of the fundamental properties of Bose quantum fluids. Liquid ^{4}He and ^{3}He remain today the most accessible strongly interacting quantum fluids partnered with the trapped cold gases as the most accessible dilute quantum fluids. Access to liquid ^{4}He also opened low temperature physics. Using liquid ^{4}He as a cryogenic fluid, it became possible to cool materials to low temperatures. For example, Kamerlingh Onnes (1911)

key goal. As discussed particularly by Leg
a fundamental understanding of superfluid
^{3}He and ^{4}He and superconductivity can be
parallel beginning with BEC and phase coh

Liquid ^{4}He also serves as a unique labor
plore other fundamental science, such as co
low energy particle physics (Baym *et al.*,
Dubbers and Schmidt, 2011; Grigoriev *et al.*,
cold neutrons (Golub *et al.*, 1991) and the
dark matter (Schutz and Zurek, 2016). Su
ation of ultra cold neutrons and detection of
requires a precise knowledge of the dynami
of liquid ^{4}He (Schmidt-Wellenburg *et al.*, 2
and Zurek, 2016).

The collective P-R response, the single

(2) As a second recent highlight, we show the abstract of a paper on proteins soon to be submitted to Physical Review E. The paper proposes a method to obtain the distribution of motional mean square displacements of atoms in proteins from neutron scattering measurements. Using existing analysis methods, only the average MSD,(averaged over all constituents) is obtained. The abstract is reproduced below.

Motional displacements in proteins: dynamical heterogeneity

Derya Vural,[1] Jeremy C. Smith,[2] and Henry R. Glyde[1]
[1]*Department of Physics and Astronomy, University of Delaware, Newark, Delaware 19716-2570, USA*
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(Dated: June 24, 2016)

The average mean square displacement (MSD), $\langle r^2 \rangle$, of hydrogen H in proteins is measured using incoherent neutron scattering methods. The observed MSD shows a marked increase in magnitude at a temperature $T_D \simeq 240$ K. This is widely interpreted as a dynamical transition to large MSDs which make function possible in proteins. However, when the data is interpreted in terms of a single averaged MSD, the extracted $\langle r^2 \rangle$ depends on the neutron momentum transfer, $\hbar Q$, used in the measurement. We have shown recently that this apparent dependence on Q arises because the dynamical diversity of the H in the protein is neglected [1]. We present models of the dynamical diversity of H in Lysosyme that when used in the analysis of simulated neutron data lead to consistent, Q independent values for the average MSD and for the diversity model.

2.4.1 Recent and active neutron scattering experiments

Some recent and future neutron scattering experiments at major neutron scattering facilities are:

1. Institut Laue Langevin: Experiment ILL: 8-02-759 Instrument D16 Oct/2016
Title: Studying transmembrane diffusion of water molecules through 2-dimensional diffusion maps.

2. Spallation Neutron Source: Experiment IPTS-16830.1 Instrument ARCS Oct/2016
Title: Bose-Einstein Condensation in Liquid ^{4}He at Negative Pressures.

3. Institut Laue Langevin: Experiment ILL: 6-01-33 Instrument IN5 from 23/02/2017 to 28/02/2017
Title: Bose-Einstein Condensation, Superflow and Excitations of liquid ^{4}He in Nanoporous FSM-16.

3 Service, Outreach and Awards

During the period 2003-2016, the PI served in various capacities to support the Physics and Neutron Scattering community and received recognition. Examples are:
1. Author (Chair) of the report: Access to Major International X-Ray and Neutron Facilities, an American Physical Society (APS) report endorsed by the Neutron Scattering Society of America (NSSA) (2009). See report on website: http://www.aps.org/programs/international/resources/facilities.cfm
2. 2004 Chair, Committee on International scientific Affairs, APS.
3. 2003 Chair, Forum for International Physics, APS.
4. 2005 Member, CNRS/CEA Assessment Committee of the Laboratoire Louis Brillouin, Paris.
5. 2010-13, Served on the Proposal Review Committee (sometimes as chair) at the SNS.
6. Frequent Long term collaborator at the Institut Laue Langevin, Grenoble, France.
7. Served on selection committees for NSSA.
8. 2010 Selected as an Outstanding Referee by the APS Journals, 2010.
9. 2012 Received award for Outstanding Service to NSSA.
10. 2014 Elected Fellow of NSSA.

4 Graduate Students Supported

Graduate students in two categories were supported in this project: (1) graduate students who received their PhD in this research program, (2) graduate students who received their PhD in other topics but worked in this project analyzing neutron scattering data, doing associated computations, preparing figures and text for publications or scientific presentations. The students in these categories are: (1) Jonathan L. DuBois, Ali A. SHAMS PhD, Asaad R. SAKHEL PhD, Soulymane O. Diallo, PhD, Derya VURAL PhD and (2) Keith BUTLER, Seth MEISELMAN, Alparsian SARI, Sameer WADAONKAR, Songjie WEI, Ertugrul YILMAZ, and Z. ZUHRIANDA.

5 Research Collaborators

In neutron scattering experiments at high neutron energy transfer from which BEC and momentum distributions are observed done at SNS (ORNL) and at the ISIS Facility, UK, my chief

collaborators are: Souleymane Omar Diallo (Delaware, SNS), Richard T. Azuah (NIST), Douglas Atherton (SNS), Norbert Mulders (Delaware), John Larese (SNS, Tennesse), Jon Taylor (ISIS) and Oleg Kirichek (ISIS), Mark Adams (ISIS), and R. Rota and J. Boronat (Barcelona). In experiments to observe collective excitations at the Insitiut Laue Langevin, my chief collaborators are Jacques Bossy (CNRS), Jacques Ollivier (ILL), Helmut Schober (ILL), Mark Johnson (ILL), T. Hansen (ILL), Jon Pearce (NPL,UK) and Oscar Vilches (UWashington).

In the analysis of nanoscale quantum liquids data and Diffusion Monte Carlo and path integral Monte Carlo (PIMC) calcuations of superfluidity and Bose-Einstein Condensation in liquid ^{4}He confined in nanopores and in Bose Gases, my chief collaborators are J. L. BuBois (LLNL), A. A. Shams, L. Vranješ Markić (University of Split) and Z. Zuhrianda (Delaware).

In the analysis of neutron scattering experiments on proteins and the simulations of proteins my chief collaborators are Derya Vural (Delaware, ORNL), Liang Hong and Jeremy Smith at the Center for Molecular Biophysics at ORNL. Particularly, all simulations of proteins to date were done by Derya Vural using computing facilities at ORNL. Dr. Vural has recently returned to Turkey, Liang Hong to China but we continue to collaborate. Experiments are done in a collaboration involving MacMaster University (Canada), Insitiut Laue langevin and the ISIS Facility, Laura Toppozini, Felix Roosen-Runge, Robert Bewley, Robert Dalgliesh, Toby Perring, Tilo Seydel, Henry R. Glyde, Victoria Garcia-Sakai, and Maikel C. Rheinstadter.

6 Expenditures and Cost Status

The chief expenditures are summer salary for the PI and stipends and operations support for graduate students. There is purchase of and fabrication of porous media samples. Some sample cells and minor equipment are also constructed at the University of Delaware. There are travel costs to conduct experiments at major neutron facilities and to attend national and international scientific meetings. All these funds are very highly leveraged by support from national and international neutron facilities which fund experiments on a competitive proposal basis and provide essential technical support and often significant major (e.g. low temperature) equipment support for experiments. There was approximately $ 7,000 remaining in DE-FG02-03ER46038 on November 15, 2016 which will be returned to DOE.

LIST OF PUBLICATIONS: Henry R. GLYDE (2003-2015)

1. MOTIONAL DISPLACEMENTS IN PROTEINS: DYNAMICAL HETEROGENIETY. D. Vural and L. Hong, J. C. Smith and H. R. Glyde *Phys. Rev. E* (to be submitted February 2017).

2. EXCITATIONS IN QUANTUM LIQUIDS. H. R. Glyde. *Rep. Prog. Phys.* (submitted January 2017).

3. SUPERFLUIDITY, BEC AND DIMENSIONS OF LIQUID ^{4}HE IN NANOPORES. L. Vranješ Markić and H. R. Glyde. *Phys. Rev. B* **92**, 064510 (2015).

4. ANOMALOUS AND ANISOTROPIC NANOSCALE DIFFUSION OF HYDRATION WATER MOLECULES IN FLUID LIPID MEMBRANES. Laura Toppozini, Felix Roosen-

Runge, Robert Bewley, Robert Dalgliesh, Toby Perring, Tilo Seydel, Henry R. Glyde, Victoria Garcia-Sakai, and Maikel C. Rheinstadter. *Soft Matter* **11**, 8354 (2015). DOI: 10.1039/C5SM01713K.

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45. EXCITATIONS AND BOSE-EINSTEIN CONDENSATION IN SUPERFLUID ^{4}He. A. R. Sakhel and H. R. Glyde. *Phys. Rev. B* **70**, 144511 (2004).

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47. ENHANCED BOSE-EINSTEIN CONDENSATION AND KINETIC ENERGY OF LIQUID ^{4}He NEAR A FREE SURFACE. J. V. Pearce, S. O. Diallo, H. R. Glyde, R. T. Azuah, T. Arnold, and J. Z. Larese. *J. Phys. Condens. Matter* **16**, 4391 (2004).

48. EXCITATIONS OF LIQUID ^{4}He IN DISORDER AND BOSON LOCALIZATION. F. Albergamo, H. R. Glyde, D. R. Daughton, N. Mulders, J. Bossy, and H. Schober. *Phys. Rev. B* **69**, 014514 (2004).

49. NATURAL ORBITALS AND BEC IN TRAPS, A DIFFUSION MONTE CARLO ANALYSIS, J.L. DuBois and H.R. Glyde, *Phys. Rev. A* **68**, 3602 (2003).

50. ELEMENTARY EXCITATIONS IN LIQUID ^{4}He CONFINED IN MCM-41. F. Albergamo, J. Bossy, H.R. Glyde and A.-J. Dianoux. *Phys. Rev. B* **67**, 224506 (2003).

51. DYNAMICS OF QUANTUM LIQUIDS IN CONFINEMENT, THEORY AND EXPERIMENT. H.R. Glyde, F. Albergamo, R.T. Azuah, J. Bossy and B. Fåk. *Eur. Phys. J. E.* **12**, 63 (2003).

52. BOSE-EINSTEIN CONDENSATE IN TRAPS: A DIFFUSION MONTE CARLO ANALYSIS. J.L. DuBois and H.R. Glyde. in "Condensed Matter Theories," Vol. 26, xxxx (Nova Science Publishers, 2003).

53. BOSE-EINSTEIN CONDENSATION IN LIQUID ^{4} He IN VYCOR. R.T. Azuah, H.R. Glyde, R. Scherm, N. Mulders, and B. Fåk. *J. Low Temp. Phys.* **130**, 557 (2003).

PRESENTATIONS: HENRY R. GLYDE 2003-2016

INVITED TALKS: 2003-2016 Henry R. GLYDE

1. *Motional Displacements in Proteins*
   Seminar, University of Split,
   Split, Croatia — July 2016

2. *Superfluidity in Confined Liquid Helium*
   Seminar, University of Split
   Split, Croatia — July 2016

3. *Landau and BEC Theories of Superfluidity have a Common Physical Origin*
   International Conference on Quantum Fluids and Solids 2015
   Niagara Falls, New York — August 2015

4. *Superfluidity, Bose-Einstein Condensation and Phonon-roton modes of Liquid 4He confined in Nanopores.*
   Seminar, Centre National de la Recherche Scientifique
   Grenoble, France January 2015

5. *Bose-Einstein Condensation, Superfluidity and Elementary Excitations in Quantum Liquids*
   Seminar, University of Birmingham
   Birmingham, United Kingdom November 2014

6. *Neutron Scattering Studies of Classical and Quantum Fluids in Nanoporous Media*
   Neutron Scattering Principal Investigators Meeting, BES, DOE
   Gaithersburg, Maryland July 2014

7. *Bose-Einstein Condensation, Superfluidity and Elementary Excitations in Quantum Liquids*
   Seminar, Chulalongkorn University
   Bangkok, Thailand January 2014

8. *Toward Determining Intrinsic Mean Square Motional Displacements in Proteins*
   Seminar, JINS, Oak Ridge National Laboratory
   Oak Ridge, Tennessee December 2013

9. *Bose-Einstein Condensation, Superfluidity and Elementary Excitations in Quantum Liquids*
   Seminar, ISIS Facility, Rutherford Appleton Laboratory
   Didcot, Oxfordshire, UK September 2013

10. *Intrinsic Mean Square Displacements in Proteins from Simulations*
    Seminar, Institut Laue Langevin
    Grenoble, France June 2013

11. *Intrinsic Mean Square Displacements in Proteins*
    Seminar, JINS, Oak Ridge National Laboratory
    Oak Ridge, Tennessee April 2013

12. *Bose-Einstein Condensation, Phonon-roton excitations and Superfluidity in liquid 4He in Nanoporous Media*
    Neutron Scattering Principal Investigators Meeting, BES, DOE
    Gaithersburg, Maryland July 2012

13. *Intrinsic Mean Square Displacements in Proteins*
    Seminar, Institut Laue Langevin
    Grenoble, France July 2012

14. *Mean Square Displacements in Proteins*
    Seminar, Oak Ridge National Laboratory
    Oak Ridge, Tennessee October 2011

15. *The Role of Neutrons in Liquid and Solid Helium: Recent Achievements and Future Opportunities*
    Seminar, Oak Ridge National Laboratory
    Oak Ridge, Tennessee October 2011

16. *Localized Bose-Einstein Condensation in Liquid Helium Porous Media*
European Conference on Neutron Scattering
Prague, Czech Republic July 2011

17. *Bose-Einstein Condensation and Superfluidity Investigated Using High Energy Neutrons*
UK-Italy Workshop, High energy Neutrons for Science and Society
Rome, Italy October 2010

18. *Bose-Einstein Condensation and Superfluidity in Liquid and Solid Helium*
Colloquium, Hunter college, CUNY
New York City, NY October 2010

19. *Bose-Einstein Condensation, phonon-roton modes and the Bose Glass phase of liquid 4He in porous media*
International Conference on Quantum Fluids and Solids
Grenoble, France, August 2010

20. *Bose-Einstein Condensation, Phonon-roton excitations and Superfluidity in liquid 4He in Nanoporus Media*
Neutron Scattering Contractors Meeting
Airlie, Warrenton, VI, July 2010

21. *Access to Major International X-Ray and Neutron Facilities*
Plenary Talk
European Research Facilities Conference on:Future Access to European Research Infrastructures.
Lund, Sweden October 2009
http://www.europeanresearchfacilities.eu/IMG/pdf/HGlyde.pdf.

22. *Vibrational Dynamics of Atoms in Proteins*
Institut Laue Langevin, Seminar
Grenoble, France October, 2009

23. *Bosons in Disorder and Superflow in Solid Helium*
Institut Laue Langevin and CNRS, Seminar
Grenoble, France June, 2009

24. *Phonon-Roton Modes, Superfluidity and a Bose Glass Phase in Nanoscale Liquid ^4He*
Indiana University, Seminar
Bloomington, Indiana December 2008

25. *Phonon-Roton Modes and a Bose Glass Phase in Nanoscale Liquid ^4He*
Ecole Normale Supérieure de Lyon, Seminar
Lyon, France July 2008

26. *Access to Major International X-Ray and Neutron Facilities*
American conference on Neutron Scattering
Santa Fe, New Mexico May 2008

27. *Phonon-roton excitations and quantum phase transitions in liquid ^4He in nanoporous media*
Institut Laue Langevin, Seminar
Grenoble, France January, 2008

28. *Superfluids in Confinement*
International Workshop on Advances in the Properties of Confined Fluids: from Superfluids to Oil
Abingdon, UK January, 2008

29. *Dynamics and superfluidity of quantum liquids in nano-porous media*
Invited but declined
International Workshop on Condensed Matter Theories 31
Bangkok, Thailand December, 2007

30. *Excitations and Quantum Phase Transitions in nanoporous media*
Invited but declined
International Symposium on New Quantum Phases in Superclean Materials
Gifu, Japan October 2007

31. *Bose-Einstein Condensation, Superfluidity and Elementary Excitations in Quantum Liquids*
Recent Progress in Many Body Theories 14
Barcelona, Spain July 2007

32. *Access to Major International X-Ray and Neutron Facilities*
International Union of Pure and Applied Physics Meeting
National Academy of Sciences, Washington DC June 2007

33. *Dynamics and superfluidity of quantum liquids in nanoporous media*
US-China Workshop on Neutron Scattering
Beijing, China November, 2006

34. *Dynamics and superfluidity of quantum liquids in nanoporous media*
Institute of Physics, Chinese Academy of Sciences, Beijing, China
Beijing, China November, 2006

35. *Bose-Einstein Condensation, Superfluidity and Elementary Excitations in Quantum Liquids*,
University of Alberta, Colloquium
Edmonton, Canada October 2006

36. *Excitations and Quantum Phase Transitions in nanoporous media*
Henry R. Glyde, J. V. Pearce, J. Bossy and H. Schober
Quantum Fluids and Solids Symposium
Kyoto, Japan August 2006

37. *Anharmonic solids and quantum liquids*
Symposium for Roger A. Cowley, Oxford University
Oxford, England July 2006

38. *Experiments on the origin of superfluidity, liquid helium at nanoscales*
Institut Laue Langevin, Seminar
Grenoble, France May 2006

39. *Dynamics of quantum liquids in nanoporous media*
International Symposium on Dynamics in Confinement
Institut Laue Langevin
Grenoble, France March 2006

40. *Excitations, Bose-Einstein Condensation and superfluidity of quantum liquids in disorder*
23^{rd} International conference of the Turkish Physical Society
Mugla, Turkey September 2005

41. *Quantum liquids in nanoporous media and on surfaces*
National Nanotechnology Initiative Workshop on X-rays and Neutrons
Washington DC June 2005

42. *Excitations, Bose-Einstein Condensation and superfluidity of quantum liquids in disorder*
Pennsylvania State University, Seminar
State College, Pennsylvania April 2005

43. *Bose-Einstein Condensation, Excitations and Superfluidity of Liquid ^{4}He in Disorder*
Institut Laue Langevin, Seminar
Grenoble, France June 2004

44. *Dynamics of Quantum Liquids in Disorder*
International Conference on Dynamics of Disordered Materials on a Nanometer Scale
Hanoi, Vietnam February 2004

45. *Bose-Einstein Condensation, Excitations and Superfluidity of Liquid ^{4}He in Disorder*
Chulalongkorn University, Seminar
Bangkok, Thailand February 2004

46. *Diffusion Monte Carlo Study of Trapped Bose Condensates, Effects beyond the Mean Field*
Bose-Einstein Condensation Euroconference
San Feliu de Gixois, Spain September 2003

47. *Excitations, Bose-Einstein Condensation and superfluidity in Liquid ^{4}He in Disorder*
Canadian Association of Physicists Annual Congress
Charlottetown, PEI, Canada June 2003

48. *Dynamics of Quantum Liquids in Confinement, Theory and Experiment*
Dynamics in Confinement, Second International Workshop
ILL, Grenoble, France January 2003

CONTRIBUTED TALKS: 2000-2016 Henry R. GLYDE

1. *Superfluidity, BEC and Dimensions of Liquid ^{4}He in Nanopores*
   Talk, American Physical Society March Meeting
   Baltimore, Maryland — March 2016

2. *Motional Displacements in Proteins Incorporating Dynamical Diversity*
   Talk, American Physical Society March Meeting
   Balimore, Maryland — March 2016

3. *Superfluidity and Bose-Einstein condensation in liquid 4he in nanopores*
   Talk, Int. Workshop on Equations of state in quantum many-body systems
   Trento, Italy — May 2016

4. *Localized Bose-Einstein condensation in disordered liquid ^{4}He films*
   Poster, Quantum Fluids and Solids 2015
   Niagara Falls, New York — August 2015

5. *Superfluidity and BEC in porous media*
   Talk, Workshop on Probing and Understanding Exotic Superconductors and Superfluids
   International Centre for Theoretical Physics (ICTP), Trieste, Italy — November 2014

6. *Extracting Q Independent Motional Displacements in Proteins from Experiment*
   Poster, American Conference on Neutron Scattering
   Knoxville, Tennessee — June 2014

7. *Localized Bose-Einstein Condensation in Films of Liquid ^{4}He in Disorder*
   Talk, American Conference on Neutron Scattering
   Knoxville, Tennessee — June 2014

8. *Long-time Intrinsic Mean Square Displacements in Proteins*
   Talk, American Conference on Neutron Scattering
   Knoxville, Tennessee — June 2014

9. *Why the observed Mean Square Motional Displacements depend on Wave Vector Q*
   Talk, American Physical Society
   Denver, Colorado — March 2014

10. *Localized Bose-Einstein Condensation in Films of Liquid ^{4}He in Disorder*
    Talk, American Physical Society
    Denver, Colorado — March 2014

11. *Localized Bose-Einstein Condensation in Liquid ^{4}He in Disorder*
    Talk, American Physical Society
    Denver, Colorado — March 2014

12. *Why Observed Mean Square Displacements in Proteins are Q Dependent*
    Poster, Neutrons in Biology and Biotechnology
    Grenoble, France — February 2014

13. *Intrinsic Mean Square Displacements in Proteins*
    Talk, neutrons in Biology and Biotechnology
    Grenoble, France February 2014

14. *Phonon-roton modes of liquid He beyond the roton in MCM-41*
    Poster, International Conference on Neutron Scattering 2013
    Edinburgh, Scotland July 2013

15. *Phonon-roton modes and boson localization in disordered liquid ^4He*
    Poster, International Conference on Neutron Scattering 2013
    Edinburgh, Scotland July 2013

16. *Intrinsic mean square displacements in proteins*
    Poster, International Conference on Neutron Scattering 2013
    Edinburgh, Scotland July 2013

17. *Excitations of amorphous solid helium*
    Talk, American Physical Society
    Baltimore, Maryland March 2013

18. *Phonon-Roton Modes in Liquid ^4He coexist with Bose-Einstein Condensation*
    Talk, American Physical Society
    Balimore, Maryland March 2013

19. *Intrinsic mean square displacements in proteins*
    Talk, American Physical Society
    Balimore, Maryland March 2013

20. *Bose-Einstein condensation in liquid ^4He under pressure*
    Poster, Quantum Fluids and Solids 2012
    Lancaster, England August 2012

21. *Phonon-roton modes and Bose-Einstein condensation in liquid ^4He*
    Poster, Quantum Fluids and Solids 2012
    Lancaster, England August 2012

22. *Modes of amorphous solid helium*
    Poster, Quantum Fluids and Solids 2012
    Lancaster, England August 2012

23. *Bose-Einstein Condensation in Liquid 4He near the Liquid-solid Transition Line*
    Talk, American Conference on Neutron Scattering
    Washington, DC June 2012

24. *Excitations of amorphous solid helium*
    Poster, American Conference on Neutron Scattering
    Washington, DC June 2012

25. *Intrinsic Mean Square Displacement in Proteins*
Poster, American Conference on Neutron Scattering
Washington, DC June 2012

26. *Intrinsic Mean Square Displacement in Proteins*
Talk, American Physical Society
Boston, Mass March 2012

27. *Mean Square Displacements of Hydrogen in Proteins Observed by Neutrons*
European Conference on Neutron Scattering
Prague, Czech Republic July 2011

28. *Bose-Einstein Condensation in Liquid Helium under Pressure*
European Conference on Neutron Scattering
Prague, Czech Republic July 2011

29. *Intrinsic Mean Square Displacements in Proteins*
American Physical Society Meeting
Dallas, TX March 2011

30. *Amorphous Solid Helium in Porous Media*
Supersolids Paris 2010
Paris, France, July 2010

31. *Bose-Einstein Condensation in Liquid Helium under Pressure*
American Conference on Neutron Scattering
Ottawa, Canada, June 2010

32. *Vibrational Dynamics of Atoms in Proteins*
American Conference on Neutron Scattering
Ottawa, Canada, June 2010

33. *Amorphous solid helium in porous media*
American Physical Society Meeting
Portland, OR March 2010

34. *Vibrational Dynamics of Atoms in Proteins*
American Physical Society Meeting
Portland, OR March 2010

35. *Bose-Einstein Condensation in Confined Solid Helium*
Supersolids Banff, 2009
Banff, Alberta, August 2009

36. *Amorphous Solid Helium in Porous Media*
Supersolids Banff, 2009
Banff, Alberta, August 2009

37. *Bose-Einstein Condensation in Solid Helium*
ICNS09, International Conference on Neutron Scattering
Knoxville, TN, May 2009

38. *Bose Glass Phase in Nanoscale Liquid Helium*
ICNS09, International Conference on Neutron Scattering
Knoxville, TN, May 2009

39. *Phonon-roton modes, Superfluidity and a Bose Glass Phase in Nanoscale Liquid ^4He*
American Physical Society Meeting
Pittsburgh, PA March 2009

40. *Bose-Einstein Condensation in Solid Helium*
American Physical Society Meeting
Pittsburgh, PA March 2009

41. *Quantum Phase Transition and a Bose Glass Phase in Nanoscale Liquid Helium*
American Conference on Neutron Scattering
Santa Fe, New Mexico May 2008

42. *Dynamic Structure Factor of One Dimensional and Two Dimensional Solid Helium Adsorbed on Nanotubes*
American Conference on Neutron Scattering
Santa Fe, New Mexico May 2008

43. *Bose-Einstein Coherence in Two Dimensional Superfluid ^4He*
American Physical Society Meeting
New Orleans, Louisiana March 2008

44. *Dynamics of One Dimensional and Two Dimensional Solid ^4He Adsorbed on Nanotubes*
American Physical Society Meeting
New Orleans, Louisiana March 2008

45. *Bose-Einstein Condensation and Superfluidity in Optical Lattices and Periodic Porous Media; a Path Integral Monte Carlo Study*
American Physical Society Meeting
New Orleans, Louisiana March 2008

46. *Phonon-Roton Modes and a Bose Glass Phase in Nanoscale Liquid ^4He*
American Physical Society Meeting
New Orleans, Louisiana March 2008

47. *Bose-Einstein Condensation and atomic kinetic energies in liquid ^3He-^4He mixtures*
SNS Workshop on eV Neutron Scattering
Oak Ridge, Tennessee October 2006

48. *Bose-Einstein Condensation in liquid helium films*
5th International Conference on Synchrotron Radiation in Materials Science
Chicago, Illinois July 2006

49. *Localization of Bose-Einstein condensation in liquid helium confined in nanoporous media*
American Conference on Neutron Scattering
St. Charles, Illinois June 2006

50. *Bose-Einstein Condensation and atomic kinetic energies in liquid ^{3}He-^{4}He mixtures*
American Conference on Neutron Scattering
St. Charles, Illinois June 2006

51. *Excitations of liquid helium confined to nanoscales*
Institut Laue Langevin Millenium Symposium
Grenoble, France April 2006

52. *Bose-Einstein condensation and superfluidity in finite sized systems*
American Physical Society Meeting
Baltimore, Maryland March 2006

53. *Bose-Einstein Condensation in liquid helium films*
American Physical Society Meeting
Baltimore, Maryland March 2006

54. *Bose-Einstein Condensation and atomic kinetic energies in liquid helium mixtures*
SNS-HFIR International Users Meeting
Oak Ridge, Tennessee October 2005

55. Contributed
    1. *Bose-Einstein Condensation and atomic kinetic energies in liquid ^{3}He-^{4}He mixtures*
    2. *Liquid helium in disorder and boson localization*
    3. *Bose-Einstein Condensation with attractive interactions*
    4. *Excitations of metastable superfluid ^{4}He at pressures up to 40 bars*
    5. *Structure of ^{4}He adsorbed on single-wall carbon nanotube bundles*

    American Physical Society Meeting
    Los Angeles, California March 2005

56. *Elementary excitations and sound speed in liquid ^{4}He at negative pressures*
Quantum Fluids and Solids 2004
Trento, Italy July 2004

57. *Excitation of metastable liquid ^{4}He at pressures up to 40 bar*
Quantum Fluids and Solids 2004
Trento, Italy July 2004

58. *Quantum momentum distributions and kinetic energy in Solid ^{4}He*
American Conference on Neutron Scattering
College Park, Maryland June 2004

59. *Liquid ^{4}He in disorder and boson localization*
American Physical Society
Montreal, Canada March 2004

60. *Full quantum Monte Carlo treatment of BEC in traps from the dilute to dense regimes*
American Physical Society
Montreal, Canada March 2004

61. *Bose-Einstein condensation with attractive interactions*
American Physical Society
Montreal, Canada March 2004

62. *Excitations of Liquid ^{4}He in MCM-41 Vycor and Geltech Silica*
American Physical Society Meeting
Austin, Texas March 2003