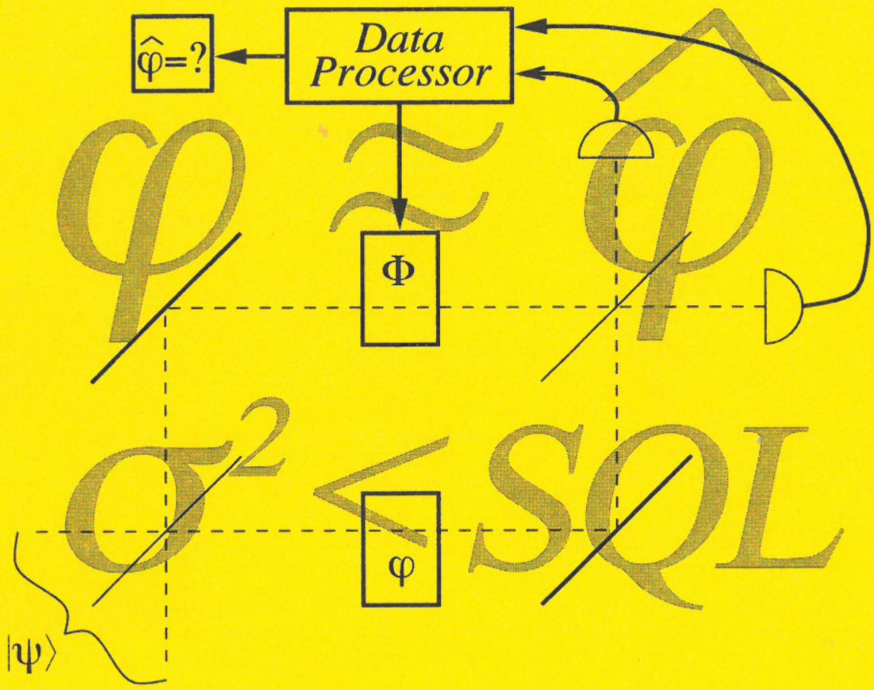
Australian Optical Society

NEWS



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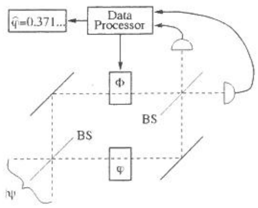

COVER:
The cover shows an experimental arrangement for measurements used to make estimates of optical phase. The article in this issue (page14) discusses the theory behind such estimation, and makes the connection to recent exciting experiments in this area.

SUBMISSION OF COPY:
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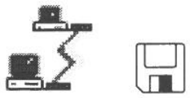

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DEADLINE FOR NEXT ISSUE
26th August, 2002

JUNE 2002 VOLUME 16 NUMBER 2

AOS NEWS

ARTICLES

DEPARTMENTS

AOS News - Editorial Board

Submission guidelines

The *AOS News* is always looking for contributions from its members. Here is a short summary of the how to make a submission.

What can you submit?

* ***Scientific Article***
A scientific paper in any area of optics.

* ***Review Article***
Simply give a run down of the work conducted at your laboratory, or some aspect of this work.

* ***Conference Report***
If you have been to conference recently, writing a short report would be greatly appreciated.

* ***News Item***
Any newsworthy stories in optics from Australia or abroad.

* ***Book Review***
If you have read an interesting (and relatively new) book in some field of optics please consider writing a review for the *AOS News*.

* ***Cartoon or drawing***
If you have some artistic bent why not consider submitting a cartoon!

How can you submit?

The easiest way is by email. Either send the document text in your mail, and attach diagrams and/or a word processor file. We accept nearly all file formats. (Famous last words!).

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AUSTRALIAN OPTICAL SOCIETY

ABN 63 009 548 387

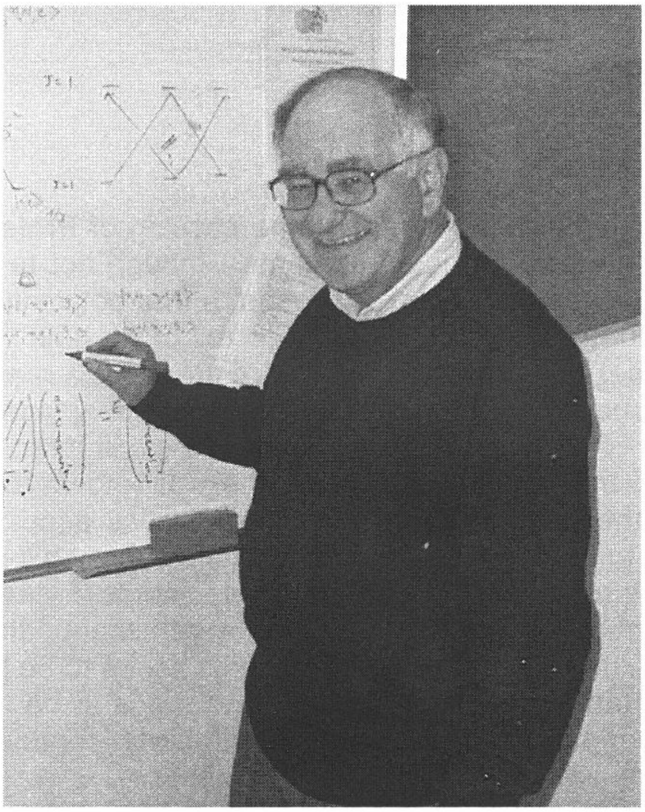
AOS News is the official news magazine of the Australian Optical Society. Formed in 1983, the Society is a non-profit organisation for the advancement of optics in Australia. Membership is open to all persons contributing to, or interested in, optics in the widest sense. See the back page (or the AOS website) for details on joining the Society.

Geoffrey Ivan Opat, AO, FAA
Scientist, Scholar, Teacher
16/11/1935 – 7/3/2002

The recent passing of Geoff Opat was a shock to all members of the Australian Optical Society, and indeed to the wider scientific community. This collection of writings serves to give some insight into the impact that Opat had on many of us. Beginning with an obituary by Opat's long-time friend and collaborator, Tony Klein, it also includes some comments from past students and colleagues.

The recent sudden death of Professor Geoffrey Opat, at the age of 66, has come as a profound shock to the University of Melbourne and to the physics community in Australia. We have lost one of our most highly respected scientists, scholars and teachers.

As a much loved, larger-than-life character, Geoffrey Opat's passing is mourned by his professional colleagues, his many current and former students in Australia and throughout the world, and by a very large circle of family and friends. His enthusiasm for teaching physics at all levels, from kindergarten to postgraduate, and his enormously creative ideas in many different areas have been the hallmarks of a remarkable career of service to the physics profession.



Geoff Opat at Swinburne University in 2001 – clear and insightful explanations were Opat's hallmark.

Geoffrey Opat was born in Melbourne on 16 November 1935 and completed his secondary education by being Dux of Brighton Grammar School. He then entered the University of Melbourne, graduating as a Master of Science in 1958 and with a PhD in theoretical physics in 1961. He spent the following three years as a Fullbright Fellow at the University of Pennsylvania in the USA.

Following the sudden death of his father, also at an early age, in 1964, he returned to Australia and was appointed Senior Lecturer in Physics at the University of Melbourne. Although his training was in theoretical physics, he formed a research group in experimental particle physics that flourished for over a decade and culminated with his appointment to the Chair of Experimental Physics in 1973.

He was known internationally for his research in nuclear and particle physics and for a very successful suite of fundamental experiments with neutrons over the past 25 years, in which I consider it a privilege to have been his close collaborator. This led to the award of the Walter Boas Medal of the Australian Institute of Physics in 1990 and to election as a Fellow of the Australian Academy of Science, in 1994.

With a broad as well as profound knowledge of all the major branches of physics, he was recognised by students as well as the general public for his ability to make even the most obscure points of physics accessible. At the same time, his insistence on the highest educational standards, during times when mass education became the norm, has led to some of the most rigorous and yet the most successful university physics courses in Australia. Because of this, he had a great and lasting influence on the teaching of physics not only in Melbourne, but also in other universities in Australia, and in several neighbouring countries, which sought his advice.

Through his membership of the examining bodies and other government-appointed committees in Victoria and through contacts with many school teachers and students, he also had a great influence on physics teaching in high schools. He was responsible for a highly successful program of enrichment activities for senior high school students, gave many public lectures and was a frequent participant in the in-service teaching programs for high school teachers. He was highly regarded as the convenor of the Victorian chapter of the Australian Academy of

Science and, until recently, was a board member of the Museum of Victoria. He also chaired the Research Committee of the Victorian College of the Arts.

For these services to the community, as well as for his outstanding service to scientific research, Geoffrey Opat was recently appointed an Officer of the Order of Australia, a high honour that pleased him enormously. Here is what he wrote in reply to people who sent their congratulations on that occasion:

"As you know, I have spent much of my life in a labour-of-love, trying to understand a little more about the world, trying to let others know about it, and hopefully interesting them in it. Most people do not have the good fortune to spend a life working at what they love. To be recognised for it as well is an added pleasure. I have every intention of continuing my pursuits into the future."

Unfortunately, he did not get the chance to do so. He leaves behind his devoted wife Diana, his constant companion and supporter for over 40 years; daughters Andrea and Vicky, sons Stephen and David and no fewer that 10 grandchildren. In recent years they were his greatest delight, the most uncritical audience for his jokes and the most eager pupils for all the science that he would teach them, at every single opportunity.

Tony Klein
University of Melbourne

In Memoriam

The School of Physics is mourning the passing of Professor Geoffrey Opat. Geoff (known by some students - though not to his face! - as "Uncle Geoff") was that rarest of breeds, a true polymath, and most of the postgraduate cohort have a tale to tell of an hour (or sometimes more than one!) spent in his office learning about a range of subjects too broad to mention. As students, perhaps our most lasting memories of Geoff are of his role as an inspired and inspirational teacher. By students and the general public alike he was known for his ability to make even the most obscure points of physics accessible, and his commitment to conveying not just the excitement of his subject matter but also the thrilling realisation that developments in an understanding of physics can be truly revolutionary - they can change the fabric of the way we think. In our hearts, not a few of us aspire to be like Geoff, and we could not ask for a better model of what it is to be a true scholar. We remember him both with respect and with fondness, and that, perhaps, is the greatest tribute we could make.

(from the Melb. Uni. Physics Grad Students' News-sheet)

When I reflect on my memories of Geoff Opat, the first thing that strikes me is his infectious enthusiasm. When you consider this, combined with his enormous intellect, it comes as no surprise that all whose lives came into contact with Geoff have such a vivid impression of a truly "rare character". Collected below are some of my favourite memories involving Geoff.

One day I observed Geoff giving a lengthy and animated explanation about the large "crown sculpture" outside the School of Physics and its former role in pre-stressing a brick smokestack. Afterwards, as the student walked away, I asked her what level of physics she was studying, to which she replied that she was in fact an art student and had simply been sketching the sculpture for a drawing assignment. As she glanced quizzically back at Geoff, bustling off into the building, she remarked that she had never before realised how much science there was in a smokestack!

During a quantum mechanics lecture Geoff became sidetracked as he explained the workings of a Babinet-Soleil compensator. I distinctly remember him enthusiastically admonishing us that if we ever saw one of these devices attached to an experiment we should "give it a good fiddle with, and see what happens to the light". In later years, during my Ph.D. in atom optics, I lived in fear that some student of Geoff's would adhere to this advice and wreak havoc on my apparatus.

Geoff's interests and expertise extended well beyond the confines of Physics. Whilst waiting for Geoff to arrive for a lecture, one student was showing her friends a strange old musical instrument. "What's that?" demanded Geoff as he entered and the student hurried to put the instrument away. When the student replied, somewhat apologetically, that it was a crumphorn (I think that was what she said), Geoff declared in mock-seriousness "No such thing! I will deal with you later." Of course, after the lecture he did indeed speak to the student, keen to find out more about the instrument and to share his own knowledge of ancient musical objects.

It is with a great sense of joy that I remember the wonderful man that was Geoff Opat, and with extreme sadness that I acknowledge his passing.

Wayne Rowlands

Agreeing to write these few words on Geoff presents one with a distinct challenge. Geoff's broad contributions to the community, and his generous manner endeared him to many in both the scientific and non-scientific community. What I have to say here cannot encompass a fraction of what Geoff meant to so many people, and rather than try to summarise or generalise about his influence, a short perspective on one aspect of Geoff is presented here.

I had the pleasure of being one of Geoff's honours students in '00 working in the lab with him, and attending his lecture courses. As a student of Geoff one could best describe him as inspirational. Not in a distant way, but in a way where the enthusiasm that oozed from Geoff was contagious. Somehow day-to-day lab work was not a laborious task, but an adventure in understanding the physical world around us, another exciting problem to be solved. Even the standard coursework that he must have presented many times before was delivered with the same vibrance and vigour as his latest idea for research.

At every meeting with Geoff he displayed a fervour for physics. His eyes would light up like those of a small child in a confectionary store whenever he explained some physical phenomenon, or new idea for an experiment. It was this passion evident in all one's dealings with Geoff that made him such a joy to work with.

In the days following Geoff's passing, a brief reflection appeared in the postgraduate student newsletter of the week. Speaking of the grad students it read "...not a few of us aspire to be like Geoff", which puts many feelings so simply. Many of us aspire to be like Geoff, a remarkable scientist, a generous character and an inspirational teacher.

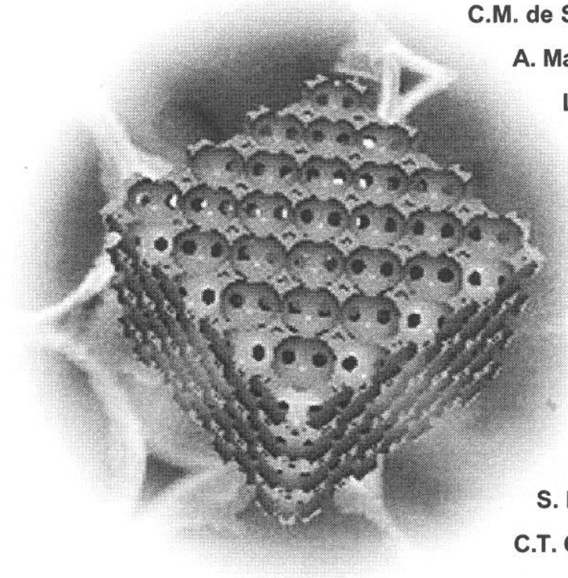
Adrian Mancuso

Photonic Crystals Down Under

The Australian National University
Research School of Physical Sciences and Engineering

Canberra - Australia - August 18 - 24 - 2002

Invited Speakers



C.M. de Sterke (School of Physics, University of Sydney)
A. Maradudin (University of California, Irvine, USA)
L.C. Botten (University of Technology, Sydney)
Yu. Vlasov (IBM, Yorktown Heights, USA)
S. John (University of Toronto, Canada)
S. Fan (Stanford University, USA)
C. Soukoulis (Ames Labs, USA)
S. Kawata (Osaka University, Japan)
A. Boardman (University of Salford, UK)
K. Sakoda (Hokkaido University, Sapporo, Japan)
M. Yokoyama (Kyoto University & Minolta Co, Japan)
S. Mingaleev (Karlsruhe University, Germany & Kiev, Ukraine)
C.T. Chan (University of Science and Technology, Hong Kong)

The main aims and objectives of the first conference on photonic crystals in the Southern Hemisphere is to bring together researchers and students from different universities and laboratories in Australia and the key overseas experts in the field of photonic crystals, in order to promote this new field, to enhance its development in Australia, and facilitate the emergence of new technologies in our country.

Conference Scope

Fundamental physical effects in periodic structures; fiber Bragg gratings; 2D and 3D photonic crystals; waveguides, waveguide bends, and waveguide circuits in photonic crystals; photonic crystal fibers, frequency conversion and parametric effects in periodic media; nonlinear modes and gap solitons in photonic crystals.

Applications of photonic crystals and photonic-crystal fibers; optical switching, super-continuum generation. Novel nonlinear materials for photonic crystals, relation between nonlinearities and other optical and physical properties of the materials. Fabrication techniques: Micro-structured dielectric media, periodically poled materials for quasi-phase matching, fabrication of photonic-crystal waveguides in different structures, Bragg gratings, photonic band gaps, micromachining, optimization of linear and nonlinear properties.

Contact Details

Prof. Yuri Kivshar
Nonlinear Physics Group, RSPhysSE
Australian National University
Email: ysk124@rsphysse.anu.edu.au
Fax: +61 2 6125 8588

For further details please visit the conference website:
http://www.rsphysse.anu.edu.au/nonlinear/meeting

Australian Academy of Science

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AOS MEDAL

AUSTRALIAN OPTICAL SOCIETY

The Australian Optical Society is seeking nominations for the fifth award of this medal, which is for an outstanding contribution or contributions to the field of optics in Australia by a member of the Australian Optical Society.

Previous winners of the medal have been:

1995: Mr Bill James, James Optics, Melbourne
1996: Dr Parameswaran Hariharan, University of Sydney and CSIRO
1997: Professor Jim Piper, Macquarie University
1999: Professor Dan Walls, University of Auckland

This Medal is the most prestigious award of the Australian Optical Society. It would normally be presented only to a nominee at an advanced stage of his or her professional career and with a strong and sustained record of authority, enterprise and innovation in the field of optics in Australia.

Nominations for the 2003 AOS Medal Winner should include brief personal details and a curriculum vitae emphasising the main contributions made by the nominee to Australian optics. Two letters of recommendation should also be provided. Nominations may be made either by or on behalf of any eligible candidate. The selection panel reserves the option to seek additional information about candidates for the award. It is hoped that the person selected to receive the medal will be able to do so at the next AOS Conference.

The closing date for nominations is **15 February 2003**.

Nominations should be sent to the Hon. Secretary:

Dr Duncan Butler
ARPANSA
Yallambie VIC 3085
Fax: (03) 9432 1835

AUSTRALIAN OPTICAL SOCIETY

POSTGRADUATE STUDENT PRIZE

A. Preamble

The Australian Optical Society wishes to encourage participation in national and international conferences by high-quality postgraduate students. To this end, the Society has instituted an award, the Australian Optical Society Postgraduate Student Prize. This will take the form of a grant to assist the grantee to attend a conference in optics or a related field. For 2003, the award will be valued at up to $1500. The Society now invites applications from suitably qualified people for this prize for 2003.

B. Prerequisites

An applicant must be: (1) a citizen or permanent resident of Australia, (2) a member of the Australian Optical Society, (3) enrolled in a postgraduate research degree in Australia at 31 October 2002, with a project in an optically related area. Non-members of the AOS may join the Society concurrently with their application for the prize. (Application forms are available in *AOS News*, or may be obtained from the Treasurer or Secretary). The prize cannot be awarded more than once to any individual.

C. Selection criteria

An applicant must be sufficiently advanced in the research project to have obtained significant results in optics or a related area, such that those results are suitable for presentation at a proposed conference that falls in the twelve month period commencing 1 December 2002. It is expected that the presentation at the proposed conference would take the form of a research paper, invited or contributed, oral or poster. The successful applicant will be expected to write a summary of the conference for *AOS News*.

Preference will be given in the selection procedures to applicants who intend to use the prize to attend and present their research results at a major conference outside Australia or New Zealand.

It is not essential that the results to be presented should already have been accepted for presentation at the proposed conference at the time of application, but no payment of the prize will be made until evidence of such acceptance is provided to the Society. Applicants are encouraged to provide tangible evidence of the results likely to be presented at the proposed conference (for example, in the form of an outline of a paper that has been accepted or submitted or is being prepared for that conference) and to make clear the benefits that would arise from their attendance at that conference.

The AOS award is not intended to cover the full cost of the applicant's attendance at the proposed conference. Wherever possible, applicants should identify means by which their research group and/or institution is likely to make a substantial contribution to their travel costs. Evidence of any such supplementary support should be provided (for example, by an undertaking in the supervisor's letter of recommendation). However, students with no identifiable supplementary travel support will not be disadvantaged in the selection process.

Since the research supervisor's report is a major factor in the assessment process, supervisors should be prepared to rank their students against the selection criteria if contacted by the selection committee.

D. Application Details

1. Curriculum vitae;
2. List of publications, conference papers, theses, reports, etc.;
3. Details of postgraduate research project;
4. Details of proposed conference (including its status and relevance to optics);
5. Details of participation in the conference (nature of contribution as specified above);
6. Details of predicted expenses, as well as other (probable or confirmed) sources of funding for attendance at the conference;
7. Reports from the candidate's research supervisor and one other referee;
8. Statement that the candidate is a citizen or permanent resident of Australia;
9. Statement of agreement to write a summary of the conference for *AOS News*.

Applications should be sent to the Honorary Secretary:

Duncan Butler
ARPANSA
Lower Plenty Road
Yallambie VIC 3085
Fax. (03) 9432 1835

and **must be received by 31 October 2002**
The winner will be announced early in 2003.

SPIE The International Society for Optical Engineering

SPIE was formed in 1955 as the Society for Photo-optical Instrumentation Engineers, and has been dedicated to providing the best possible service to the optical engineering community. SPIE is an international technical society dedicated to promoting the engineering and scientific applications of optical, photonic, imaging and optoelectronic technologies through its education and communications programs, meetings and publications.

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International Networking

Today SPIE is the largest international professional engineering society serving the practicing engineer and scientist in the field of optics and photonics. The Society serves the global technical and business communities, with over 14,000 individual, 320 corporate, and 3,000 technical group members in more than 75 countries worldwide. Advance professionally through networking and visibility among your peers. Learn from others and gain access to the voices, ideas, and the energy of a global community.

Meetings

Among the many services the Society offers are the sponsorship, planning, and execution of technical conferences, product exhibitions, and symposia. SPIE's technical meetings and symposia are internationally-acclaimed gatherings of engineers and scientists working in optics, optoelectronics, and many related fields. They take place in large and small venues, from specialised topics to cross-disciplinary information exchanges, complete with extensive programs including short courses, workshops, and other special activities.

Publications

A major activity of SPIE is the publication and distribution of archival professional journals, full-manuscript conference proceedings, newsletters, and optics-related texts and monographs. SPIE publications deliver timely, high-quality technical information to the optics, imaging, and photonics communities worldwide. Membership includes a subscription to *OE Reports*, a monthly newspaper that provides news and commentary on cutting-edge technology.

...and More

In addition, SPIE provides numerous services to its members, including on-line electronic databases, electronic bulletin board and networking services, and employment assistance. To further serve the public good, the Society sponsors a number of awards, scholarships, and educational grants every year, and publishes a comprehensive catalogue of educational resources in the optics field, *Optics Education*.

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Adaptive Quantum-Limited Estimates of Phase

Written by: H. M. Wiseman

Centre for Quantum Dynamics, School of Science, Griffith University, Nathan 4111, Queensland, Australia

Latest Theory by: D. W. Berry

Department of Physics and Centre for Advanced Computing – Algorithms and Cryptography, Macquarie University, Sydney 2109, NSW, Australia

Experiments by: H. Mabuchi and co-workers

Norman Bridge Laboratory of Physics 12-33, California Institute of Technology, Pasadena, CA 91125, USA

Quantum-limited estimation of an optical phase using adaptive (i.e. real-time feedback) techniques is reviewed. One case is explored in detail, as it can be understood using only elementary concepts such as photonic shot-noise and error analysis. Very recent experimental results are discussed.

I. Introduction

Having been working on the topic of quantum-limit adaptive estimation of optical phase for some years now [1–9], when I (HMW) was asked to contribute an article on it, the question "why now?" naturally arose. I believe there are three good answers to this question. In order of increasing importance,

1. The work done by me, and more particularly my students, covers a wide range of cases. It is only now that it is possible to put them all in an overall context.
2. Some of the latest results are actually the easiest to explain to a non-specialist.
3. The first experiments verifying the theory have very recently been performed in the laboratory of Hideo Mabuchi at CalTech.

Before discussing these interesting developments, I should explain what quantum-limited adaptive phase estimation means. The phase in question is an unknown (and possibly varying) optical phase φ. The *aim* is to estimate this phase, on the basis of measurements, as well as quantum mechanics allows. The *allowed resources* are practical ones: photodetectors, electronics, and linear (electro-)optics. The *fundamental limitation* is the number of photons (per pulse or per coherence time). There are also many *practical limitations* such as efficiency, the source of light, time delays, and processing limitations. These have all been considered [2, 4, 6, 7], but for simplicity I will not discuss them here.

Where *adaptive* estimation comes in is that to realise the above aim using the allowed resources it turns out that it is necessary to use *real-time* feedback during the measurement. The basic idea is as follows. If φ is known to a very good approximation, then a simple measurement scheme will usually give near-optimal results. An example is homodyne measurement of the phase quadrature of a pulse [10]. However if φ is totally unknown then the standard solution is to measure both quadratures (e.g. by heterodyne detection). This is far from optimal. The alternative is adaptive detection: use the results *so far* in the measurement to make an estimate $\hat{\varphi}$ of φ and use this in a feedback loop to make the rest of the measurement closer to optimal.

I believe this work is important for a number of reasons:

First, quantum phase has a long and controversial history [11]. Although ideal phase measurements can be defined, there is no way to make them without optical materials with arbitrarily high orders of nonlinearity [3]. Hence it is of fundamental interest to know how well one can do with linear devices.

Second, with continued miniaturisation of devices there will come a time when quantum limits do set the fundamental limits for technology. There is every reason to expect that phase estimation, as required for phase locking loops for example, will still be a practical concern then.

Third, the idea of adaptive measurements may have applications far beyond that of phase measurements, so the theoretical and experimental expertise gained here potentially opens new frontiers in quantum measurement theory. It also has implications for the way in which we understand phenomena such as the "collapse of the wavefunction".

Finally, the cutting-edge technology required for quantum-limited adaptive measurements is a stepping stone towards more general methods for controlling quantum systems, another area of future importance as engineering heads towards the quantum realm. As will be discussed in Section V, the new technology being applied is both electronic and optical.

II. Overview of Past Results

There are many different cases that can be considered, and they can be systematised by considering the following four questions:

1. Is the detection *dyne* (that is, using an optical local oscillator) or *interferometric*?
2. Is the light source *coherent* (e.g. a laser), or *nonclassical* (e.g. squeezed)?
3. Is the scheme *non-adaptive*, or *adaptive*?
4. Is it *single-shot* with a single phase, or *CW* with a varying phase?

Two of these distinctions definitely require further explanation.

First, *dyne versus interferometric* detection. These are illustrated in the figures below.

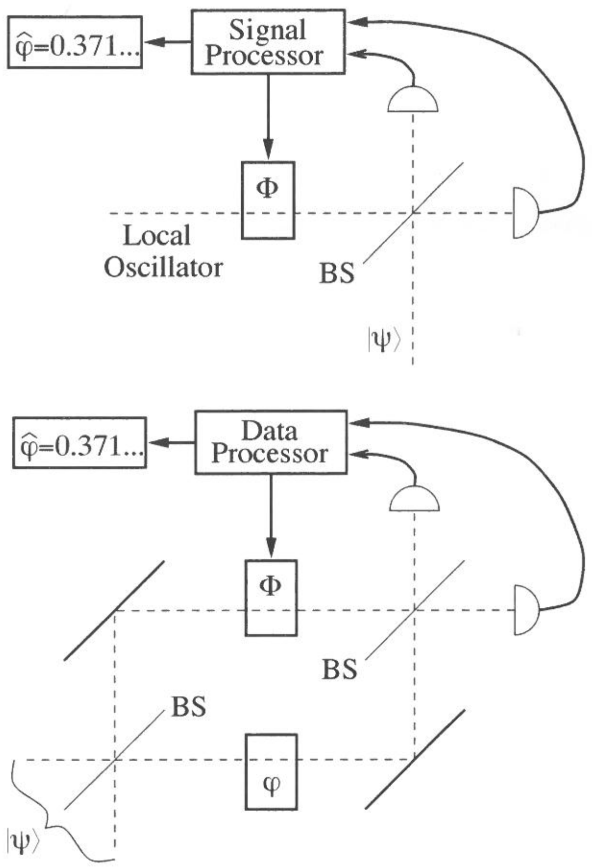

Fig 1: Adaptive phase estimation: dyne detection (top) and interferometric detection (bottom). BS = Beam Splitter, and dashed lines are optical paths.

It might well be objected that dyne detection (of which homodyne and heterodyne are two examples [2]) is merely one sort of interferometric measurement [12], in that the local oscillator is interfered with the signal light before detection. This is quite true; I am using the two terms to make a distinction between how the accounting is done. In dyne detection only the signal pulse or beam is treated as quantum, and only the number of photons in it is counted for the purposes of determining the quantum limit. In interferometric detection both input pulses or beams into the Mach-Zehnder interferometer are treated as quantum, and the photon number in both is counted [5, 8]. There is also a practical distinction in that dyne detection uses a photoreceiver that yields a photocurrent which does not distinguish individual photons, whereas interferometric detection uses photon counters. In both cases the aim is to measure the phase φ; in the former this phase is defined relative to the local oscillator, while for the latter it is as a relative phase between the two arms of the interferometer.

Second, *single-shot versus CW*. In a single-shot measurement, there is a single pulse of light (which may however be split over two modes for the case of interferometric detection). There is a single unknown phase φ imprinted on the pulse. The relevant parameter for the fundamental limit is n (or $\bar{n}$), the (mean) number of photons in the pulse. In *Continuous-Wave* detection, there is a beam (or two beams in the interferometric case) of light. A time-varying phase $\varphi(t)$ is imprinted on (one of) the beam(s). In this article I will consider only the case where the time variation is that of white noise. That is,

$$\dot{\varphi} = \sqrt{\kappa}\,\xi(t). \qquad (2.1)$$

This could arise from thermal mechanical fluctuations of miniaturised optical elements, for example. The parameter κ is the rate of phase diffusion, or, equivalently, the resulting linewidth of the beam. The relevant parameter in this case is N, the mean number of photons per coherence time: $N = P/\hbar\omega\kappa$, where P is the beam power.

Having explained the various cases, I can now give the promised overview. The simplest results arise by considering the mean square error (MSE) in the estimated phase, in the asymptotic limit where n or $\bar{n}$ or N go to ∞. The results for the MSE scale as in table 1.

There is a good deal of regularity in this table, as the reader may discern. I wish to draw attention to one feature in particular. The sixteen MSEs (some still undetermined) can be divided into four squares of four MSEs. In each square for which results are fully known, three of the MSEs scale in the same way. This scaling represents the *standard quantum limit* (SQL) for that particular case. The fourth, underlined in the above table, beats the SQL. In each case, this requires both *non-classical light* and *adaptive detection*.

		dyne		interferometric	
		coherent	non-class.	coherent	non-class.
CW	adaptive	$0.5/N^{1/2}$	$\underline{\sim 1/N^{2/3}}$	$1/N^{1/2}$	?
	non-adapt.	$0.71/N^{1/2}$	$0.66/N^{1/2}$	$1/N^{1/2}$	?
Single shot	adaptive	$0.25/\bar{n}$	$\underline{\sim \log\bar{n}/\bar{n}^2}$	$1/n$	$\underline{\gtrsim \log n/n^2}$
	non-adapt.	$0.5/\bar{n}$	$0.25/\bar{n}$	$1/n$	$\sim 1/n$

Table 1: Asymptotic mean square errors for phase estimation. The results that beat the standard quantum limits are underlined.

III. Latest Results: CW Dyne Detection

To try to explain adaptive phase estimation in more detail, I will concentrate now on the particular case of CW dyne detection. This is one the latest areas to be investigated, by Dominic Berry and myself [9], but turns out to be probably the simplest to explain. To reiterate the basic idea, we want the best estimate of the *current value* of $\varphi(t)$ which obeys $\dot{\varphi} = \sqrt{\kappa}\xi(t)$ where $\xi(t)$ is white noise with unit spectral power.

Consider first the case of *coherent light* of power $P = \hbar\omega\alpha^2$, detected by interfering with a local oscillator at a balanced photoreceiver. The resulting dyne photocurrent, suitably scaled, is [2]

$$I(t) = 2\alpha\cos[\Phi(t) - \varphi(t)] + \zeta(t) \tag{3.1}$$

where $\Phi(t)$ is the local oscillator phase, and $\zeta(t)$ is another Gaussian white noise term, independent of $\xi(t)$, with unit spectral power. It can be thought of as local oscillator shot noise, or vacuum noise. In any case, it is *quantum noise*.

The standard non-adaptive technique to estimate phase is to vary $\Phi(t)$ over all phases. This can be achieved by heterodyne detection with a detuning $\Delta >> \sqrt{\alpha\kappa}$, which makes Φ vary as $\Phi(t) = \Phi(0) + \Delta \times t$. From Eq. (3.1) we would expect better sensitivity if we were to choose $\Phi(t)$ to maximise the slope of $\cos[\Phi(t) - \varphi(t)]$. That is, we should set $\Phi(t) = \hat{\varphi}(t) + \pi/2$ so that

$$\begin{aligned} I(t) &= 2\alpha\sin[\varphi(t) - \hat{\varphi}(t)] + \zeta(t) \\ &\approx 2\alpha[\varphi(t) - \hat{\varphi}(t)] + \zeta(t) \end{aligned} \tag{3.2}$$

for $\hat{\varphi}(t) \approx \varphi(t)$. The question is, how should we choose the estimate $\hat{\varphi}(t)$?

One obvious possibility is to choose it from the immediately preceding photocurrent. We can rearrange Eq.. (3.2) to get

$$\varphi(t) \approx \left[\hat{\varphi}(t) + \frac{I(t)}{2\alpha}\right] + \frac{\zeta(t)}{2\alpha} \tag{3.3}$$

For a given $\hat{\varphi}(t)$, we could thus form

$$\hat{\varphi}_{imm}(t + \delta t) = \frac{1}{\delta t}\int_t^{t+\delta t}\left[\hat{\varphi}(t) + \frac{I(s)}{2\alpha}\right]ds \tag{3.4}$$

This has the MSE

$$\begin{aligned} \sigma^2_{imm}(t + \delta t) &= \left\langle\left[\hat{\varphi}_{imm}(t + \delta t) - \varphi(t + \delta t)\right]^2\right\rangle \\ &\approx \frac{1}{4\alpha^2\delta t} \end{aligned} \tag{3.5}$$

This diverges as $\delta t \to dt$, so clearly $\hat{\varphi}_{imm}$ is not a good estimate. Instead, we need a $\hat{\varphi}(t)$ that involves a finite time average.

The optimal time-average for $\hat{\varphi}(t)$ can be determined as follows. Say the MSE in $\hat{\varphi}(t)$ is $\sigma^2(t)$. Over the interval $[t, t + \delta t)$, the diffusion of $\varphi(t)$ causes this to increase to

$$\begin{aligned} \sigma^2_{old}(t + \delta t) &= \left\langle\left[\hat{\varphi}(t) - \varphi(t + \delta t)\right]^2\right\rangle \\ &= \left\langle\left[\hat{\varphi}(t) - \varphi(t)\right]^2\right\rangle + \left\langle\left[\varphi(t) - \varphi(t + \delta t)\right]^2\right\rangle \\ &= \sigma^2(t) + \kappa\delta t \end{aligned} \tag{3.6}$$

By standard error analysis, the optimal $\hat{\varphi}(t + \delta t)$ weights $\hat{\varphi}(t)$ and $\hat{\varphi}_{imm}(t + \delta t)$ appropriately:

$$\hat{\varphi}(t + \delta t) = \sigma^2(t + \delta t)\left[\frac{\hat{\varphi}_{imm}(t + \delta t)}{\sigma^2_{imm}(t + \delta t)} + \frac{\hat{\varphi}(t)}{\sigma^2_{old}(t + \delta t)}\right] \tag{3.7}$$

where

$$\frac{1}{\sigma^2(t + \delta t)} = \frac{1}{\sigma^2_{imm}(t + \delta t)} + \frac{1}{\sigma^2_{old}(t + \delta t)} \tag{3.8}$$

Taking $\delta t \to dt$ yields a differential equation for $\sigma^2(t)$ that has the stationary solution

$$\sigma^2 = 1/2\sqrt{N}, \quad \text{where } N = \alpha^2/\kappa \tag{3.9}$$

Substituting this into Eq. (3.7) gives $d\hat{\varphi}(t) = (\kappa/\sigma^2) \times (I(t)dt/2\alpha)$. Since the feedback sets $\Phi(t) = \hat{\varphi}(t) + \pi/2$, the *feedback algorithm* is simply

$$\dot{\Phi} = \frac{\kappa}{\sigma^2}\frac{I(t)}{2\alpha} \tag{3.10}$$

By way of comparison, for heterodyne (nonadaptive) detection, the stationary MSE can be shown to be [9]

$$\sigma^2_{het} = 1/\sqrt{2N}. \tag{3.11}$$

That is, the adaptive technique offers a factor of $1/\sqrt{2}$ improvement in the mean square error.

IV. What is quantum about it?

This is a question I am often asked. A feedback algorithm of the form

$$\dot{\Phi} = \chi I(t)/2\alpha \qquad (4.1)$$

looks like a standard classical phase-locking algorithm with gain χ. The quantum feature is that the optimal value of χ is finite:

$$\chi_{opt} = \frac{\kappa}{\alpha^2} = 2\sqrt{\kappa\alpha}. \qquad (4.2)$$

In the classical limit (with no other noise sources), χ_{opt} would be infinite, as can be seen by writing it explicitly in terms of classical quantities and $\hbar$:

$$\chi_{opt} = 2\sqrt{\kappa P/\hbar\omega} \qquad (4.3)$$

For general χ, the stationary MSE can be shown to be

$$\sigma^2 = \frac{\chi}{8\alpha^2} + \frac{\kappa}{2\chi} \qquad (4.4)$$

which diverges as $\chi \to \infty$. Moreover, if χ differed from χ_{opt} by a factor greater than about 2.4 (in either direction), then all advantage gained by doing an adaptive detection would be lost. That is, the MSE would become greater than that which can be achieved by the nonadaptive technique of heterodyne detection (3.11).

The advantage offered by adaptive detection is only a constant factor (of $1/\sqrt{2}$) because so far I have discussed only coherent light. To break the SQL scaling $\sigma^2 \sim N^{-1/2}$ it is necessary to use nonclassical light. The most obvious sort of nonclassical light to consider for this situation is broad-band squeezed light [14]. This is light where the spectrum of the dyne photocurrent of one quadrature, normalised as in Eq. (3.1), has a noise spectrum S below unity over some bandwidth broad compared to $\sqrt{\kappa\alpha}$. For moderate *phase quadrature squeezing* of spectral noise S, we can use the same feedback algorithm (4.1) to get an improvement in the MSE by a factor of $\sqrt{S}$:

$$\sigma^2 = \sqrt{S}/2\sqrt{N}, \quad \text{for } \chi = \kappa/\sigma^2 \qquad (4.5)$$

It would appear from this that the MSE in the phase estimate could be made as small as one desires by making the phase quadrature more squeezed. However this is not the case because the noise gets "squeezed" into the amplitude quadrature of the light [10, 14].

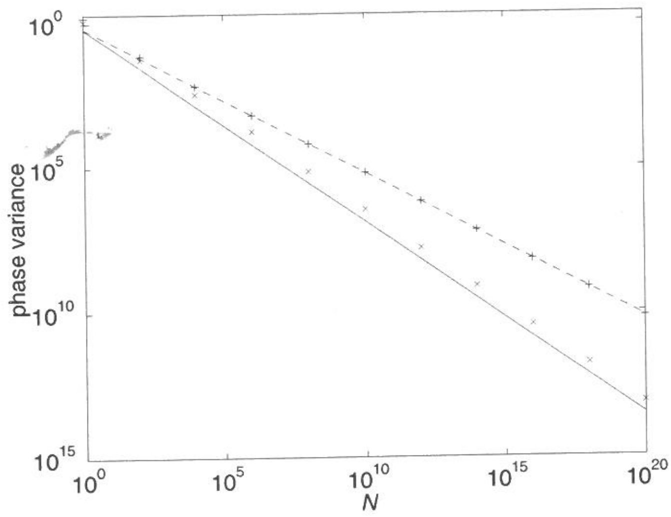

Fig. 2: Numerical results for the mean square phase error using optimal squeezing, for heterodyne (+) and adaptive (x) detection. Note that these were obtained using a more sophisticated feedback algorithm than that explained above. The analytical asymptotic results are: heterodyne (– –), $0.66/N^{1/2}$ and adaptive (—), $0.63/N^{2/3}$.

Because the local oscillator phase Φ is only orthogonal to the *estimated* system phase $\hat{\varphi}$, not the true phase φ, the amplitude fluctuations *do* contribute to the noise in the phase measurement. It can be shown that as a consequence there is an *optimal* non-zero squeezing spectrum $S \sim N^{-1/3}$. This is, in a sense, a "more quantum" feature than the existence of shot noise which gave the above limit (3.9), because it is a consequence of the uncertainty relation between amplitude and phase for a light beam [10]. In any case, with squeezed light we can beat the SQL, and find a new quantum limit for CW phase locking:

$$\sigma^2 \sim N^{-2/3} \qquad (4.6)$$

V. Experimental Progress

Performing a quantum-limited adaptive phase measurement has been one of the primary research objectives of Assoc. Prof. Hideo Mabuchi since his appointment at CalTech in 1999. As mentioned in the introduction, this is the first step towards a longer-term goal of investigating quantum-limited control in general, and in particular in cavity QED systems. This first step has proven quite challenging in its own right!

Rather than a CW measurement of a varying phase as discussed above, Mabuchi's group has been working on single-shot estimates of an unknown phase imprinted on a pulse of light, as originally considered in Ref. [1]. Here the parameter $\overline{n}$ (see table 1) is simply the mean number of photons in a single pulse on which a single unknown phase is imprinted. For an adaptive measurement, the phase must be estimated when only a fraction of these $\bar{n}$ photons have entered the detector. The fact that this can work even for $\bar{n}$ of order unity is described by Mabuchi as a "pretty wild fact that makes you think twice about field quantisation".

In this single-shot case the feedback algorithm is considerably more complicated than that in section IV, as the local oscillator phase $\Phi(t)$ may depend nonlinearly upon various integrals of the photocurrent *during the course of a single pulse* [6]. The form of these integrals can only be derived from the full quantum theory [3]. Mabuchi thus decided to use digital electronics, and to discretise the feedback algorithm.

Just as the CW result requires the magnitude of the feedback χ to be close to its theoretical optimum (as discussed in section IV), the single shot case is sensitive to the design of the feedback loop. Through numerical modeling, Mabuchi's group have found that the discretisation requires at least of order 100 divisions of the total pulse length *T*.

The only electronics fast enough to do the required processing are field programmable gate arrays [13]. These are so fast (10s of MHz) that the feedback bandwidth, of around 5 MHz, is actually limited by the bandwidth of the electro-optics (in particular the synthesiser used to modulate the feedback). This bandwidth allows each time-division to be of order 500 ns, for a total time *T* of only about 50 μs. This still required the production of a coherent state of this duration. In other words, it required light with a shot-noise limited amplitude spectrum down to about 50 kHz. This was another enormous technical challenge, as this is far below the usual frequency regime of quantum-limited experiments [14]. It was achieved using a very high Q cavity of lifetime 16 μs as a mode cleaner.

Because they are not (as yet) using any non-classical source, the experimental signature Mabuchi's group is seeking is a reduction of the MSE (by at most a factor of 2 – see table 1) below the heterodyne limit of $0.5/\bar{n}$. In work just released to the physics archive [15], this reduction has been convincingly demonstrated. Of course, much work remains to be done. For example, Mabuchi plans to investigate the tails of the distribution as well as its standard error, to verify some of the predictions of Ref. [3]. Employing non-classical light to break the SQL is another longer term goal. Other experimental groups are interested in this as well.

VI. Conclusions

Estimating an *unknown* phase φ at the quantum limit is a difficult problem. There are many different cases that can be considered, but for all of them the standard quantum limits (SQLs) for the mean-square error arise for coherent light or non-adaptive measurements. The SQLs can be beaten only by using nonclassical light *in conjunction with adaptive measurements.* When devices including phase-locking loops are sufficiently miniaturised, quantum limits will become practical limits. Thus, as well as being of theoretical interest, adaptive measurements should become part of the tool-kit of the future "quantum engineer" who seeks to manipulate quantum systems as well as nature allows.

The improvement offered by adaptive detection over non-adaptive detection in phase estimation is being sought by the group of Hideo Mabuchi at CalTech, and very recent results appear to show that it has been achieved. This experiment breaks new ground in the use of low-frequency optical mode cleaning and high-speed digital electronics in quantum-limited experiments. The theoretical and experimental techniques developed also pave the way for future research into the feedback-control of quantum optical systems in general.

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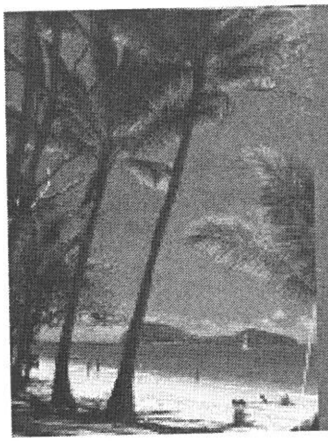
CONFERENCE ANNOUNCEMENT



ICOLS 03

16th International Conference on Laser Spectroscopy

Palm Cove, Australia

ICOLS 03 : 13-18 July 2003

Venue

The conference will be held at the Novotel Palm Cove Resort, a beautiful, year-round coastal resort 20 km north of Cairns International Airport, between Cairns and Port Douglas, in Tropical North Queensland. Palm Cove is located where the mountain rainforests of the Atherton Tableland meet the palm fringed beaches of the Coral Sea near the Great Barrier Reef.

Format

Following the tradition of ICOLS conferences, the program will consist of single sessions of invited talks and posters covering the latest developments in Laser Spectroscopy and related topics. Scheduling will allow significant time for informal discussions. The number of participants will be limited to about 250-300.

Topics

* Atomic and molecular laser spectroscopy
* Precision spectroscopy and metrology
* New methods in laser cooling
* Bose condensation, degenerate Fermi gases, and atom lasers
* Cold collisions and cold molecules
* Atom optics and interferometry
* Cavity QED
* Quantum optics
* Nonlinear optics
* Quantum computation, information, and communication
* Laser sources
* Ultrafast spectroscopy and high field physics
* Spectroscopy in biology and medicine
* Novel applications of spectroscopy

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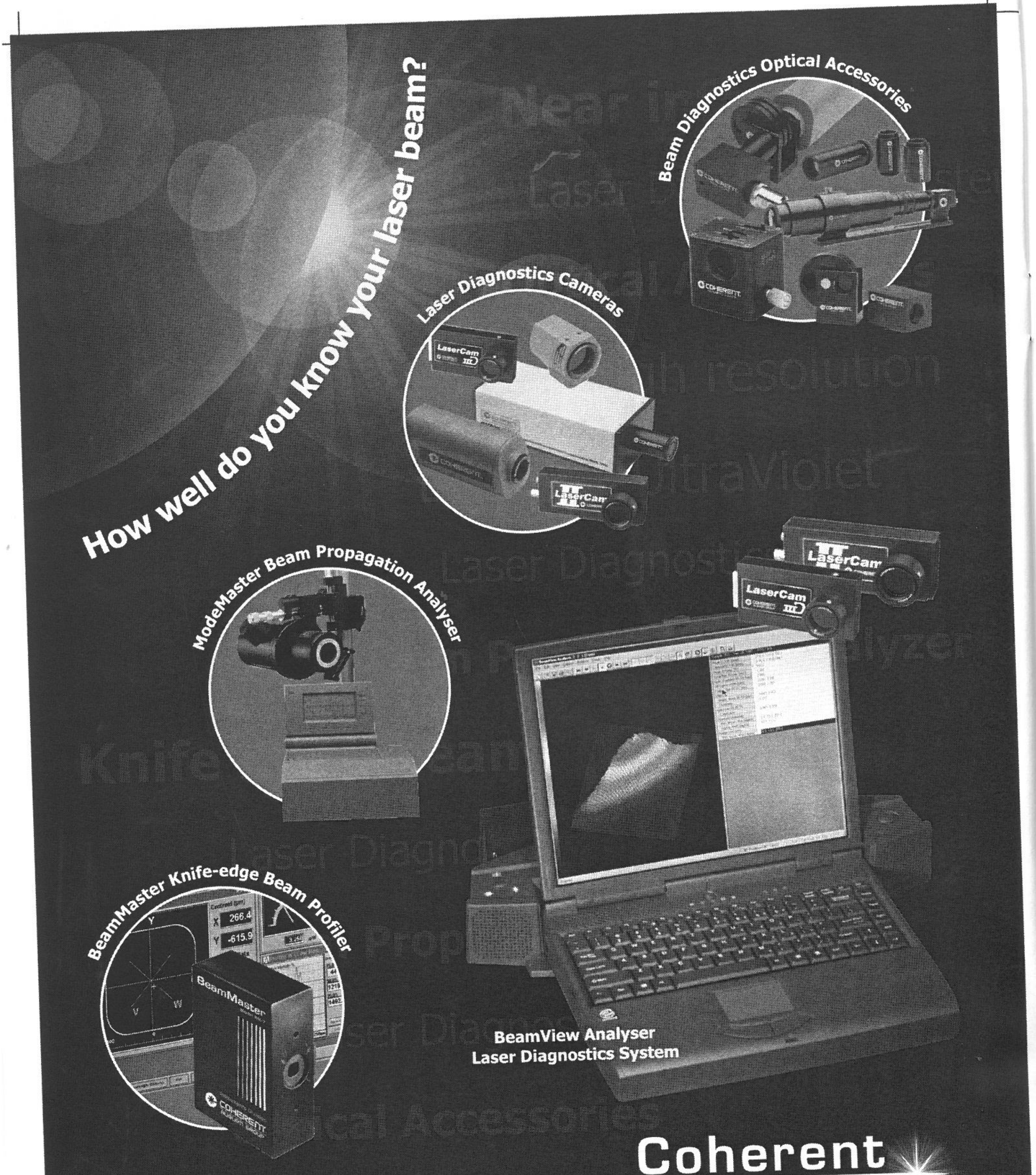
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Report from FASTS

Chris Fell

President, Federation of Australian Scientific and Technological Societies

IN SUMMARY

1. THE PRIME MINISTER AND THE "SECOND LEG"
2. PRIME MINISTER'S SCIENCE COUNCIL
3. NATIONAL RESEARCH PRIORITIES CONSULTATIVE PANEL
4. HIGHER EDUCATION REVIEW
5. WORKSHOPS FOR MEMBER SOCIETIES
6. SCIENCE MEETS PARLIAMENT DAY
7. NEW EDITION OF FASTS' POLICY DOCUMENT
8. STATE GOVENMENTS' GROWING INTEREST IN SCIENCE
9. FASTS' WEB SITE

1. THE PRIME MINISTER AND THE "SECOND LEG"

The $2.9 billion dollar Innovation Statement was launched in January 2001. At the time FASTS welcomed the funding boost as a promising first step.

But it needs far more than $2.9 billion over 5 years to allow Australia to catch up to the average OECD expenditure in science and research.

Recently I wrote to the Prime Minister asking him what his Government was planning to do about the next step, the "second leg" of the Innovation Statement. The letter read in part:

"We are concerned that some elements in your Government may regard science and technology as a job that was completed with the announcement of "Backing Australia's Ability". Our concern was heightened when you outlined the priorities for your Government in a speech to the Liberal Party Federal Council on 13 April, and science and technology was not among them."

The Prime Minister has responded, saying that his Government is still monitoring the outcomes of the initiatives announced in 2001. He goes on to say:

"*It would, however, be premature for PMSEIC to consider a 'second stage' package of spending measures before the current initiatives have been implemented fully and evaluated.*"

FASTS will continue to press for a proper national investment in science and research. You can read the full text of both letters on our web site: www.fasts.org

2. PRIME MINISTER'S SCIENCE COUNCIL

The first full PMSEIC this year was held on May 31, beginning with a dinner hosted by the Prime Minister. Although proceedings of PMSEIC and its Standing Committee are confidential, the text of three key presentations will be shortly available on the web.

The first dealt with sustainable production, pointing to the increasing need for a triple bottom line reporting within the corporate sector, and requirements by major importers of foods to have guarantees from their suppliers that sustainable production methods have been used. The Government has been asked to explore how such matters can most appropriately be handled.

The second was on biodiversity and questioned whether current government policies were coordinated in this regard; and the third dealt with aquaculture and the export opportunities that this offered.

Whilst all three presentations looked at economic considerations as well as scientific ones, there was the overriding theme that good science would be necessary for these areas to be properly addressed.

The Council was also briefed on progress with *Backing Australia's Ability* and on the Higher Education Review and the National Research Priorities processes.

3. NATIONAL RESEARCH PRIORITIES CONSULTATIVE PANEL

The Government is determined to maximise the return to Australia of our research efforts, by concentrating research in areas where we have a competitive advantage and putting new efforts into areas of weakness where we should have a stronger presence.

FASTS supports this view.

The practicalities are interesting. I am a member of an eight-person consultative panel, along with FASTS' Board Member Melissa Little (both of us serving in a personal capacity). The Panel is chaired by Chief Scientist Robin Batterham.

We have been split into two groups, with each conducting consultative meetings throughout Australia (dates and times are on the FASTS' web site).

There are two stages of the process, and two important dates for submissions:

a. determining the framework for setting national research priorities (submissions close 28 June)

b. views on what these priorities are (submissions close 9 August)

The Government intends to have priorities in place for the 2003 Federal Budget.

There appears to be common acceptance that it is appropriate for the Government to set national research priorities and that these should be both thematic and inspirational and should not direct funding to the exclusion of other promising areas of good science.

In another part of the process, Science Minister Peter McGauran consulted FASTS directly. He hosted a dinner at Parliament House for 8 members of the FASTS' Board and Executive, to discuss informally these two matters

4. HIGHER EDUCATION REVIEW

I am a member of the Higher Education Review Reference Group. The first meeting in May was primarily to discuss the process to be adopted, and to offer initial comment on *Higher Education at the Crossroads.*

DEST officers are now preparing five issues papers which will form the basis for national debate on higher education issues.

In the light of these it will be important for FASTS and its Member Societies to make submissions in which the importance of science is highlighted, both in terms of the need to produce scientists and mathematicians and for universities to participate fully in the national research effort.

I would appreciate Member Societies forwarding a copy of any submissions they may make to the FASTS office, so that I can read them personally.

Submissions close on 28 June; and further information about making them is at:

http://www.dest.gov.au/crossroads/how_sub.htm

5. WORKSHOPS FOR MEMBER SOCIETIES

I am pleased to announce that our proposal to run capacity-building workshops for our Member Societies has been successful.

The first stage will be to establish the content of the workshops. What do you as office-bearers of our Member organisations need to make your jobs easier in these challenging times? How would you like the workshops to be organised?

We have a good broad indication of what our Members think from earlier surveys, but now we need to refine these ideas.

Over the next few days FASTS will be contacting all Presidents of Member Societies, first by email and then by phone, to work out how each Society might take advantage of these workshops.

We expect to offer the first workshops by about September.

6. "SCIENCE MEETS PARLIAMENT" DAY

This event will be on Tuesday-Wednesday 12-13 November in Canberra.

It has several new features this year, including a science-industry-Parliamentarians dinner on Wednesday night, at prestigious Members' Dining Room at Old parliament House.

SmP provides an interesting opportunity to run regular business meetings of your Society, or to hold side meetings like last year's discussions on biotechnology and Nanotechnology. Please discuss these with the FASTS' office.

Full details of the program are on our web site.

Here are some comments from last year's participants:

Very well organised. The impact is becoming obvious.

The pollies are taking this seriously. I have no doubt that past SmPs have helped put science on the political agenda.

A fantastic experience. I'm glad I came and congratulations to FASTS for making it possible!

Both MPs were cordial. The level of interest in science was high and unexpected to me

And one from an obvious masochist:

Great, let's do it again. I would like more interaction with MPs - a boat trip?

7. NEW EDITION OF FASTS' POLICY DOCUMENT

The fourth edition of the FASTS' Policy Document will be launched later this year.

One of the most comprehensive statements on science policy, the document will cover all aspects of science from education, to research training, funding for science and research, and innovation.

Ken Baldwin is coordinating the production of the document as Chair of the Policy Committee. A draft will be considered by the FASTS' Board next month, and all Member Societies will have the opportunity to comment on the draft before it goes to print.

Launch of the revised policy is scheduled for mid-September.

8. STATE GOVENMENTS' GROWING INTEREST IN SCIENCE

It's wonderful to see State Governments competing over the new synchrotron, instead of those disputes about who will host golf tournaments or the Australian Grand Prix.

An illustration is the recently-reported size of the State delegations attending the world's biggest Biotechnology Conference in the US - 140 delegates from Victoria and 90 from Queensland, with both delegations headed by the premier.

SA Premier Mike Rann will also be there, along with delegations from all other States and the Federal Government.

NSW will not be sending the Premier, and not even the Science Minister - because it stands alone among all States in not having one.

This mirrors the low profile of science in the Premier State. The expansive budget NSW announced this month contained many spending initiatives, but little to stimulate the research an innovation community.

One hopes State efforts will also contribute to a national vision and priority setting.

9. FASTS' WEB SITE

Our web site should be a central source of information on science policy. As well as carrying the latest information on events such as "Science meets Parliament" Day, the site also links readers to information on current issues like the research priority-setting exercise.

All our media releases are there, as well as speeches and feedback from our events at the National Press Club.

We are putting more resources into the site (at: www.fasts.org) and will soon be upgrading to a new design. Suggestions and comments welcome.

Chris Fell
President
June 2002

EDITORIAL

There are a few important announcements in this edition that AOS members should take special note of. Firstly, members should give some thought to nominations for AOS prizes and awards. This issue has details about the AOS Medal (page 10) and the Postgraduate Student Prize (page 11). Supervisors of postgraduate students should strongly encourage applicants for the latter award. It seems that for 2002 the prize will not be awarded due to lack of applicants. The opportunity to travel and present work at an international conference is certainly worth a little effort in applying.

Thus leads to the other announcements of interest in this edition: conferences. The "Photonic Crystals Down Under" meeting will be held in Canberra from August 18–24 (see page 9). Looking further into the future, the 16th International Conference on Laser Spectroscopy will be held in Australia next year, in far north Queensland (see page 20).

This edition pays tribute to the recently passed Geoff Opat, with an obituary from Tony Klein and some other reflections. Also in this edition is some very cutting edge science, with a report on the latest theories of optical phase estimation which relate to some exciting and inspiring experiments currently underway at CalTech.

It should be noted that the AOS has a new Corporate member, Laserex Technologies. Keep in touch with all of the changes in the AOS through the website, and of course (as always) we strongly encourage comments or any other contributions to the *AOS News*. I look forward to hearing from some of you soon!

Wayne Rowlands

Meetings Calendar

The following list of optics-related conferences is compiled from several sources and should be used as a guide only.

Date	Meeting 2002	Contact	Location
Aug 4-8	ACCGE-14 - 14th American Conference on Crystal Growth and Epitaxy	OSA	Seattle, USA
Aug 11-15	Seventh International Conference on Near-field Optics and Related Techniques	OSA	Rochester, USA
Aug 16-18	2nd International Conference on Imaging and Graphics	SPIE	Hefei, China
Aug 18-24	Photonic Crystals Down Under		Canberra, Australia
Aug 19-22	Third International Conference on Advanced Optical Materials & Devices	SPIE	Riga, Latvia
Aug 22-28	Astronomical Telescopes and Instrumentation	SPIE	Waikoloa, Hawaii
Aug 25-30	19th Congress of the International Commission for Optics	EOS	Florence, Italy
Aug 25-30	Two Dimensional Photonic Crystals	EOS	Ascona, Switzerland
Aug 26-30	XIV International Symposium on Gas Flow & Chemical Lasers and High Power Lasers	SPIE	Wroclaw, Poland
Sep 1-6	ICEM-15 - 15th International Congress on Microscopy	EOS	Durban, South Africa
Sep 2-4	Nonlinear Guided Waves and Their Applications	OSA	Stresa, Italy
Sep 2-5	OWLS-VII: 7th Conference of the International Society of Optics Within Life Sciences	EOS	Luzern, Switzerland
Sep 5-8	Photonics Korea 2002	SPIE	Seoul, South Korea
Sep 8-12	European Conference on Optical Communication	EOS	Copenhagen, Denmark
Sep 9-13	7th International Symposium on Laser Metrology	SPIE	Novosibirsk, Russia
Sep 16-20	7th International Workshop on Laser Beam and Optics Characterisation	SPIE	Boulder, USA
Sep 16-27	Euro Summer School 'Optics in Astrophysics'	EOS	Cargese, Corsica, France
Sep 22-25	ISOS 2002 - 6th International Symposium on Optical Storage	SPIE	Wuhan, China
Sep 24-28	Laser Induced Plasma Spectroscopy and Applications (LIBS2002	OSA	Lake Buene Vista, USA
Sep 29-Oct 3	Laser Science XVIII	OSA	Orlando, USA
Sep 29-Oct 3	25th International Congress on High Speed Photography and Photonics	SPIE	Beaune, France
Oct 1-4	Symposium on Quantum Informatics	SPIE	Zvenigorod, Russia
Oct 7-11	27th European Conference on Laser Interaction with Matter	SPIE	Moscow, Russia
Oct 14-18	Photonics Asia	SPIE	Shanghai, China
Oct 21-23	Biomedical Optics and Photomedicine 2002	OSA	Sapporo, Japan
Oct 21-26	Euresco Conference on Quantum Optics	EOS	San Feliu de Guixols, Spain
Oct 30-Nov 1	International Symposium on Biomedical Optics and Photomedicine	SPIE	Tokyo, Japan
Nov 21-23	Advanced Topics in Optoelectronics: Micro- and Nanotechnology	SPIE	Bucharest, Romania
Date	**Meeting 2003**	**Contact**	**Location**
Jan 25-31	Photonics West	SPIE	San Jose, USA
Mar 23-28	Optical Fiber Communication Conference & Exposition 2003	OSA	Atlanta, USA
Jun 1-6	CLEO - Conference on Lasers and Electro-Optics 2003	OSA	Baltimore, USA
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