Photon correlation and scattering: introduction to the feature issue

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This special issue of *Applied Optics* contains research papers on photon correlation and scattering, many of which were presented at the OSA Topical Meeting that was held 16–18 August 2004.

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1. Introduction

The Photon Correlation and Scattering (PCS) 2004 meeting welcomed all interested in the art and science of photon correlation and its application to optical scattering. The meeting was intended to enhance its participants, interactions with the science—its theory, applications, and instrument design.

This special issue of *Applied Optics* contains a selection of papers on PCS, some of which were presented at the Optical Society of America (OSA) topical meeting from 16–18 August 2004 in the Trippenhuis of the Royal Netherlands Academy of Sciences (KNAW), Amsterdam, The Netherlands (Fig. 1). Additional papers available since this topical meeting are also included.

Photon correlation spectroscopy conferences began as informal discussions between members of different institutions in the late 1960s as the colloquial 'Correlator Club.' Because researchers came to England expressly to participate in these afternoon chats, it became clear that more formal discussions might be useful. Two NATO Advanced Study Institutes in Capri, Italy established a trend[1,2], that has continued now through 16 international conferences. European conferences in Cambridge, England[3] (April 1977), Stockholm, Sweden,[4] (June 1978), and again Cambridge, England[5] (March 1980) expanded to the United States to Stanford, California[6] USA (August 1980 and Wellesley, Massachusetts[7] (August 1980). Meetings continued in Europe and North America in Kiel, Germany[8] (May 1983); Maratea, Italy[9] (June–July 1982); Cambridge, England[10] (July 1985); Washington, D.C.[11] (June 1988); Boulder, Colorado[12,13] (August 1992); Capri, Italy[14,15] (August 1996); Krakow, Poland[16] (August 1996); Whistler, Canada[17] (August 2000); and most recently Amsterdam, The Netherlands[18] (August 2004). For a more detailed summary, please see Table 1. The meetings in Washington, D.C. (1988), Boulder (1992), Capri (1996), Whistler (2000), and Amsterdam (2004) were OSA Topical Meetings, with the last three being supported by the National Aeronautics and Space Administration (NASA) and the 2004 meeting being cosponsored and also supported by the University of Amsterdam.

Initially the main interest in photon correlation spectroscopy was to understand the theory and whether, how, and where the technique might be useful. Applications appeared immediately. Necessary hardware was developed, primarily digital correlators and individual photon detectors. These spurred innovation of optical techniques and implementations to make possible many physical measurements that were formerly difficult or inaccessible. Initial experiments in light-beating spectroscopy for the study of materials and structures in pure and multiphase liquids expanded rapidly into other fields. Much early interest was in laser anemometry and velocimetry for the study of fluid flow and turbulence in general and in wind tunnels and rotating and re-

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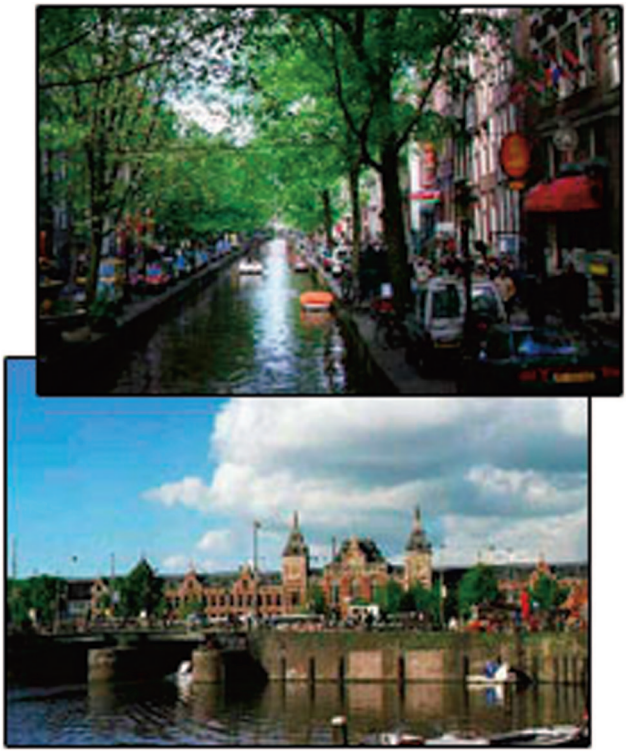

Fig. 1. (Color online) The Netherlands.

ciprocating machinery in particular. Since then many applications relying on the measurement of any quantity that may be encoded upon a light beam have been introduced, as is clear from the wide range of topics that the subject now embraces. Beginning with studies of velocity and turbulence in wind tunnels, in aircraft engines and in the ocean, they expanded to include measurement of scattering from surfaces, liquids, colloids, and biological specimens from fundamental research to medical diagnostics. A developing trend is toward more biologically and pharmaceutically oriented research, as an aspect of biophotonics.

Even after more than 30 years of development, the field continues to expand to exploit improvements in techniques, devices, electronics, algorithms, and software. Every indication is that the technique originally labeled as photon correlation spectroscopy will continue to develop and to find new applications for many years ahead.

2. Contents

The first section of this special issue of *Applied Optics* presents highlights from the Photon Correlation and Scattering 2004 conference in Amsterdam, which was partitioned into five topical sections: (i) Colloidal Systems, (ii) Near-Field Scattering, (iii) Fluctuations in Fluids, (iv) Photon Scattering, and (v) Correlation of Optical Fields.

A digest of many of the original presentations may be found in *2004 Photon Correlation and Scattering Conference*, edited by William Meyer, Anthony Smart, Gerard Wegdam, Aristide Dogariu, and Bradley Carpenter and published by the NASA Glenn Research Center; this digest is also available on the web.[18] Full papers, where available and after peer review, are presented here.

That the PCS field continues to grow is reflected through the breadth of topics covered in this special issue. Established topics in the field embrace photon correlation spectroscopy, light scattering, surface scattering, multiple scattering, diffusing wave spectroscopy, near-field scattering, particle sizing, photonic materials, complex fluids, and biophotonics. Some are addressed here and are extended to cover the spectrum from the visible to the microwave, from one gravity to microgravity, from Gaussian to non-Gaussian statistics, from clear to turbid media, and from fluid–fluid interfaces to thin films.

3. Cover

The cover shows four colorized images of enhanced concentration and temperature fluctuations for fluid samples driven by temperature gradients on Earth and in the microgravity environment provided by space flight. Measuring these fluctuations is the goal of the GRADFLEX (gradient-driven fluctuations experiment) project, planned to be flown for 12 days in the second half of 2007 aboard the Foton-M3 capsule, shown at the lower left. This project is funded by the European Space Agency (ESA), with ground-based support in the U.S. provided by NASA. The left pair of images shows fluctuations calculated for a 1-mm-thick layer of a two-component mixture, a solution of low-molecular-weight polystyrene in toluene, with an applied gradient of 200 K/cm. Coupling between random thermal velocity fluctuations and the concentration gradient induced by the Soret effect increases the range and amplitude of the concentration fluctuations. This effect is measurable on Earth but is predicted to be much stronger in the absence of gravity, as shown by the upper image. These images are colorized to show the areas of lowest concentration as black, with violet, blue, red, orange, yellow, and white indicating progressively higher concentration regions. The two images on the right show calculated temperature fluctuations for a 3-mm-thick layer of a single-component fluid, carbon disulphide, subjected to a temperature gradient of 100 K/cm. In this case, the coupling is between the velocity fluctuations and the applied temperature gradient. These images are colorized to show the areas of lowest temperature as black, with blue, green, yellow, and white indicating progressively warmer regions. Each of the four panels shows a 13-mm-sqare area, with the upper panels illustrating the immense spatial scales that such fluctuations are expected to exhibit in the absence of gravity. Under these conditions, the spatial scale of gradient-driven fluctuations is expected to diverge until limited by the sample thickness.[19] The logos at the bottom right represent funding agencies and participating universities and research centers.

Much is owed to NASA's Office of Biological and Physical Research (OBPR), especially to Brad Carpenter in the Physical Sciences Division (PSD) at

Table 1. History of Photon Correlation Conferences

When	Where	Proceedings	Publisher/Publication	Chair(s)
16–27 July 1973	Capri, Italy	Photon Correlation and Light Beating Spectroscopy	Plenum, B3 (1974)	H. Z. Cummins and E. R. Pike
26 July–6 August 1976	Capri, Italy	Photon Correlation Spectroscopy and Velocimetry	Plenum, B23 (1977)	H. Z. Cummins and E. R. Pike
6–7 April 1977	Churchill College, Cambridge, UK	Conference on Photon Correlation Techniques in Fluid Mechanics	Privately circulated by the CEGB Laboratories, Marchwood, UK	P. H. Richards
14–16 June 1978	Stockholm, Sweden	Second International Conference on Photon Correlation Techniques in Fluid Mechanics	Physica Scripta **19** (1979), special issue	L. Danielsson
21–23 March 1979	Churchill College, Cambridge, UK	Third International Conference on Photon Correlation Techniques in Fluid Mechanics	Optica Acta **27** (1) (1980), (special issue)	P. H. Richards
25–27 August 1980	Stanford University, Stanford, California, USA	Fourth International Conference on Photon Correlation Techniques in Fluid Mechanics	Privately published by Joint Institute for Aeronautics and Acoustics, Stanford University (1980)	W. T. Mayo Jr. and A. E. Smart
23–26 May 1982	Kiel-Damp, Federal Republic of Germany	Fifth International Conference on Photon Correlation Techniques in Fluid Mechanics	Springer-Verlag Series in Optical Sciences, **38** (Springer-Verlag, Berlin, 1983)	E. O. Schulz-DuBois
10–12 July 1985	Churchill College, Cambridge, UK	Sixth International Conference on Photon Correlation and Other Techniques in Fluid Mechanics	Optical Techniques in Fluid Mechanics, Institute of Physics Conference Series Number, Vol. 77 (Adam Hilger, Bristol, 1985)	P. H. Richards
31 May–2 June 1988	Catholic University of America, Washington, D.C.	Photon Correlation Techniques and Applications	Volume 1 of OSA Conference Proceedings Series (Optical Society of America, Washington, D.C., 1988)	J. B. Abbiss and A. E. Smart
August 1992	Boulder, Colorado	OSA Eighth Topical Meeting on Photon Correlation and Scattering: Theory and Applications	Applied Optics **32**(21) (1993) and Vol. 20 of 1992 OSA Technical Digest Series	T. Fansler and R. Nossal
21–24 August 1996	Capri, Italy	Photon Correlation and Scattering	Applied Optics, Vol. **36**(30), (1997)	W. V. Meyer, A. E. Smart, R. G. W. Brown, and M. A. Anisimov
26–30 August 1996	Krakow, Poland	Light Scattering and Photon Correlation Spectroscopy	Kluwer Academic, Vol. 40 (1997)	E. R. Pike and J. B. Abbiss
20–24 August 2000	Whistler, Canada	Photon Correlation and Scattering 2000	Applied Optics, **40,** 24, (2001)	W. V. Meyer A. E. Smart and R. G. W. Brown
16–18 August 2004	Amsterdam, The Netherlands	Photon Correlation and Scattering 2004	Applied Optics **45**(10) 2006	G. H. Wegdam, W. V. Meyer, A. E. Smart, and A. Dogariu

NASA HQ, who funded a significant portion of this conference, allowing us to meet the OSA topical meeting guidelines. Additional support from NASA also funded many advances in photon correlation and optical scattering, as evidenced by several of the papers submitted for this conference. The University of Amsterdam was also a significant sponsor of this meeting, playing the lead role in its local organization and success. They also provided a tour of the Van der Waals-Zeeman Laboratory (Fig. 2). Gayle Dibiasio, InDyne / NASA, provided the graphics and layout for the front cover with guidance from the authors of the accompanying paper by Vailati *et al.*[19] in this issue. Brookhaven Instruments; Correlator.com; Malvern

Fig. 2. (Color online) (a) Part of the conference included a tour of the prestigious Van der Waals-Zeeman Institute.

Instruments, Ltd.; Ocean Optics BV; and Particle Sizing Systems provided additional financial support and exhibited instrumentation at the conference.

Special thanks are due to Kristin Mirabal of OSA; Rita Vinig of the Van der Waals-Zeeman Institute at the University of Amsterdam, who helped organize and coordinate the meeting; and Christine Gorecki of NASA's National Center for Space Exploration Research, who also helped organize the conference and was responsible for the printed agenda and technical digest.[16] Additionally, we benefited from the support at OSA of Cynthia Gady, Senior Director and Namoi Chavez, Director of Meetings and Exhibits. Thanks are also due to Keith Jackson, AO Journal Assistant; Joseph Richardson, AO Team Manager; Antoinette P. Wrighton, AO Managing Editor; and the rest of the staff at OSA, for making this publication possible.

Anthony Smart provided the digital photos for the meeting scrapbook that was posted on the OSA website. The group photo in this Introduction was taken

Fig. 3. (Color online) Group photograph of meeting attendees.

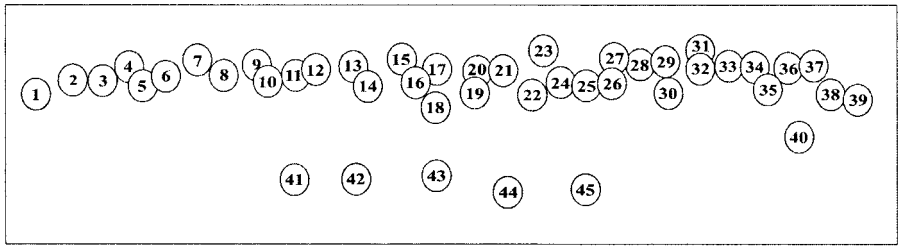

Fig. 4. Associated listing for the individuals shown in Fig. 3. 1. Barbara Hirz; 2. Antonio Verga; 3. Roy Pike; 4. Alberto Vailati; 5. Thomas Gisler; 6. Sandor Balog; 7. Christoph Eisenmann; 8. Y Piederriere; 9. Wim de Jeu; 10. Gerard Wegdam; 11. Gerhard Grübel; 12. Robert Brown; 13. Ivo Vellekoop; 14. Takashi Okamoto; 15. Regis Sarcia; 16. Oleg Aktispetrov; 17. Aristide Dogariu; 18. Caterina Vozzi; 19. Fabrizio Croccolo; 20. Oleg Angelsky; 21. Roberto Cerbino; 22. Hua Guo; 23. Jan Dhont; 24. Kyongok Kang; 25. Frank Scheffold; 26. Marzio Giglio; 27. Jay Adin Mann; 28. Alexander Ushenko; 29. Marco Potenza; 30. Jixiang Zhu; 31. Frank Molster; 32. Walther Tscharnuter; 33. Yuriy Ushenko; 34. David Nicoli; 35. David Weitz; 36. Ulf Nobbmann; 37. William Meyer; 38. Kristin Mirabal; 39. Evgenia Kim; 40. Paul Chaikin; 41. Carlos Rega; 42. Kit Meader; 43. Anthony Smart; 44. Christine Gorecki; 45. Nicole Bos

by Gary Gorecki (Fig. 3). The locations for associating the listed names of individuals pictured in Fig. 3 are noted in Fig. 4.

The conference organizers, Gerard Wegdam, William Meyer, Anthony Smart, and Aristide Dogario extend their thanks and gratitude to the local organizers who gave generously of their time to ensure the success of the meeting. We especially thank everyone who attended the Photon Correlation and Scattering Topical Meeting in Amsterdam and extend additional thanks from the editors of this special issue of *Applied Optics* to all who have contributed.

Appendix A. Technical Program Committee

Aristide Dogariu, University of Central Florida/CREOL, USA, Chair
William Meyer, NCMR/NASA Glenn Research Center, USA, Chair
Anthony Smart, USA/UK, Chair
Gerard Wegdam, University of Amsterdam, The Netherlands, Chair

Mikhail Anisimov, University of Maryland, USA
Robert Brown, University of Nottingham, UK
David Cannell, University of California at Santa Barbara, USA
Paul Chaikin, New York University/Princeton University, USA
Jan Dhont, IFF-Institute, Germany
Barbara Frisken, Simon Fraser University, Canada
Marzio Giglio, Università di Milano, Italy
Dominique Langevin, Laboratoire de Physique des Solides, France
J. Adin Mann, Case Western Reserve University, USA
Roberto Piazza, Politecnico di Milano, Italy
E. Roy Pike, King's College, London, UK
Raj Rajagopalan, National University of Singapore
David Weitz, Harvard University, USA
Simone Wiegand, IFF-Institute: Soft Matter, Germany

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