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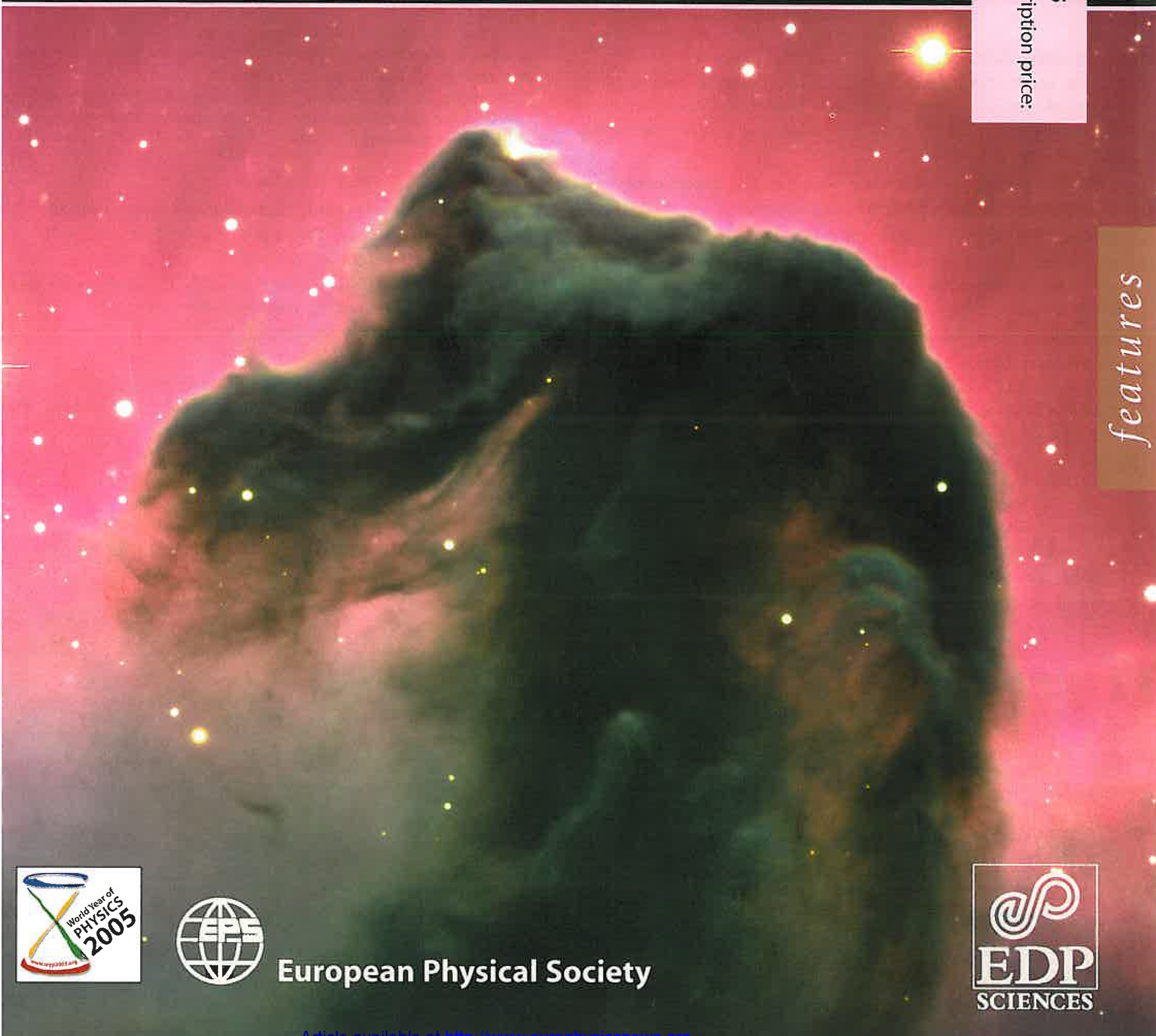

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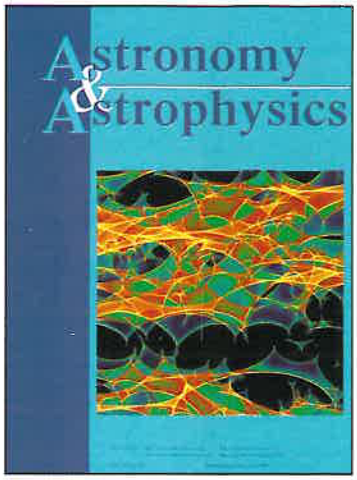

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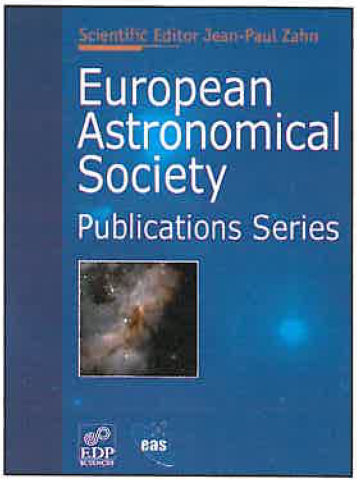

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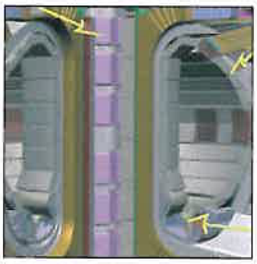

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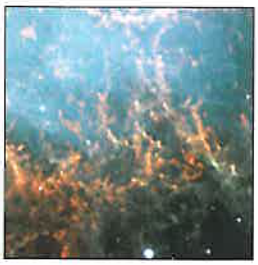

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Albert Einstein in Bern, 1905 — Bern welcomes EPS13 in 2005

Martin C.E. Huber, EPS President

In 1905, the 26-year-old Albert Einstein lived in Bern. In that year he wrote within a few months five papers, which changed the foundations of physics and our understanding of the Universe. The year 1905 therefore is referred to as Einstein's wonder year or annus mirabilis. The probably most famous among the five papers deals with what today is called the theory of special relativity. Later on, Albert Einstein received the Nobel Prize in Physics for his revolutionary article on the quantum nature of light.

As described in the last issue of europhysicsnews, the centennial of the annus mirabilis will be commemorated as the «World Year of Physics» in a large number of events taking place around the world. Bern, Einstein's place of residence and place of work during his annus mirabilis, will celebrate the centennial with a broad variety of cultural and scientific events that will culminate on 9 July 2005 in a Day of Celebration — the «Festtag» — and in the ensuing General Conference of the European Physical Society, EPS13, which will take place in the week 11 to 15 July in the University of Bern, where Einstein was a lecturer (cf. www.eps13.org).

Participants in EPS13 will be offered an outstanding scientific programme with the theme «Beyond Einstein — Physics for the 21st Century». Following a plenary Opening Session on Monday morning with talks by Thibault Damour on «100 Years of Relativity», by Ferenc Krausz on «Attosecond Physics» and by Pierre-Gilles de Gennes on «Brownian Motion», three Conferences running in parallel will cover the fields unlocked by Albert Einstein during his annus mirabilis, namely

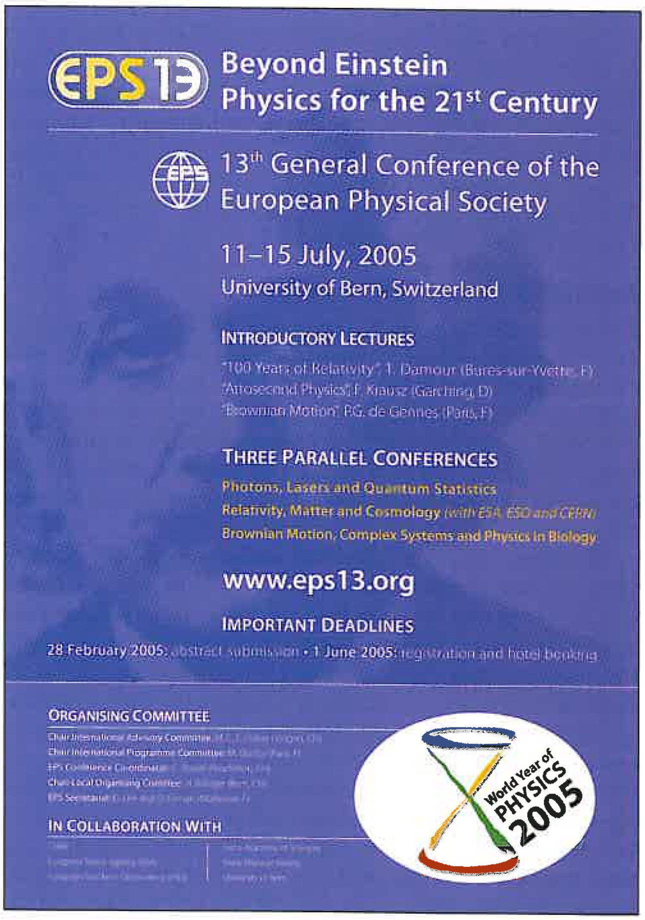
- Photons, Lasers and Quantum Statistics
- Relativity, Matter and Cosmology (which will at the same time be the triennial ESA-ESO-CERN Symposium), and
- Brownian Motion, Complex Systems and Physics in Biology.

Each of the three Conferences will feature three to four topical Symposia with ample space being given to contributed talks and posters. Thus we hope that many young scientists will be coming to EPS13 (cf. www.eps13.org). On Friday, 15 July, an Open Day will be organised jointly with the Swiss Physical Society, the Swiss Academy of Sciences, CERN, ESA and ESO. Quite likely, the other four European Inter-governmental Research Organisations (EIROs), i.e., the European Fusion Development Agreement (EFDA/JET) and the European Molecular Biology Laboratory (EMBL), the European Synchrotron Research Facility (ESRF) and the Institut Laue Langevin (ILL) will contribute to the Open Day as well.

Beyond these physics activities, participants in EPS13 will have the opportunity to attend a series of events taking place in the «Kultur-Casino» of Bern towards the end of the week preceding the conference: on Thursday and Friday, July 7 and 8, some of the best Einstein biographers will give talks and debate how Einstein arrived at the revolutionary results presented in his papers of 1905. In the morning of Saturday, 9 July, there will be a Symposium on «Perspectives of Physics in the Tradition of Einstein» with Claude Cohen-Tannoudji, Alan Guth and Anton Zeilinger as speakers. The actual celebration on Saturday afternoon (held mostly in German) will be opened by the President of the Swiss Confederation, will feature the award of the Einstein medal and comprise talks on new facts leading up to the award of the Nobel Prize to Einstein and on what it means to be a physicist today. The musical pieces performed in the course of the official celebration will include pieces by Mozart, a composer held in high regard by Einstein and the violin sonata written by Bohuslav Martinu° for the keen amateur violinist Albert Einstein (cf. www.einstein2005.ch).

On excursions to the environs of Bern and into the Alps, EPS13 participants can also learn how the popular Gruyère cheese is made, take a boat trip and attend a wine tasting, or go into the Alps and visit the International Alpine Research Station on the Jungfraujoch.

When in town, participants will be offered a reception on the first evening of EPS13 in the Historical Museum of Bern, where a major exhibition on Einstein's life and work will be presented. Participants can also explore Einstein's tracks in Bern along the newly opened Einstein Path, which gives insights at 90 places in the city on how he lived and worked there (cf. www.einstein2005.ch). EPS13-participants can also visit the «Einsteinhaus», i.e., the house, where he lived with his family from 1903 to 1905 and where he actually wrote the papers on the quantum nature of light and on special relativity. A concert on Tuesday, 12 July, with music written around the time of the annus mirabilis might also be an attraction for music lovers among us physicists, while others can in the same evening explore the medieval town of Bern and inspect the ancient clockworks in the «Zytglogge» tower.



Global warming in a nonlinear climate - Can we be sure?

Tim Palmer, European Centre for Medium-Range Weather Forecasts, Reading, UK

Picture this. It's Sunday morning and you are standing on the first tee of your local golf club, ready for that all-important first drive of the day. Settling yourself over the ball, and freeing your mind of extraneous thoughts, you begin your swing. But, half way through, a big drop of rain hits you squarely on the top of your head! It's too late to abort the swing, and with your state of concentration momentarily disturbed, your golf club strikes the ball well off centre and it ends up in a thick patch of rough, 50 yards to the right of the tee. As you walk up to the ball, the rain drops begin falling more frequently. By the time you hit your second shot, which only succeeds in moving the ball into yet deeper rough, the rain becomes persistent. At this point, you think to yourself: wait a minute, they never said anything about rain on the weather forecast last night! And so you continue your round, cursing in equal measure, your inelegant golf swing, the miserable weather and those lousy weather forecasters. Eighteen torrid holes later, you return to the club house, soaked through and in a generally foul mood. Someone turns on the TV to catch the 1 O'Clock news. Top stories are the Prime Minister's commitment to tackle the problem of climate change, and a related report that the Government's Chief Scientific Advisor has proclaimed climate change as the most serious problem facing humanity - more serious even than the terrorist threat. You've never had a view on climate change - until today. You mutter under your breath "Nothing but hot air - those bloody weather forecasters can't even get tomorrow's weather right!"

Another climate sceptic is born!

The golfers among us will no doubt sympathise with the plight of our protagonist, but as physicists, should we sympathise with the logic of his final argument? The conventional scientific view is that we should not; weather forecasting is an initial value problem, while the global warming problem focuses on estimating how long-term weather statistics are affected by some prescribed climate forcing associated, say, with a doubling of atmospheric CO_2.

However, I will conclude that whilst the global warming problem indeed poses a severe threat to humankind - with a quantified risk that the Greenland and Antarctic ice sheets would melt in the coming century - the magnitude of global warming in the coming century is still very uncertain. These uncertainties are in fact linked to those in weather prediction, through an inability to simulate key kilometre-scale phenomena in global weather and climate models. This inability arises from lack of supercomputer capacity rather than scientific capability. I believe that significant reduction in uncertainty in forecasts of climate change will require investment in significantly greater computing resources than currently available. This investment will benefit weather forecast accuracy too, and will help link weather and climate forecasting more quantitatively. Like CERN, this is an investment which may be unaffordable at the national level and which in any case will benefit from international cooperation.

Uncertainty in Weather Prediction

Perhaps the one thing all physicists know about the weather is that it is chaotic - its evolution is sensitive to initial conditions. The prototype (Lorenz, 1963) chaotic model is given by the three equations:

$$\begin{aligned} \dot{X} &= -\sigma X+Y \\ \dot{Y} &= -XZ+rX-Y \qquad (1) \\ \dot{Z} &= XY-bZ \end{aligned}$$

For suitable values of the parameters (eg $r = 28, \sigma = 10, b = 8/3$) the model has a chaotic attractor (see background in Figure 1). As discussed below, this model doesn't describe weather at all; however, like the weather it is a nonlinear dynamical system.

Because of nonlinearity[1], the growth of uncertainty depends on the initial state. This dependence is illustrated in Figure 1; initial uncertainty is represented by a small circle, and the evolution of this uncertainty is estimated by integrating equation (1) from an ensemble of initial states on this ring. Depending on the starting conditions, the forecasts can be "very predictable", "somewhat predictable", "or very unpredictable".

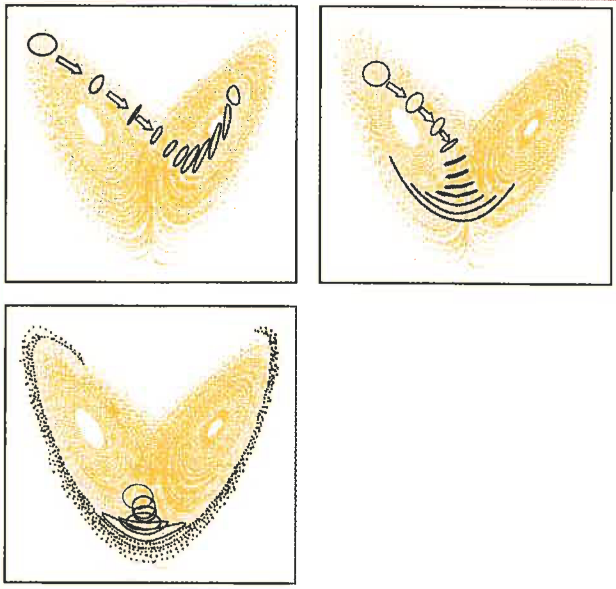
Figure 1 highlights the problem facing weather forecasters every day. Is the weather evolving through a stable or unstable part of state space? If the former, then they can be confident about the forecast; if the latter, they can't be confident. Let's take a liberty with the Lorenz model and suppose that all states on the left hand regime of the attractor are "dry" states, and all states on the right hand regime are "rainy" states. Then the predictability of the weather forecast that our golfer recalled on the first hole of his doomed round was, perhaps, like that in the top right of Figure 1: the most likely evolution is for the weather to stay dry, there is a significant probability of rain. If the golfer had been aware of the full ensemble distribution, rather than its mode, he would have known there was a quantifiable risk of rain.

Can forecasters use this ensemble technique in reality to determine the predictability of their forecasts ahead of time? In practice this is a computationally challenging problem, as the state space of a contemporary weather forecast model is several millions of times larger than that of the Lorenz model (see below). Nevertheless, in recent years, with the development of supercomputers, ensemble weather forecasts are becoming commonplace (Palmer, 2000); these ensembles start from sets of initial conditions, each of which is consistent with the available weather observations (see Fig 2 for a realistic example of an exceptionally unpredictable weather event).

However, why are the initial conditions of weather forecasts uncertain? Can we reduce this uncertainty? At a superficial level it may appear that initial-condition uncertainty arises because the thermometers, barometers and satellite instruments that remotely sense the atmosphere, do not have perfect accuracy. However, that is only part of the reason. To understand this better, and to see the link with climate prediction, we need to discuss weather and climate forecast models in more detail.

Let us return to equation (1). Lorenz derived these from the equations for a thermally-convecting laboratory fluid (the two regimes in Figure 1 correspond to distinct modes of convective

[1] If F in $\dot{X} = F[X]$ is nonlinear, then dF/dX in $\delta\dot{X} = dF/dX\ \delta X$ must depend on X



▲ Fig. 1: The background shows the attractor of equation (1). The foreground shows finite-time evolutions of (1) from three different rings of initial conditions. These initial rings represent a measure of uncertainty in the initial state. The figure illustrates the fact that in a nonlinear system, growth of uncertainty is dependent on initial state. In the top left there is essentially no growth in uncertainty - hence a prediction in evolution from the left to right-hand lobe of the attractor can be made with certainty. In the top right, there is significant growth of uncertainty, and only probabilistic predictions of regime change can be made. In the bottom left, the growth of uncertainty is explosive.

overturning). The fundamental fluid equations are nonlinear partial differential equations (PDEs); they describe a potential continuum of interacting circulations.

The climate system shares with the laboratory fluid the property that it too is described by nonlinear PDEs - the atmosphere is also a thermally-forced turbulent system. In this respect, weather and climate prediction models are similar to the Lorenz model; they correspond to a reduction of some underlying PDEs to a finite set of finite difference equations with quadratic nonlinearities. Hence the state vector of the Lorenz model is the three-component $\mathbf{X}_L = (X, Y, Z)$, whilst the state vector of a weather forecast model

$$\mathbf{X}_W = (X_1, X_2, X_3 \ldots X_{10^7}) \qquad (2)$$

has as many as 10^7 components. These components can be thought of as representing the amplitudes of circulations of different spatial scale (eg associated with a spherical harmonic decomposition of the basic fluid variables). Hence X_1 describes a planetary-scale circulation feature in the atmosphere whilst X_{10^7} represents a circulation feature near the truncation scale of the model, some tens of kilometres in the horizontal for a weather forecast model, and some hundreds of kilometres for a climate model.

The accuracy to which a particular component of the atmospheric circulation can be simulated, depends on how close this component is to the truncation scale; at the truncation scale itself, the model's representation of the atmospheric circulation is obviously very poor indeed. This issue is central to the problem of assimilating observations into a weather forecast model in order to create an initial state $\mathbf{X}_W^{(i)}$. Data assimilation is achieved by a sophisticated form of least-squares fitting, which, given the observations, finds, by minimisation, a time-evolving solution of the model equations using *a priori* error estimates of the observational instruments, and the short-range forecasts (eg Courtier et al, 1994). In such schemes there is a clearly a fundamental problem when we try to assimilate observations which are strongly influenced by circulations near or below the model's truncation scale. No matter how accurate these observations are, it is impossible to represent them properly in the model - the model equations simply do not allow the corresponding weather elements to be simulated accurately.

That is, one of the key uncertainties in the specification of the initial state arises, not because the observations themselves are uncertain, but because the model equations do not allow observations of small-scale weather elements to be properly assimilated.

At initial time, this uncertainty is confined to scales near the truncation scale. However, as the forecast progresses, the uncertainty in the initial state propagates upscale non-linearly and starts to infect the forecast accuracy of larger cyclone/anticyclone scales, ultimately affecting the forecast accuracy of the planetary scales. This is, of course, the butterfly effect.

The key to improving the accuracy of weather-forecast initial conditions is, therefore, not just better observations, but more powerful computers, so that models can better resolve the scales which (for example) the satellite sensors are capable of observing, and hence so that these observations can be better assimilated into the models. As discussed in the next section, this inability to assimilate observations of small-scale weather is also leading to major uncertainty in our predictions of climate change.

Uncertainty in Climate Prediction

If we use the Lorenz model by way of illustration, then the weather forecast problem consists of finding finite-time trajectories on an underlying attractor, as shown in Figure 1. The climate change question, on the other hand, can be thought of as the problem of estimating how the attractor as a whole will change as a result of some prescribed perturbation to the equations of motion (Palmer, 1998). However, like the weather forecast problem, there are fundamental uncertainties in predicting the impact of such a perturbation. As in weather forecasting, these uncertainties arise from the limited resolution of our models.

As mentioned, there are similarities between the atmospheric envelope in which we live, and Lorenz's laboratory convecting fluid. However, there are also some key differences. One very important difference is that the atmosphere is not a single phase fluid; water exists in the atmosphere in all three phases. Water vapour is the primary greenhouse gas in the atmosphere; feedbacks between water vapour and CO_2 are of primary importance in determining the magnitude of anthropogenic global warming. Moreover, the release of latent heat associated with the condensation of water vapour into cloud liquid water is one of the principal processes which fuels atmospheric circulations. Such latent heating occurs in frontal regions in extratropical latitudes and in deep-convective thunderstorm clouds in both tropics and extratropics. Anyone who has been in a thunderstorm knows how awesome these "heat engines" can be; anyone who has been near a multi-cell convective storm - the sort that can spawn flash floods (such as the one that caused such devastation to Boscastle in Cornwall, UK last summer), or form intense downbursts from which aircraft cannot escape, or from tornadoes which can throw vehicles and houses into the air, will not be surprised that the latent-heat energy released in one of these convective systems is comparable to that of an fission bomb. A schematic of such a multi-cell convective system is shown in Figure 3.

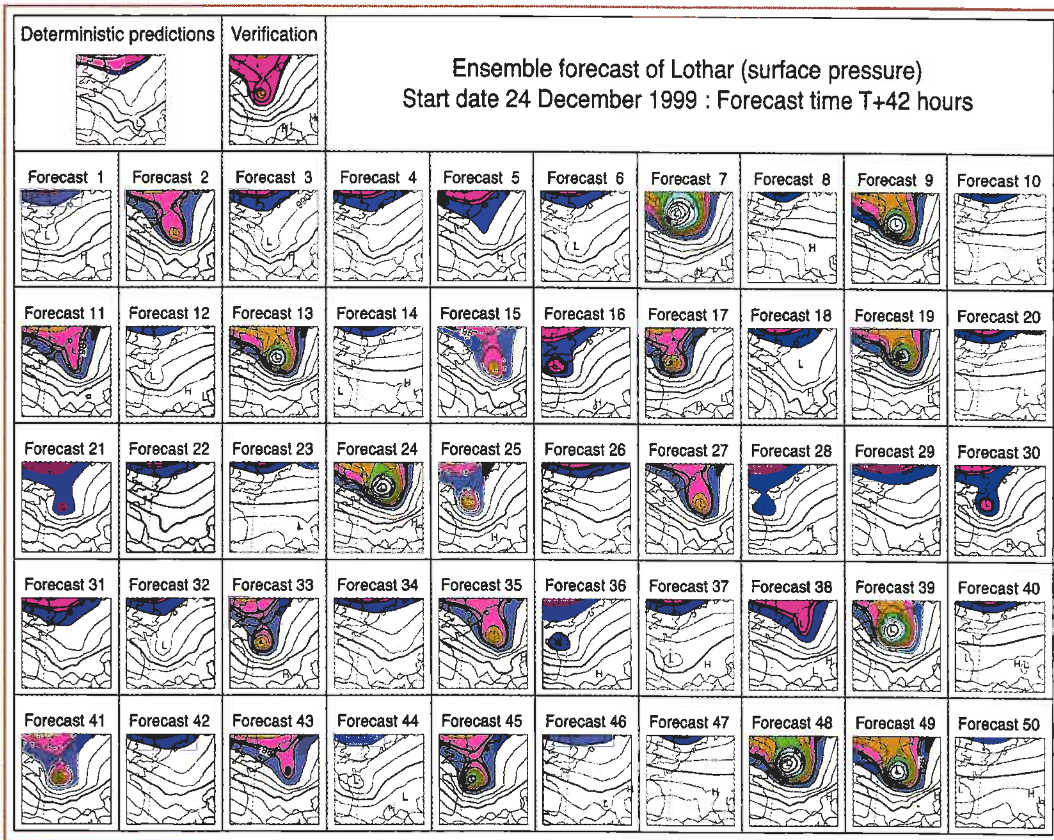
These deep convective systems have multiple roles in the climate system. They cool the Earth's surface, leading to significantly lower surface temperatures than would be expected from estimates of pure radiative balance. They transport moisture from the surface to the free atmosphere, and therefore are intimately associated in the determination of the feedback between CO_2 and atmospheric water. Also, because the atmosphere is a nonlinear system, the kinetic energy in these convective systems can trigger yet larger-scale circulations. For example, it is believed that organised deep convective storms over the tropical West Pacific can trigger eastward-propagating wave-like disturbances (known as Madden-Julian Oscillations) with scales of thousands of kilometres. In turn these wavelike disturbances can trigger the occurrence of El Nino events where much of the central and east Pacific Ocean warms. In turn, these El Nino events lead to an elevation of global mean surface temperature. This is an example of upscale energy transfer from small to planetary scales that one would expect to occur generically in a turbulent system like climate.

Because of the computational constraints discussed above, global climate models cannot resolve and hence simulate the sort of deep convective systems illustrated in Figure 3. As has been discussed, the inability to resolve kilometre-scale weather elements is a source of initial condition uncertainty for weather forecasts. What impact does this have for predicting global warming?

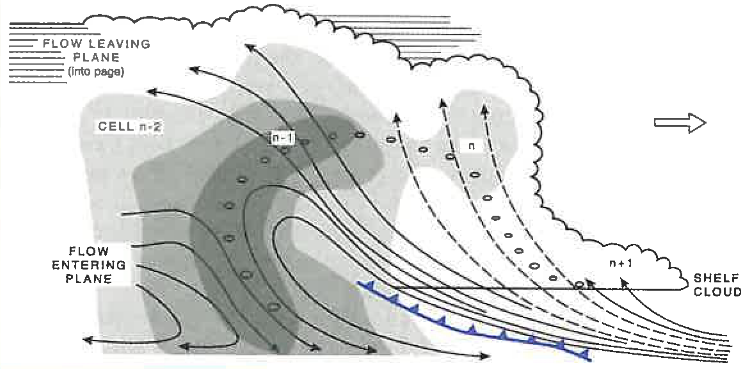
The problem faced by anyone trying to model weather and climate is that we cannot totally ignore the unresolved scales of motion. Following work of Osborne Reynolds in the 19th century and Lewis Fry Richardson in the early 20th century, we try to represent the unresolved scales in climate models by imagining an ensemble of sub-grid processes in approximate secular equilibrium with the resolved flow. The ensemble-mean (or "bulk") effect of these sub-grid processes is then given by a set of relatively simple (eg diffusive-like) deterministic formulae. We call such formulae "parametrisations" of the sub-grid processes.

In practice these parametrisations have a number of free parameters that influence the distribution of water vapour and cloud liquid water in the grid box, as well as the amount of water that precipitates out. Because of the feedbacks between CO_2-induced global warming and the distribution and amount of water in the atmosphere, these parameters can strongly influence the magnitude of simulated global warming arising from a doubling of CO_2, a quantity known as "climate sensitivity". Since the values of these parameters are uncertain, there is a corresponding uncertainty in climate sensitivity. The blue curve in Figure 4 (from Murphy et al) gives a probability distribution of simulated climate sensitivity based on a 53-member ensemble of integrations of the Hadley Centre climate model, made by varying some of the key parameters in the sub-grid parametrisations, within prescribed confidence intervals. The probability distribution of global warming is rather broad. Between the extremes of the distribution, global warming could vary from less than 2K to 8K.

A more recent study by Stainforth et al (2005) using a multi-thousand ensemble of climate change forecasts (making use of the distributed climate*prediction*.net experiment) has estimated uncertainties in forecasts of global warming which are even larger than in the Murphy et al (2004) study, with climate sensitivities ranging from less than 2K to more than 11K. An 11K warming would be catastrophic for humankind; the implications of the sea-level rise implied by the melting of the Greenland and Antarctic ice sheets are enough to focus the mind.



◄ **Fig. 2:** Isobars (lines of constant surface pressure) from a 51-member ECMWF ensemble forecast of the exceptionally severe storm "Lothar", based on initial conditions 42 hours before the storm crossed northern France in December 1999.Part of the coastline of Europe is shown for reference. The top left shows the forecast made from the best estimate of these initial conditions.This did not indicate the presence of a severe storm.The 50 forecasts which comprise the ensemble indicate exceptional unpredictability and a significant risk of an intense vortex.



◄ Fig. 3: Schematic cross section of a mature multi-cell convective system. A typical horizontal scale for such a system is a few tens of kilometres. The gray shades denote the strength of radar reflectivity. Such systems are fuelled by temperature gradients in the lower few kilometres in the atmosphere, arising from the heating of the land (and ocean) surface by solar radiation. From Browning et al (1976)

These two studies, Murphy et al (2004) and Stainforth (2005), demonstrate conclusively that global warming is a potential threat that must be taken very seriously indeed. On the other hand, the range of uncertainty is also disconcerting. In view of the unprecedented seriousness of this problem for humankind, there is an urgent need for scientists to try to make these forecast probability distributions sharper. How could we do this?

It would seem reasonable to suppose that the key to solving the problem is to reduce the uncertainties in the climate model parameters. What about more and better observations? Improving the observational base for climate is important for many reasons, however, many of the key model parameters are not directly observable. The fundamental reason for this is that the assumptions that underlie parametrisation theory are not always satisfied in any quantitative sense (Palmer et al, 2005). For example, rarely can one find, within the region defined by a model grid box, an ensemble of deep convective systems in secular equilibrium with the large-scale flow; indeed when one does, these are not the most energetically important types of convective systems.

Another way to try to determine the values of the free parameters is through a procedure that one could perhaps call "tuning". The idea is to vary sets of parameters until the climate-model simulation of large-scale well-observed features agrees with the observed global climate of, say, the last 100 years. Unfortunately, this procedure does not discriminate between different sets of parameter values as well as one might like. For example, the red curve in Figure 4 is based on a weighting of the ensemble members of the Hadley Centre ensemble, based on how well a model with particular set of parameters, fits the observations of the large-scale climate. Doing this has not decreased the uncertainty in climate sensitivity - all that has happened is that low climate sensitivity has become less likely and high climate sensitivity has become more likely.

Towards Petaflop Supercomputing

The recent ensemble-based results of Murphy et al (2004) and Stainforth et al (2005) show that uncertainties in processes which are unresolved in the current generation of climate models, lead to substantial uncertainty in forecasts of global warming (even more so, uncertainties in regional climate change). As discussed above, we cannot use observations to reduce substantially the uncertainty in these parameters, because the assumption behind parametrisation theory, that unresolved small-scale climate processes can be treated by statistical mechanical methodologies, does not stand up to close scrutiny.

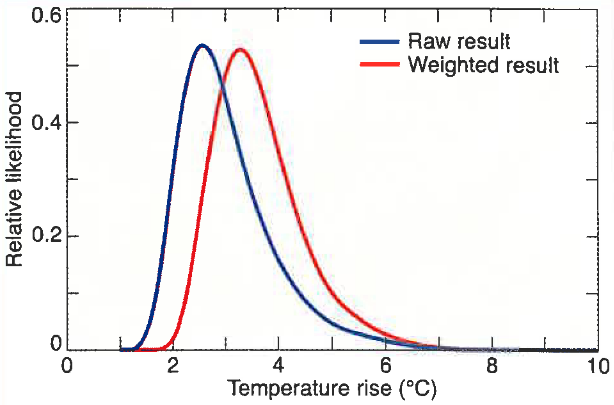
My view is that to reduce significantly the uncertainty in forecasts of climate change, global climate models should be able to resolve more of the atmospheric processes that directly determine the cloud cover and water vapour distribution in the atmosphere. In order to resolve deep convection requires grid lengths on the order of 1 km. How far are we from being able to do this? Currently the dedicated Japanese Earth Simulator (the leading climate computer at the end of 2004) runs global climate models with best sustained speeds of around 20 Teraflops (10^{12} floating point operations per second). Their standard climate change models have atmospheric grid spacing between one and two hundred kilometres. Experimental cloud-resolving models are being developed on the Earth Simulator. However, such models take a significant fraction of one day's wall-clock time to run one day of simulated climate - it would clearly be impossible to integrate such cloud-resolving climate models on the Earth Simulator for long enough to make meaningful forecasts of climate change.

To quantify climate change with cloud-resolving climate models will require computers with substantially higher performance - we must start looking towards machines with sustained speeds in the Petaflop range (10^{15} floating point operations per second).

In fact improved resolution is only one of four reasons why higher computer capacity is urgently needed for climate prediction research. The second reason is the continued need to run large ensembles of climate integrations. Even with models that can resolve deep convective processes, the effects of uncertainties in cloud microphysical parameters will have to be quantified using ensemble integration techniques. The third reason is associated with the growing complexity of climate models. Increasingly it has become recognised that climate models must include much more sophisticated representations of bio-geo-chemistry, aerosols, the cryosphere and so on. Such comprehensive models are now referred to as "Earth-System" models. Each new variable increases the complexity of such Earth-System models, requiring more processor power, and greater memory requirements for efficient integration. The final reason for enhanced computing is associated with the fact that one of the most severe tests of an Earth-System model will be its ability to simulate the paleo-climatic record, including the abrupt changes found in ice-core data (Alley, 2002). This will require model integrations of thousands of years.

It can be noted that, apart from the ensemble methodology, Grid technology alone does not offer a viable way forward to attack these issues. When a climate model is run over multiple processors, the sustained performance depends critically on how rapidly and efficiently the different processors can communicate with each other. Acceptable performance will be impossible to achieve with remotely distributed current-generation processors.

Can we be sure that investment in Petaflop computers for climate will lead to a reduction in uncertainty in global warming? I would say "yes" for two reasons. Firstly, one would reduce



▲ **Fig. 4:** Probability distributions of global average annual warming associated with a 53-member ensemble for a doubling of carbon dioxide concentration. Ensemble members differ by values of key parameters in the bulk formulae used to represent unresolved processes, in a version of the Hadley Centre climate model. Blue curve: based on "raw model output". Red curve: with the probability distribution weighted according to the ability of different model versions to simulate observed present day climate. From Murphy et al (2004).

uncertainty in simulating one of the key climatic processes: deep convection in the atmosphere. Secondly, if global climate models can be formulated at resolutions comparable with the best numerical weather prediction models, the sorts of techniques that are currently used to validate short-range numerical weather forecasts (eg Klinker and Sardeshmukh, 1992; see also www-pcmdi.llnl.gov/projects/capt/index.php) could be brought to bear on climate models. For example, recall that many of the key uncertainties in climate models are associated with poor representations of cloud processes. These processes (as opposed to the feedbacks between cloud and CO_2) have intrinsic timescales of hours. Hence, by initialising the climate models with the sorts of sophisticated data assimilation procedures used in weather prediction, as described above, and by running the models for just a few hours from many different initial states, it may be possible to reject either the high and low climate sensitivity models through their relative fit to detailed observations of cloud, humidity and temperature. At present, it is likely that climate models have too coarse resolution for these tests to be sufficiently discriminating. From this latter perspective, investment in computing for climate could be seen as important requirement for getting value for money from the corresponding investment in space-based observations of climate.

Petaflop computing is not science fiction - the main high-performance computing manufacturers are actively working towards this goal and are expected to reach it in the coming few years. In many countries, resources for such climate computing will be beyond national funding levels, eg within Europe. In any case, what would be the point of duplicating such a climate computing resource in many different national countries - like CERN, this is exactly the sort of project that should be resourced at the international level.

Postscript

Imagine this. It's Sunday morning, some years in the future. Your thirst for that perfect golf swing is undiminished, but your ability to play in the rain has deteriorated. The alarm rings; it's time to get up if you want to play golf. You glance at your laptop, set up on the bedside table. Based on the latest cloud-resolved weather-forecast ensembles, the predicted probability of mesoscale convective storms over your golf course in the coming five hours has increased to 40%; 4% higher than the predicted figure last night when you went to bed. Most likely it won't rain, but you don't want to take the risk; you get so bad tempered when it rains. With little further thought, a text message you prepared last night is sent to your golfing partners' mobile phones: "Not playing today...feeling terrible...stayed out much too late last night!"

You switch on the bedside TV. The Prime Minister has announced agreement on a new climate treaty, endorsed by all governments. As the PM explains, the change in heart has come from the latest ensemble forecasts produced at the new international petascale climate computing centre; uncertainties have been reduced to such an extent that humankind can now agree on a course of action.

It's raining outside. You smile... and go back to sleep.

About the author

Dr Tim Palmer leads a research division at ECMWF based in the UK. He was lead author of the 2001 assessment report of the Intergovernmental Panel on Climate Change, and has coordinated two European Union climate projects. He is a Fellow of the Royal Society and will give a public lecture based on this article at the Royal Society in London on the evening of April 26th.

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What will we learn from ITER?

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At the time of writing, we are once again at the threshold of an international agreement to go ahead with the construction of the ITER (International Thermonuclear Experimental Reactor) project, uniting the research efforts of Europe, Japan, China, Korea, Russia and the USA. It is very much the hope that at the time of reading, preparations at the construction site, whether in Europe or Japan, will be well underway. The project is extremely ambitious and carries a significant construction cost, roughly 500M€ per year over 10 years of construction. If built in Europe, the likely domestic cost will be 250M€ per year to the European taxpayer, including Switzerland. Although this is of course very large for a scientific research project, it still only represents the sum of 2.5€, or the average price of a small beer in Europe for each taxpayer every year, a much lower cost than many marketing projects.

Why spend so much? What will we learn from ITER? These questions have been raised in some academic circles, contesting the size of such an investment in a scientific experiment. We consider it judicious to attempt a reply, addressed to the general physics research community, explaining what will be achieved and especially what lessons will be learned. Is ITER a project in the basic sciences lineage, searching ultimate truths about the nature of the world, or about the origins of our universe? The answer is "No". Such questions have an essential purity about them, a purity that has always appealed, both to the initiated and to the uninitiated, as representing a noble cause, a scientific golden fleece. The world's largest accelerators have always received relatively constant support in Europe, in spite of the difficulty the public at large has to grasp the significance of the results obtained, or even understand the questions being addressed.

ITER is nonetheless a noble cause, even though its main motivation stems from our increasingly urgent quest for sustainable energy. The nobility resides equally in the physical understanding to be acquired of the complexity of plasmas and in the technical challenges to be met. The requirements for controlled nuclear fusion are potent drivers for advances in physics and technology. This quest has also brought a harvest of fundamental knowledge in physics, in such complex areas as turbulence, magnetohydrodynamics and even material sciences, with implications for apparently unrelated areas such as astrophysics, space physics and industrial plasmas, spawning applications ranging from plasma processing to space propulsion systems, the development of novel materials and superconductors. The ITER project is set to take this endeavour a major step further into uncharted territory.

In the following we shall try to remind the reader of the "why ITER?" with a brief introduction and then recall the present state of our research into controlled fusion using magnetic confinement of plasmas. The status today is, simply stated, that we believe that our long-term vision can become reality, but we need to make a leap forwards to demonstrate this. ITER is the long-awaited step needed to take fusion out from the present large laboratory experiment in the direction of a full power station. We shall see that our question "why ITER?" leads to a simple answer "to establish whether our vision can become real".

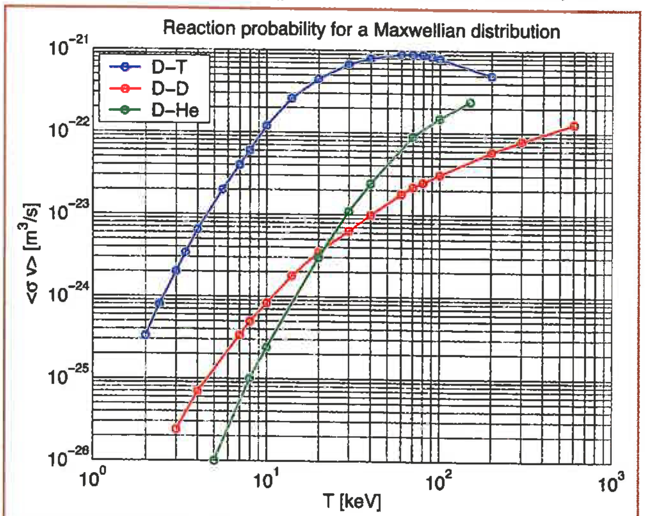
Basics of controlled fusion

A previous special issue of Europhysics News (Vol. 29, 6, Nov/Dec 1998) contained an excellent set of articles on controlled fusion research, so our introduction here is brief and the motivated reader is encouraged to return to this special issue for more details.

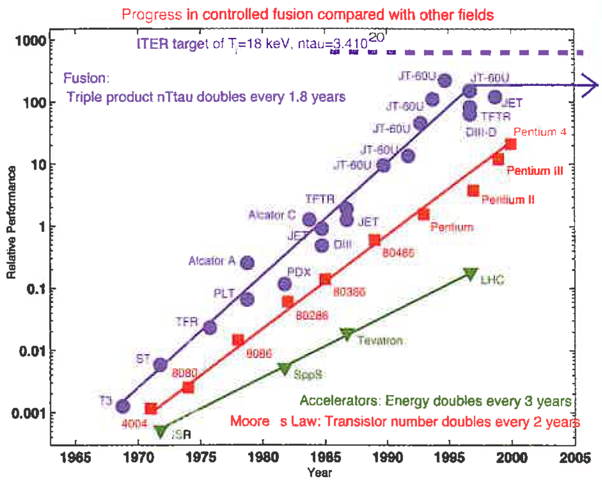
The construction of any nucleus out of its neutron and proton building blocks leaves a total mass that is slightly less than the mass of its constituents, making the nucleus more or less energetically stable. This binding energy is lowest for very large nuclei, therefore only weakly bound, and for very small nuclei, therefore also very weakly bound. This is best seen in the well-known binding energy, or missing mass curve. Breaking apart a large nucleus leaves two more stable nuclei and the difference in binding energy is released as kinetic energy of the resulting nuclear fractions, the process known as nuclear fission. Combining two small nuclei also leads to a more stable nucleus and again the difference in binding energy is released as kinetic energy of the final state products, the process known as nuclear fusion. The energy released in both classes of reaction is enormous (MeV) compared with molecular or atomic energy changes (eV).

Our understanding of nuclear fusion and of nuclear fission emerged in the 1930's. Although fission reactors started delivering power during the following decade, it's only 6 decades later that a modest 16MW of fusion power were produced for a second by the JET (Joint European Torus) tokamak sited at Culham in the UK [1]. Why is fusion power generation so much more difficult?

The underlying reason lies in a fundamental difference between fission and fusion. The problem of running a fission reactor is getting it to go slowly, releasing the energy stored in the reactor fuel (~200 GJ) over a period of 2 years rather than in a fraction of a second. The fission reaction occurs as a chain reaction, the neutrons released from one reaction triggering the following reactions. Chain reactions can run away, deliberately in a weapon and accidentally in a power plant. For the fusion reaction, there is



▲ Fig. 1: Reaction rate coefficients (cross section x impact velocity averaged over a Maxwellian velocity distribution) for the 3 major fusion reactions as a function of the ion temperature.



▲ Fig. 2: The progress of fusion performance figure of merit, $nT\tau$, compared with advances in silicon wafer technology and high energy physics accelerators. The somewhat arbitrary timescale is the date when an experiment was planned for accelerators and performed for tokamaks.

no mechanism for running away. Light nuclei fuse reluctantly because of their electrostatic repulsion. Getting them within the short range of the attractive nuclear forces requires enough energy to overcome the long-range Coulomb potential. As a result the reaction probability or cross section for fusion reactions is significant only for energies well in excess of 10keV. For self-sustained fusion reactions, the fuel must be kept hot by the heat released from its own reactions, implying a confinement scheme for the hot fuel. Criteria for self-sustaining reactions were developed by John Lawson in the early 1950's and defined a minimum value for the product of the fuel density and the characteristic confinement time of the energy in the fuel.

A second difference between fusion and fission reactions is worth recalling. There are only a few fusion reaction channels in the D-T mixture in ITER:

$$D^2 + T^3 \rightarrow He^4\ (3.5\ \text{MeV}) + n\ (14.1\ \text{MeV})$$
$$D^2 + D^2 \rightarrow He^3\ (0.8\ \text{MeV}) + n\ (2.5\ \text{MeV})$$
$$D^2 + D^2 \rightarrow T^3\ (1.0\ \text{MeV}) + p\ (3.0\ \text{MeV})$$
$$D^2 + He^3 \rightarrow He^4\ (3.7\ \text{MeV}) + p\ (14.7\ \text{MeV})$$

On the other hand, fission reactions take place by adding a neutron to create an unstable nucleus, which then splits into a large number of possible final states. This leads to an uncontrolled radioactive mixture of fission end-products, spread over the middle mass range, and remains one of the drawbacks of fission power. These differences lead to the preferred title of "controlled fusion" over "nuclear fusion" to avoid an ill-informed knee-jerk reflex of public opinion.

Fusion reactions only occur at a sufficient rate for useful power production when the nuclei have energies in the range 10-100keV and can collide almost indefinitely. The cross sections for fusion reactions are much smaller than those for Coulomb collisions between ions, excluding an energetically useful beam-target design of a reactor because most of the beam particles would slow down and thermalise without producing fusion reactions. These conditions are therefore obtained in a confined medium, where the ions have time to thermalise via their electrostatic collisions, giving rise to the original "thermonuclear" label of controlled fusion. The reaction rate coefficients for the most important fusion processes are shown in Figure 1. The Deuterium-Tritium reaction has the largest rate, and is maximum at a temperature of around 60keV (100 million degrees), at which all the light elements are completely ionised, constituting a globally neutral gas of ions and electrons called a plasma.

The plasma pressure $p \approx (n_D + n_T + n_e)kT \approx 2n_e kT$ is limited by MagnetoHydroDynamic (MHD) stability and operation close to the pressure limit provides the highest fusion power for a given temperature. This leads to an optimum operating temperature well below the 60keV at which $<\sigma v_{D\text{-}T}>$ is maximum. Beyond this optimum temperature, the increased fusion rate does not compensate the density reduction imposed by the pressure limit.

The fuel has to be isolated from any solid structure to stay hot. Magnetic fields provide the best method of stopping the energetic charged particles from hitting the wall. The dynamics of each single charged particle interacting with a magnetic field and an electric field are simply determined by $\underline{F} = q(\underline{E} + \underline{v} \times \underline{B})$. To a first approximation, the electrons and ions gyrate around magnetic field lines with a radius $\rho_L = v_\perp/\omega_c$ known as the Larmor radius, where $\omega_c = qB/m$ is the respective cyclotron frequency, rather than cross them. We have to include the radiative energy loss when a particle accelerates in the electric field of an ion, which unfortunately makes the Coulomb collisions between ions and electrons inelastic. We then have to add the nuclear reaction rates, some atomic physics to describe the ionisation equilibrium and radiative losses from collisions with impurity ions, and our knowledge of plasmas should be more or less complete. Why then is this such a complicated field of physics?

The fundamental difficulty is not simply the large number of particles, typically 10^{20} per m^3 or about 10^{23} particles in ITER. The difficulty is that when electrons and ions move, they produce magnetic fields; when electrons and ions drift apart, they create electrical fields. The particles are therefore moving in magnetic and electrical fields generated partly from the outside using magnetic coils (imposed fields) and partly as a result of the movement of all the other particles (self-consistent fields). As a result, we cannot write down a first principles prediction of the collective behaviour of the plasma particles and most importantly, of particle and heat transport through the plasma. A "neoclassical" description of transport resulting only from Coulomb collisions and particle orbits in inhomogenous fields, essentially the imposed fields, was developed more than 30 years ago, but underestimated most of the observed transport processes by 1-2 orders of magnitude. The reason is that low amplitude small scale collective instabilities, with typical wavelengths of a few ion Larmor radii, develop in confined magnetised plasmas, creating turbulence which is responsible for the lion's share of the heat and particle transport out from the hot core of the confined plasma. This turbulence is sustained by the free energy available in the gradients of temperature and number density and causes these gradients to be eroded, unless the transport is compensated by an externally provided source of heat or particles. Despite being the rule, rather than the exception, this form of transport is still referred to as anomalous.

Advances in theory and computing power are still leading to substantial progress in the modelling of anomalous transport, but it is fair to say that a first principles prediction of transport in fusion plasmas is still some way ahead. The major difficulty is associated with the disparity of scales. The ion Larmor radius is typically millimetres, but the distance covered before a fuel ion undergoes a fusion reaction is about 10^7 m. The electron cyclotron frequency is hundreds of GHz, whereas we need to confine the electrons for many seconds. The fundamental problem facing theory is to reconcile these disparate scales in a single model.

Magnetic confinement experiments

Magnetic confinement experiments have been performed since the 1940's, but it was soon realised that magnetic confinement fusion was not going to be as simple as originally hoped. Devices with open field lines, even with magnetic mirrors, produced by longitudinal field gradients, proved to be too lossy. Today all magnetic field configurations considered to have potential for fusion have a set of nested magnetic flux surfaces with twisted field lines produced by the combination of magnetic fields. The most advanced and one of the simpler ones is the tokamak, which was developed in the former Soviet Union in the 1960's and has the symmetry of a torus. The toroidal (parallel to the torus "tyre") magnetic field of the tokamak is produced by external coils like a circular solenoid, while the second, slightly weaker field necessary for twisting the field lines, is produced by a current flowing through the plasma itself in the same toroidal direction combined with the field from toroidal coils external to the plasma. In most tokamaks this current, which reached 7 million amps in JET and will be up to 17 million amps in ITER, is induced in the plasma by a transformer coil. Driving the plasma current non-inductively using particle beams or radio-frequency waves has been demonstrated in many devices and will be used in ITER.

Many tokamaks were built throughout the industrial world after the Russian successes in the 1960's. 5 million Euros get you a rather nice plasma device with a temperature around 1 keV, but not nearly hot enough, nor well enough confined, for fusion power. The seventies and eighties saw the construction of generations of successively larger tokamaks, with the three largest, JET (Europe), JT-60 (Japan) and TFTR (USA) completed in the early 1980's. These devices have already achieved the plasma densities and temperatures required for a fusion reactor, but their confinement time, the ratio of the plasma kinetic energy to the heating power, is still an order of magnitude below that required for self-sustained burning of the plasma fuel. Confinement improves as the plasma cross section increases, roughly as expected from diffusion and also increases with the plasma current. The latter is limited by MHD stability and scales linearly with the plasma minor radius and toroidal magnetic field.

Figure 2 illustrates the progress made in designing and operating tokamaks, compared with the rapid progress of accelerator energies and chip densities, the well-known Moore's law. Tokamaks have increased their performance, expressed by the product of temperature, density and confinement time, by 6 orders of magnitude in the thirty years between the first experiments and the time of the JET deuterium–tritium experiments of the last decade of the 20th century. To be sure, as size and performance increased, so did the costs and the manpower requirements, necessitating wide national and supranational funding sources and collaborations as in the case of JET, which was constructed by the members of what then was the European Community, with Swiss and Swedish participation.

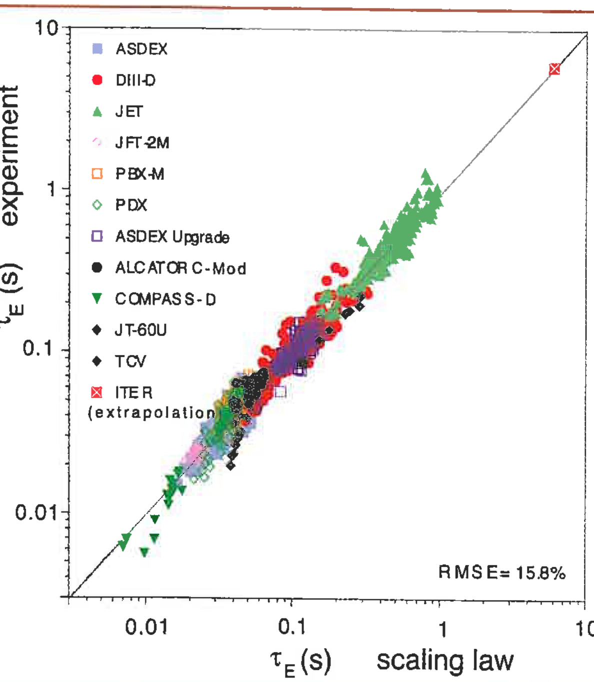
During this period, a large number of tokamaks investigated different means of heating the plasma, increasing the delivered power from the 10 kW level to the 20 MW level in present devices. At the same time, our skills in measuring the properties of the hot plasma were refined, simple "diagnostics" being replaced by huge arrays of detectors to measure the radiation and particle emission from the plasma, or to send particle or electromagnetic beams into the plasma. The advances in diagnostic techniques led to a parallel development of interpretative analysis and modelling codes. This work continues.

The next step

The last 25 years of experimental work in a large number of different tokamaks has provided us with an extensive database on fusion plasmas and most importantly, on the scaling of confinement with plasma size [2]. Projections of the performance of next step devices such as ITER and fusion reactor studies are largely based on empirical and semi-empirical scaling laws derived from this work and on theoretical models benchmarked against the experimental database. Figure 3 shows the experimental confinement time versus the empirically regressed one, together with the extrapolation for ITER.

Choosing the device to construct as a next step has been a question of optimising what will be learned from the project and how useful this information will be in going ahead in the future. In the mid-1980's, Europe was busy preparing a large project (Next European Tokamak, NET) which stalled when the multi-national ITER project including Europe, the then Soviet Union, Japan and the United States, was launched as a conceptual design activity in 1988. ITER appeared more attractive, splitting the costs. In 1992 the partners agreed to progress towards the engineering stage. Six years of international collaborative work within the framework of the ITER Engineering Design Agreement culminated in the approval by the ITER Council in June 1998 of the ITER Final Design Report, Cost Review and Safety Analysis. This provided a comprehensive design of a fusion reactor based on well established physics and technology. Its design fulfilled the overall programmatic objective of ITER - to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes.

Unfortunately, ITER itself then stalled in 1998, when countries baulked at the cost and a "reduced objectives" ITER was designed by a tripartite collaboration of the European Union, Japan and



▲ Fig. 3: Measured experimental energy confinement time plotted versus a regression from the world tokamak database [2]

features

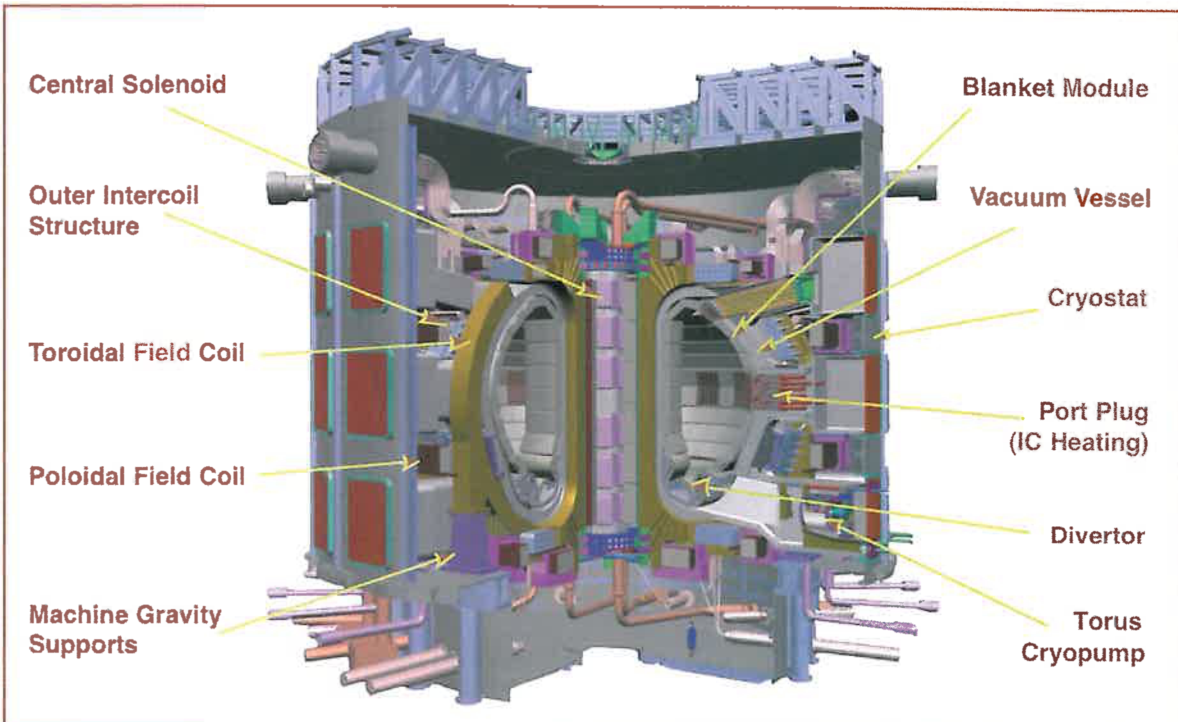
Russia, with the aim of cutting the capital investment by half, while maintaining all of the key physics objectives and as many of the technology objectives as possible, especially the programmatic objective that ITER should be a single step between the present experiments and a fusion power reactor. This redesign led to a reduced size, reduced performance, reduced margin design, delivered to the remaining parties in 2001, which ironically but not surprisingly, is not unlike the size of the NET design of the 1980's. Reference [3] provides a wealth of design information. The reduction in size also increased the pressure on researchers working on tokamak experiments worldwide to find ways of subtly enhancing the performance beyond the baseline reflected in the scaling laws.

The extrapolation of the experimentally measured energy confinement time in existing tokamaks towards ITER is illustrated in Figure 3, and is considered to be robust because ITER does not differ any more in size from JET and JT-60 than these devices themselves differ from several currently operating medium size devices. Yet ITER will enter unexplored territory. The relevant physics variables are not the engineering parameters of the device, but dimensionless parameters such as the pitch of the field lines, the ratio of plasma pressure to the magnetic pressure ($B^2/2\mu_0$), the ratio of the Larmor radius to the machine radius and the ratio of the Coulomb collision frequency to the frequency of the periodic drift motion in the inhomogenous field. The combination of the values for the two latter parameters (key parameters for anomalous transport), as required for a reactor, cannot be achieved in current devices and must be assessed by experiments in a reactor sized device.

Extrapolation of other key plasma parameters and present tokamak operating procedures to ITER also has uncertainties, because the reactor plasma conditions cannot be fully emulated in present day devices. The mission of ITER will be to demonstrate that all the physics issues, and most of the technology issues, that fusion reactors will be facing can be dealt with in an integrated way.

These issues include the effects of the alpha particle population produced by the fusion reactions on the plasma. After birth at 3.5 MeV, the alphas slow down, transferring their energy and momentum to the thermal particles, mostly to the electrons. In ITER they are expected to provide more than 2/3 of the heating power necessary to sustain the plasma, corresponding to the target fusion gain, $Q \sim 10$, where Q is the ratio of the fusion power to the auxiliary heating power. Energetic particles are known to stabilise certain usually benign instabilities in the plasma core, as well as to produce new kinds of plasma instabilities, which may enhance transport, especially that of the alpha particles, and thereby reduce the fusion power. The transport of fuel to the hot core, where most of the fusion power is released, and the transport of the resulting helium ash away from it, is also an issue. If particle transport is too slow compared with heat transport, fusion output is reduced as the fuel slowly poisons itself with helium, increasing the radiated power loss and diluting the fuel.

Other issues are linked to the 400-1000 second duration of the discharges in ITER and the necessity of actively cooling the plasma facing vessel components. The very nature, magnitude and distribution of the heat load is particularly difficult to extrapolate because of the wide variety of behaviour observed in existing devices. The last closed flux surface (LCFS), defining the confined plasma, is not in direct contact with a material wall. Beyond the LCFS a set of open field lines channel the heat and particles from the plasma towards a target area called a divertor, seen as a notch in the lower part of the vacuum vessel in Figure 4. On the way, the majority of the heat is lost as radiation, cooling the edge plasma. However part of the power flowing to the divertor arrives as millisecond bursts of energy, caused by MHD instabilities at the plasma edge, which can cause accelerated erosion of the plasma facing components, as well as contaminating the plasma with impurities and diluting the fuel. These bursts vary from insignificant to excessive in current devices, which are developing countermeasures. The general control of plasma-wall interactions needs to be demonstrated in ITER before the road is cleared towards a reactor. The avoidance and handling of potentially damaging sudden terminations of the plasma current and



▲ **Fig. 4:** View of the ITER device.

confinement, known as plasma disruptions, which can lead to large j x B forces on the in-vessel components, will also need to be rehearsed in ITER.

ITER is a formidable technological challenge that must be met before physics investigations can even begin. ITER contains 400 tonnes of superconducting Nb_3Sn and NbTi within its 48 coils and will have to demonstrate 2 decades of superconducting magnet operation. It must demonstrate that the auxiliary heating methods developed over the past three decades allow us to heat the plasma up to the point where alpha particle heating takes over. It must demonstrate the handling of high heat fluxes on the plasma facing components, especially in the divertor. It must demonstrate the capability of pumping the helium ash out of the vessel, tritium handling and fuelling. Reactors will ultimately have to produce their own tritium in breeding blankets by making use of the $n+Li^7 \rightarrow He^4+T+n$ or the $n+Li^6 \rightarrow He^4+T$ reactions, where the reacting neutrons are produced by the fusion reactions in the plasma. ITER must perform functional tests of concepts of tritium breeding blankets required for a reactor.

There remains one important technology issue that ITER is not designed to deal with, which concerns the testing of radiation resilient low activation materials that will be required for a reactor. Due to its low average operational duty cycle as a research installation, neutron induced damage in the structural materials inside the vessel, built mainly from conventional austenitic steel, will not be an issue in ITER, nor will ITER be a suitable test environment for the most stringent requirements of materials developers. The development of materials suitable for fusion reactors requires an effort parallel to the construction and operation of ITER and will involve the construction of the International Fusion Material Irradiation Facility IFMIF, a beam/target neutron source, which will generate continuous 14MeV neutron loads comparable to those of a reactor in a small test volume for material samples.

ITER is not an end in itself. It is the bridge between the devices built in the 1980's and a demonstration power plant. The essential role of ITER is to validate the tokamak fusion concept as a viable approach to power production and to develop the reactor technologies needed for any fusion power plant. The endeavour will also spur valuable fundamental advances in physics and technology. In view of the promise of fusion and of the necessity of developing new sources of energy that are environmentally acceptable and close to inexhaustible, we believe that ITER is a step well worth taking. The members of the ITER design teams have steadfastly brought this project to the point of fruition all through the difficult times of the successive design phases. Let their effort be crowned by success.

About the authors

Jo Lister and **Henri Weisen**, of British and Luxembourg origins, are involved in experimental tokamak research at the CRPP-EPFL in Lausanne, Switzerland. Jo Lister is currently chairman of the EPS Plasma Physics Division. Both authors are engaged in extensive international collaborations and are fervent supporters of a positive decision to go ahead with ITER.

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Astronomy and Astrobiology

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Astrobiology is the study of the origin of life on Earth, and whether life may exist elsewhere in the Universe. This article will seek to convey some of the new discoveries in Astronomy which relate to Astrobiology and which have energised the field. These discoveries are little isolated illuminated patches and it is difficult to link them together into a coherent picture. More questions are raised than answered, but this is only as it should be; we do not understand the origin of life, but we are beginning to assemble pieces of the puzzle.

An overview

For the range of life as we know it, we need an abundance of the elements oxygen, carbon, hydrogen, nitrogen and also traces of many others, such as magnesium, silicon, iron, aluminium, sodium, potassium, chromium, manganese, phosphorous and more, even including tungsten. All heavy elements necessary for life have been created in the interior of stars in the 13,500 million years since the Big Bang. The massive first star in the Universe [1] was formed roughly one million years after the Big Bang and exploded as a supernova. In this explosion, small amounts of elements heavier than H (and He) were made from nuclear reactions at the very high temperatures of the explosion.

The Universe reassembled, so to speak, after this first destructive event to make a generation of new stars. Perhaps 100 million years later the first galaxies formed. Their component stars were quite unlike our Sun. They were again massive, and exploded as supernovae, spreading heavy elements throughout their host galaxies. This created a medium enriched in heavier elements between the stars, an "interstellar medium". A new generation of stars formed in this interstellar medium in turbulent knots of gas with high local density, and ultimately, as for all stars, through the overwhelming force of gravitational attraction.

Recent simulations suggest that this new generation of stars contained stars was of similar mass to the Sun [2]. These stars would have been much longer-lived than earlier stars. However biology was not yet feasible since the abundance of heavy elements was still very low, for example 100 times below that of the Milky Way. Sufficient raw materials for rocky planet formation, let alone life, were still lacking. Further generations of stars lived and died, each enriching the medium between the stars with heavy elements. As time has gone by, 1.7% of H atoms created in the Big Bang have been converted into elements heavier than He.

Nine thousand million years after the Big Bang, in one of the spiral arms of the Milky Way, a Galaxy among more than 10^{11} others, a particular cloud of gas - the "pre-solar nebula" - containing the elements necessary for life, began to undergo gravitational collapse and formed the Sun. There was a sufficient abundance of elements such as oxygen, silicon, iron, magnesium, aluminium and sulphur to form rocky planets. At this juncture, we enter a realm in which our ignorance is paramount. After a few hundred million years, single cell organisms appear to have formed, though how this happened from the bare chemical ingredients of

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biochemistry remains one of the outstanding mysteries of biology. Putting this problem in biology to one side, we will concern ourselves with the problem in Astronomy of how the ingredients for biochemistry became available for evolution into living organisms.

Young stars and planets around other stars

What were the physical conditions in the gas around the very early Sun when the planets were forming? What molecules were present in this solar nebula and in what form did they become incorporated into the Earth: in a nutshell, what is the interstellar-Earth connection? Answers to these questions come from both astronomical observations and from the analysis of meteorites. First Astronomy: to study how the Sun and planets formed, we observe stars which we believe may one day be similar to the Sun, but which are forming "now" - that is, as we see them now. The closest and most heavily studied active star-forming region is the Orion Nebula, which we see as it was 1500 years ago. An infrared image of this region is shown in figure 1. In the last decade, using the Hubble Space Telescope and ground-based telescopes such as the Canada-France-Hawaii Telescope (CFHT) and the European Southern Observatory Very Large Telescope (VLT), the angular and hence the spatial resolution has become good enough to resolve objects at the distance of Orion on the scale of the solar system, that is, better than 100 Earth-Sun distances (100 Astronomical Units or AU).

Data from the Hubble Space Telescope show that very young stars ("protostars") caught in the act of formation can be surrounded by disks of dusty gas, from 50 to 1000 AU in diameter. Figure 2 shows a large (1000 AU) protostellar disk seen near edge-on in the Orion Molecular Cloud. The mass of material in this disk is enough to make more than 700 Earths - or a little more than 2 Jupiters. The inner, denser part of this disk is where planets may form, in a plane just as around the Sun. However, until a few years ago, it was only a well-informed guess that there were planets around other stars.

Our ignorance of the presence of planets around other stars has now been dispelled, only to reveal our ignorance of how planets form. In 1995, Mayor and Queloz reported a planet around the star 51 Pegasi [3]. This was the first detection of an extra-solar planet around a solar-type star and it has been followed by the detection of 123 or more planets. Some stars have been found to have two or three planets in orbit around them. For technical reasons, detections have only been made of massive planets [4], some sizeable fraction of the mass of Jupiter, which is 300 times more massive than the Earth. Therefore we still do not know if there are any Earth-like planets in orbit around other stars. Be that as it may, in many cases massive planets have been found to orbit eccentrically, approaching very close to or moving very far from their host star, in defiance of any existing theory of planet formation. Such orbits are inimical to life, since any nascent biological system would be alternately frozen and thermally decomposed. By contrast, a good candidate for life would be a planet (with an atmosphere) which performs a circular orbit at a radius such that water would not boil or freeze - in a so-called "habitable zone", comparable to that of the Earth. Liquid water appears essential to the evolution of life. The search for less massive and more bio-friendly planets is accelerating with the NASA Kepler mission (2007), the largely French COROT mission (2007), the European Space Agency EDDINGTON (maybe) and the GAIA missions (~2011), the NASA Terrestrial Planet Finder (2015) and the European Space Agency DARWIN (2015+) mission. Later missions, for example DARWIN, will also seek to find evidence for life on extra-solar planets through analysis of the planetary atmosphere gases.

▲ **Fig. 1:** The Orion Nebula imaged in the infra-red using the European Southern Observatory Very Large Telescope (VLT). The bright Trapezium stars lie at the centre of the image. To the north of the Trapezium may be seen red emission which delineates the Orion Molecular Cloud, where young stars ("protostars") are forming. This image is 180,000 by 180,000 Earth-Sun distances (AU) in scale, that is, roughly 2.7x2.7 light years. Credit : Mark McCaughrean and the European Southern Observatory (ESO)

Gas and Dust around very young stars

The gas around protostars is 90% molecular hydrogen, H_2, with 10% by number of He. A few ten thousandths of the total number density provide carbon monoxide, water, ammonia and an array of dozens of other molecules (and ions), both familiar such as alcohol and less familiar such as HCO^+. The total number density ranges from a few hundred particles per cubic centimetre (cm3) to more than 10^{11} per cm^3 close to hot massive stars. The gas temperature may be as low as 10K but for short periods of weeks, months or years may be heated to temperatures as high as 5000K or more. Small particles ("dust grains") composed of magnesium and iron silicates and carbon-based graphitic composites make up 1% of the total mass of the gas. These particles range in size from "large molecule" dimensions of a few tens of Ångstroms to microns, with many more smaller particles than larger. These grains are very cold, at typically 10K, and observations show that they are coated with a cocktail of water, ammonia, carbon dioxide and other ices. A striking effect of the presence of grains is to obscure visible starlight and create what Herschel called "holes in the sky" where there are apparently no stars. One of the most dramatic illustrations of the obscuring effects of grains is shown in Figure 3 which shows the Horsehead Nebula (Barnard 33), a dust cloud which obscures from our view in the visible part of the spectrum the stars which lie behind. The Horsehead nebula lies close to the Orion Nebula in Figure 1 that now becomes a focus of our account.

First, more than 1000 stars have formed in the Orion nebula in the last one million years and many stars are indeed evident in Figure 1: this is a prime site for observing star formation in operation [e.g.5,6]. Second, many different gas phase molecules have also been observed in the Orion Nebula. For example in a recent radioastronomy survey covering quite a narrow range of frequency [7], more than 15 different chemical species were found, including methanol, dimethyl ether (CH3-O-CH3), ethyl and methyl cyanide, sulphur dioxide, deuterated ammonia and others. To give a taste of the future, just four to five years away, the European Southern Observatory Atacama Large Millimetre Array (ALMA) will achieve a level of sensitivity in perhaps ten seconds of observing time which would require 100 hours on the telescope used in the radio-observations described in [7]. When we come to consider the message of meteorites below, we should recollect the rich molecular harvest which radioastronomy has yielded, and the still richer harvest which is just around the corner with ALMA.

Star and planet formation

How did the thousand stars in Orion form in the last one million years and how may planets have formed around them? Stars form in the cores of dusty, dense molecular clouds, such as the Orion molecular cloud associated with the Orion Nebula. This is known because at long wavelengths very young stars may be imaged buried deep in the Orion Molecular Cloud. However, the manner in which stars form remains a very contentious issue. Nature seems to perform the act of star formation - and perhaps planet formation - very readily, but it remains beyond us to create a unified model that includes the vital physics and chemistry. Certainly gravitational collapse is dominant in the brief final stage in the innermost part of the zone where the protostar is forming. However in the disk, such as that shown in Figure 2, where the planets are created, and around the protostar in general, the physics and chemistry are not known. Suffice it to say that giant planet formation is the subject of two opposing models, in the one case supposing a slow process of accretion over a period of many millions of years [8] and in the other case the formation of planets through turbulently created self-gravitating clumps of gas and dust in the disk, with an accompanying timescale of about 1000 years [9]. The factor of 1000 or more between the timescales associated with the two models speaks volumes for our imperfect understanding of planet formation.

What is observed when we look at regions where very young stars are forming, so-called "protostellar zones"? Protostars are strongly obscured in the visible because the light that they emit is absorbed and scattered by dust in the dense gas surrounding them, just as visible light is blocked out by dust in the Horsehead nebula, in figure 3. Emission is less strongly obscured in the infrared and so observations of the very earliest period of star formation are performed at the longer infrared wavelengths. It turns out that a beacon of the early stages of star-formation is emission of very hot molecular hydrogen (H_2) in the infrared spectral region around a wavelength of 2 microns. H_2 emission reveals that gas is bursting out of the protostar at speeds of 5 to 50 km/s in collimated outflows, at right angles to the plane of the disk where planets are expected to form. These flows crash into the surrounding gas, creating so-called "interstellar shocks". The shocked gas is heated and compressed by the supersonic impact and, H_2, the major constituent of the gas, emits light in the infrared as the gas cools from several thousand degrees and returns eventually to 10K. A graphic representation of a shock buried within the Orion molecular cloud is shown in Figure 4 [10]. Here we see hot H_2 moving towards us with radial velocity components up to ~20 km/s relative to the surrounding cooler gas. This H_2 ploughs through cold gas ahead of the shock and extensive chemical processing takes place. High temperature chemistry may proceed while dust grains crash into molecules at velocities of tens of km/s, the ices on their surface evaporate or are blasted off and the grains may be etched, introducing silicon and iron into the gas phase. These events take place in a medium that is already of considerable chemical complexity, as seen above from radioastronomy observations [7]. Thus the gas around the protostar becomes a veritable witches' brew of organic chemicals. Some proportion of these chemicals condense once more onto the surface of the dust grains, and are ripe for further processing by ultraviolet light, where it can penetrate into the medium, or through spontaneous surface chemical reactions or by low energy electrons which continually bombard dust grain surfaces.

The detailed nature of the complicated chemistry around protostars remains unknown, but it is a problem which laboratory experiments are starting to address. For example, it has been shown that ultraviolet irradiation of an ice mixture of water, methanol, ammonia, carbon monoxide and carbon dioxide yields 16 different amino-acids [11].

The chemical wealth of meteorites

While we may be ignorant of how molecules are synthesised around protostars, we do have entirely independent information on the final outcome of some of the chemical events in the inner protostellar disk. This information is provided through the chemical analysis of primitive meteorites. These meteorites are recent, million year old chips off much older parent bodies and the chips carry the chemical signature of the era in which the parent bodies formed.

The Murchison meteorite, which fell in Australia in 1969, is one of the most primitive meteorites known and carries the signature of the era in which the Earth was first forming, 4500 million years in the past. Many grains are found within the matrix of the meteorite and are remnants of the dust grains within the dusty clouds forming the pre-solar and solar nebulae. Murchison contains 2%-2.5% by weight of carbon and 0.09% to 0.16% by weight of nitrogen, in the form of a variety of organic matter, diamond, macromolecular organics (for example large polycyclic aromatic hydrocarbons), the bases of DNA and RNA and at least 79 different amino-acids. Of these amino-acids, there are 8 which are chemically the same as those found in present-day biochemistry, in which there are 20 active amino-acids. Seven diamino-acids have also been identified: these are constituents of peptide nucleic acids [12] which have been proposed as the earliest progenitors of life, predating RNA or DNA. A variety of sugar and sugar-related compounds has been identified in quantities similar to

▲ Fig. 2: A Hubble Space Telescope image of a disk of dusty gas around a protostar in the Orion Molecular Cloud taken through a medium-band continuum filter at 547 nm. The diameter of the disk is about 1000 Earth-Sun Distances (AU). The bright patch of light seen in the central part of the image is light from the hidden protostar reflected off clouds of dust surrounding this region. Image taken from M.J.McCaughrean and C.R.O'Dell, "Direct imaging of circumstellar disks in the Orion Nebula", Astron.J. 111, 1997

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amino-acids [13]. In addition more than 50 organic acids (carboxylic acids) up to C_{10} are present in Murchison [14]. As techniques are refined, the suite of molecules essential to living systems becomes ever broader and more suggestive of an extraterrestrial contribution to the origin of life.

One further point exemplifies the interstellar-Earth connection. In cold interstellar clouds at 10K, the precursors to the dense dusty presolar and solar nebulae, thermochemistry and surface chemical mechanisms drive molecules to replace their H atoms with D atoms, that is, to become preferentially deuterated. The deuterium to hydrogen ratio in the cosmos is ~$2x10^{-5}$. However it has proved possible to observe with radioastronomy such exotic species as triply deuterated ammonia (ND_3) [15] with an abundance orders of magnitude greater than expected on the basis of the cosmic D/H ratio. D/H fractionation, as it is called, is diagnostic of chemical processing within a very cold interstellar cloud. and thus of an interstellar molecular origin. The amino-acids in Murchison are found to have a D/H ratio which is several times greater than observed in terrestrial amino-acids. Thus the Murchison amino-acids show a clear trace of their interstellar ancestry in their relation to compounds such as deuterated ammonia, formaldehyde (HDCO, D_2CO), acetic acid and other possible precursor chemicals from which amino-acids are likely to have been formed.

The Interstellar-Earth Connection: the delivery of biochemicals from space

It is certainly fascinating that so diverse and relevant a range of biochemicals, exemplified in the Murchison, could be synthesised in the solar nebula at the time of formation of the Earth. But does this have any bearing on the origin of life on Earth? In particular, is it possible that a significant budget of biochemicals were delivered ready-made to the early Earth?

First, it is generally accepted, through crater counting on the Moon, that the early Earth was subjected to an intensive "period of bombardment" by asteroids and comets. These may themselves have delivered significant quantities of material to the early Earth. At all events, the Earth would have been subjected to heavy bombardment up to 3.9 thousand million years ago, a process gradually decreasing and largely ceasing at 3.5 thousand million years.

At this point we introduce micrometeorites. These are tiny meteorites of typically 100 microns in size, larger than interstellar grains but much smaller than familiar meteorites. Dedicated scientists, notably the micrometeorite pioneer Michel Maurette and his colleagues [16], have extracted large quantities of micrometeorites from sites in Antarctica. Studies have established that Antarctic micrometeorites (AMMs) are ancient and date back to the period of bombardment. It is also known that they contain a significant budget of "organic carbon" (carbon contained in organic chemicals). Because of the small size of AMMs, analytic techniques cannot show that AMMs contain the inventory of biochemicals that Murchison contains - but we will suppose that some do so.

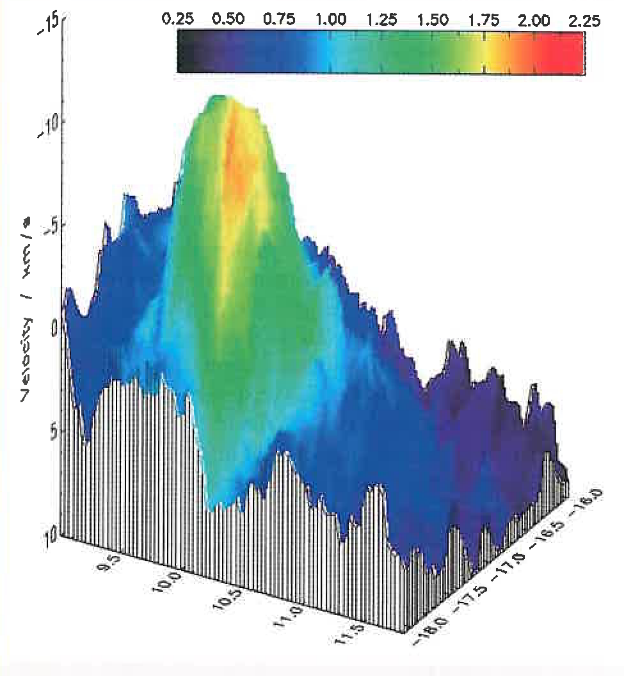
Detailed observations of AMMs show that 75% of smaller micrometeorites (50-100 microns) passed though the atmosphere of the Earth without strong melting. Hence the delicate organic chemicals which they are assumed to contain survived the passage to Earth. The present-day inventory of organic carbon falling to the Earth in the form of micrometeorites is ~500 tons per year. This is roughly $5x10^5$ times more than falls to Earth through the impact of carbon-containing meteorites, such as Murchison. The inference is that micrometeorites make the strongly dominant contribution in the delivery of organic carbon to the Earth not only at the present time but throughout the entire history of the Earth. There is now a difficult and uncertain extrapolation back in time: how much organic carbon was delivered to the Early Earth during the period of bombardment by micrometeorites? Michel Maurette in [16] suggests a figure of 1000 increase in flux of micrometeorites to the early Earth compared to the present day. This implies that the amount of organic carbon delivered by micrometeorites during the entire period of bombardment would have been 100 times greater than the total budget of organic carbon in the present-day biosphere. No doubt this figure could be questioned by other experts, but there is at least a large margin for error.

This is as far as we can go today while remaining on reasonably safe ground. To summarise, the Big Bang followed by supernovae and the passage of generations of stars within galaxies created the 36 elements that are necessary for all life on Earth. Clouds of dust and gas formed between the stars and in their midst stars and planets were created. Prebiotic molecules, that is, biochemicals, formed in interstellar space, both in the gas phase and on the cold surfaces of dust grains. On the surface of dust grains, Nature creates a laboratory in which there is locally a very high concentration of molecules, ripe for the production of larger species. Processing by high energy photons, cosmic rays and cold electrons allows molecular complexity to develop. Around protostars further chemical processing is induced by shock heating and etching, both within the protostellar disk in which planets form and around the disk in supersonic outflows of gas. The resulting primeval soup in space contains many vital precursors of biochemistry. Molecules are processed time and again in an active region such as Orion, cycled from gas to surface, becoming eventually encapsulated and protected within larger particles. These particles grow, by accretion - perhaps - to form rocky planets, or

◄ **Fig. 3:** The Horsehead Nebula, Barnard 33, in the Orion Complex. This dusty cloud of gas obscures from view the starfield that lies beyond it. The Orion Molecular Cloud, part of the Orion nebula, shown in Figure 1, lies close by in the sky and at a similar distance from the Earth. Image taken using the European Southern Observatory Very Large Telescope. Credit: European Southern Observatory (ESO).

maybe become part of the early Earth through a much more rapid process of gravitational collapse. Micrometeorites rained down upon the early Earth between 4.5 and 3.5 thousand million years ago, seeding the Earth with the basic ingredients of biochemistry. If this is a correct scenario, then it surely gives a prodigious kick-start to the evolution of life upon Earth, with the ingredients of biochemistry ready laid-out for evolution to begin. A great puzzle is of course to relate what we know of the physics and chemistry of star-forming regions to the inventory of molecules in Murchison and other meteorites.

I conclude with two conjectures. The first is this: similar biochemical material will have landed on Mars during the "period of bombardment". Given that Mars may be a fossil of the early Earth, we may find traces of early life upon Mars, initiated in the way suggested above for the Earth. Perhaps the Mars rovers, Spirit and Opportunity, that at this time are still actively exploring Mars, will shed some light on this. The second conjecture is this: the Sun is a reasonably typical star and there are more than 10,000 million stars similar to the Sun in the Milky Way. One presolar and solar nebula is likely to be much like another and thus, if Earth-like planets exist elsewhere, then they too may be bombarded by the molecular manna that appears to have been the lot of the early Earth. This supply of biochemicals may be found wherever Sun-like stars with planets are found. The widespread occurrence of "extremophiles", ice lovers, rock-dwellers, thermophiles, suggests that with the right biochemicals and over a broad range of conditions, life may evolve. Perhaps therefore life may be found throughout the Universe.



▲ Fig. 4: Molecular hydrogen emission from a star-forming region in the Orion Molecular Cloud (see Figure 1) in the infrared at a wavelength of 2.121 microns. The image shows the plane of the sky, measured in arcseconds on the x and y-axes, where 1 arcsecond = 450 Earth-Sun distances (AU), with radial velocity relative to the local standard of rest on the vertical axis. The scale is 200 times smaller than the scale in Figure 1. Colours refer to the brightness of emission. Data show the presence of an interstellar shock travelling at 15 to 20 km/s out of the plane of the sky. Data obtained using the Canada-France-Hawaii Telescope [10].

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David Field is a Professor of Physics at the University of Aarhus. He received his PhD and ScD at the University of Cambridge and worked at the University of Göttingen (1973-1975) and thereafter at the University of Bristol until 1999. His main interests are in electron-molecule collisions and observational astronomy of star-forming regions.

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features

Single photons on demand

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One hundred years since the introduction of the photon to explain the photoelectric effect, researchers are working towards creating single photons on demand. Quantum information technology is an important driver of this research effort, with single photons operating as carriers of quantum information for optical quantum computing and for quantum cryptography. Ideally, the creation of single photon on demand means providing exactly one photon, in a transform-limited wavepacket, precisely when it is required.

In reality, a variety of criteria are used to characterize a single photon source, depending on the envisioned application. Weak coherent pulses, obtained by strongly attenuating a laser beam, in order to get closer to the 'single-photon regime', provide a good comparison scale. Such pulses have a Poissonian photon number statistics, which means that they present a large vacuum component (i.e. many pulses are empty), as well as non-negligible multiphoton contributions (i.e. a fraction of the pulses contain two photons or more). By contrast, a good source of single photons should be efficient, i.e. the vacuum component (the likelihood of not getting a photon) should be small. For a given probability to get a photon, the probability to get two photons or more should be negligible compared to the Poisson value.

In addition it is desirable for applications that the source can produce a train of single photons on demand at a high repetition rate. The capability to produce single photons at or near room temperature is also desirable from a practical viewpoint. For quantum information applications, a rapid production of single photons is required to produce a large number of qubits per unit of time. Shaping of the spatio-temporal mode of the single photon is also important to provide optimal coupling efficiency with components of the quantum network, such as communication channels, quantum memory and detectors. In addition, optical quantum computation requires that all photonic qubits are identical, i.e., indistinguishable.

In recognition of the importance of single photons and the rapid advances in the field of research, the open-access journal *New Journal of Physics* has published a Focus Issue on "Single Photons on Demand". Representing the absolute state-of-the-art in the field, the issue features articles from some of the leading research groups working on single photons. This review of the contributions therefore provides an overview of the research area in 2004 and an inspiration of what is to come.

The advances reported in the issue include new and improved sources of single photons, characterization and applications of single photons, improved efficiency of single photon sources by interferometry and accepting the output field based on only certain photon counting outcomes, and preparing intracavity photon number states. Physical realizations of sources are quite varied, including quantum dots in pillar microcavities, parametric down-conversion, falling neutral atoms, trapped atoms in optical cavities, single defects in diamond nanocrystals, and individual molecules in a solid. The *New Journal of Physics* presents the latest developments in all these areas.

Moerner, from Stanford University, presents results on using single terrylene molecules in host crystals of p-terphenyl, which operate at low (liquid helium) and room temperature. Controllable emission was demonstrated for single molecules in using adiabatic rapid passage. Terrylene is a particularly interesting source as it is exhibits high photostability under continuous, intense irradiation and can operate effectively at room temperature by exploiting fast pumping into vibrational sidebands of the electronically excited state. The single-photon emission at a detected count rate of 300,000 photons per second exhibits strong antibunching, which indicates a negligible rate of multi-photon events.

Alléaume and co-workers from CNRS, the École Normale Supérieure, Laboratoire Kastler Brossel, and the Université Pierre et Marie Curie, employ the molecule DiIC18 as a room temperature single-photon source with a good photostability. They achieve strong antibunching and realized a careful analysis of intensity noise, in order to demonstrate an explicit sub-Poissonian photon statistics (negative value of the Mandel parameter) for the emitted train of single photons.

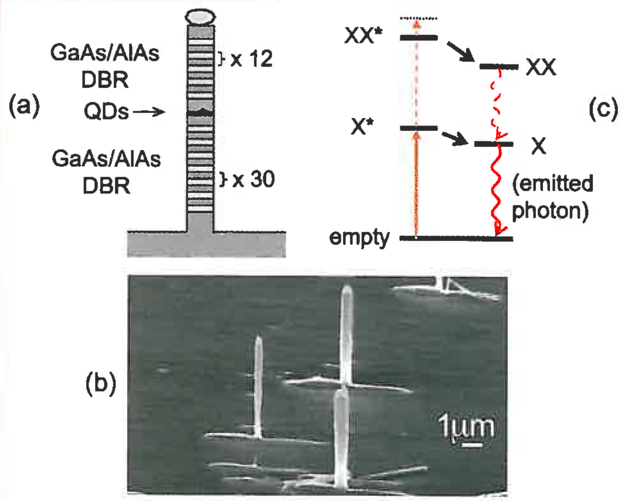
Heinrich et al, from the Max-Planck Institut für Quantenoptik, obtain single photons from neutral atoms in an optical cavity. The cooled atoms fall randomly through a high-finesse optical cavity and are driven by a periodic sequence of laser pulses. The output light is strongly antibunched, but the Poisson statistics of the number of atoms in the cavity prevents sub-Poissonian photon statistics from the source.

A collaboration by Santori et al, involving Stanford University, University of Tokyo and NTT Basic Research Laboratories of Japan, demonstrate single-photon generation with InAs quantum dots. These quantum dots are in pillar microcavities (see Fig. 1 for the schematic, scanning-electron microscope image of an actual pillar structure, and the optical excitation scheme for the quantum dot), and the effects on performance of the excitation wavelength and polarization, the collection bandwidth and polarization, are studied in detail. Measured results for efficiency of generating single photons and the purity of the states are reported, and they discuss prospects for improving these devices.

Aichele et al from Humboldt University and from ETH in Zürich also consider single photons from quantum dots. They report photoluminescence measurements from single InP and CdSe quantum dots, which produce visible photons in the visible spectral range 510–690 nm, and characterize this photoluminescence by the autocorrelation function and via Fourier spectroscopy on several transitions in the quantum dot. In particular they observe and interpret carrier trapping and recapture in InP quantum dots, which leads to anomalies in the measured correlation functions.

In an overlapping collaboration with the work reported in the previous paragraph, Zwiller et al from ETH in Switzerland and Humboldt University discuss single quantum dots as single-quantum emitters with all the requirements to generate single photons at visible and near-infrared wavelength. They also show that single quantum dots can be used to generate non-classical states of light, from single photons to photon triplets.

A collaboration between the Universities of Stuttgart, Bremen and Würzburg, reported by Benyoucef et al, study enhanced



▲ Fig. 1: (a) Schematic diagram of single-photon device, (b) scanning-electron microscope image of actual pillar structures; and (c) optical excitation scheme. Santori et al. *New Journal of Physics* 6, 89 (2004)

correlated photon pair emission from a pillar microcavity. They demonstrate efficient generation of triggered photon pairs and report photon cross-correlation measurements between bi-exciton and exciton decay, which reveals a bunching effect under pulsed excitation due to the cascaded nature of the emission and polarization correlation between the exciton and biexciton emission. They undertake a careful study of the emission mode structure of the pillar microcavities. The photoluminescence intensity of quantum dots in pillar microcavities yields an enhancement factor of forty in comparison with photoluminescence intensity of quantum dots in bulk semiconductors.

Brokmann et al, from the École Normale Supérieure, CNRS and Université Pierre et Marie Curie work with colloidal CdSe/ZnS quantum dots as single-photon sources. They show that the fluorescence of colloidal CdSe/ZnS nanocrystals at room temperature exhibits perfect antibunching under continuous or pulsed excitation, and they discuss the consequences of fluorescence properties of CdSe nanocrystals on the generation of single photons. In particular, they examine the role of Auger processes in the inhibition of multiexcitonic emission and the relationship between Auger processes and the fluorescence intermittency of CdSe quantum dots.

Gaebel and collaborators from the University of Stuttgart report on generation of single photons by optical excitation of the nickel–nitrogen complex (NE8) centre in diamond, with its most striking feature being its emission bandwidth of 1.2 nm at room temperature. The emission wavelength of the defect is around 800 nm, which is suitable for telecom fibres, and little background light from the diamond bulk material is detected in this spectral region. Consequently, a high contrast in antibunching measurements is achieved.

Two research groups propose a controlled single-photon source produced by a calcium ion in a high-finesse optical cavity, by exploiting Raman scattering of the pump. This scheme exploits the stable localization of the ion within the cavity, in contrast to the motion of neutral atoms. Maurer et al from the University of Innsbruck propose this scheme as a deterministic source of single photons and show that the efficiency of photon emission into the cavity mode reaches 95%. Keller and collaborators at the Max-Planck-Institut für Quantenoptik and the National Institute of Information and Communications Technology in Kobe show numerically that photons from the pump beam are Raman-scattered by the ion into the cavity mode, which subsequently emits the photon into a well-defined output channel, and present a proposal for an experiment.

Berry and his collaborators, from the Australian Centre for Quantum Computer Technology at Macquarie University, Imperial College, the Institute for Quantum Computing at the University of Waterloo, the Perimeter Institute for Theoretical Physics, and the Institute for Quantum Information Science at the University of Calgary, consider the improvement of single photon sources by mixing several photons in a train together in an interferometer, subjecting all but one of the interferometer outputs to photon counting measurements, and accepting the field from the last port only for specific photon counting data. They show that it is impossible to increase the probability for a single photon using linear optics and photodetection on fewer than four modes due to the incoherence of the inputs. If the inputs were pure-state superpositions, it would be possible to obtain a perfect single-photon output. In general, they show that a chain of beam splitters can increase the efficiency but at the expense of increasing the multiphoton component.

Thus far the emphasis has been on producing single photons on demand, but parametric down-conversion offers the prospect of heralded photons, by detecting one partner of a correlated pair of photons, and using the herald to effectively create a single photon on demand. Three research collaborations present advances on parametric down-conversion with heralded or on-demand single photons in mind.

Castelletto and her co-workers, from the Istituto Elettrotecnico Nazionale G Ferraris in Torino and the Optical Technology Division of the National Institute of Standards and Technology in Gaithersburg, present theory on the measurement of two-photon single-mode coupling efficiency in parametric down-conversion photon sources. Spontaneous parametric down-conversion creates two correlated photons from one pump photon at random times, which can serve as a source of photon pairs or, if one photon is detected, then as a heralded photon source with one photon being identified by detecting its correlated partner. In practice, the output light from the parametric down-converter is collected into a single spatial mode of an optical fibre. Castelletto et al consider two models for coupling parametric down-converters to single-mode fibres in a non-collinear configuration, and obtain different results for the two models. As a proper model is required for sophisticated experimental arrangements and improved collection efficiency, an experiment is proposed to test which model is valid.

Jeffrey et al from the University of Illinois at Urbana-Champaign present an experimentally feasible scheme to create single photons deterministically out of a non-deterministic spontaneous parametric downconversion source. They provide an analysis of efficiency for obtaining exactly one photon in the output and demonstrate a method for controlling the purity of an output photon using a partial measurement of a polarization-entangled photon pair, which is a partial implementation of remote-state preparation. The combination of these two techniques could allow on-demand preparation of single photons in arbitrary states.

The team of Fasel and co-workers from the University of Geneva, the CNRS, and the University of Nice–Sophia Antipolis report on the experimental realization and characterization of an asynchronous heralded single-photon source based on spontaneous parametric down-conversion. The 1550 nm photons are heralded as being inside a single-mode fibre with more than 60% probability, and the multi-photon emission probability is reduced by a factor of up to more than 500 compared to Poissonian light sources. These figures of merit, together with the choice of telecom wavelength for the heralded photons, are compatible with practical applications needing very efficient and robust single-photon sources.

Photodetectors are critical tools for heralded photons and also the photon efficiency enhancement proposal of Berry et al. Romestain et al of CNRS and CEA present superconducting photodetectors as an alternative to traditional photon counting systems such as photomultiplier tubes and avalanche photodiodes. They explain that different mechanisms are exploited to detect photon absorption, depending on the type of detector, whether it is a transition edge sensor, a superconducting tunnel junction, or a hot electron bolometer. Following a brief introduction to the first two types of detectors, the hot electron bolometer made with very thin superconducting NbN films is discussed in detail. This latter detector is promising due to its unique capability of fast single-photon detection.

Whereas the emphasis thus far has been on producing single photons, Varcoe and co-workers from the University of Sussex and the Max Planck Institute for Quantum Optics review their work on the creation and detection of arbitrary photon number states in the micromaser. Specifically they demonstrate the creation of steady-state Fock state via trapping states and the creation of dynamic Fock state via state reduction of lower state atoms. Furthermore, they analyze their experimental results regarding the creation of Fock states on demand.

Alléaume and co-workers, from Institut d'Optique and the École Normale Supérieure de Cachan describe the implementation of a BB84 quantum key distribution system using a single-photon source. The experimental scheme is depicted in Fig. 2, and shows that each photon is transmitted through free space and classical communication is via the internet. A single nitrogen-vacancy colour centre in a diamond nanocrystal serves as the single photon source. They show that, for strong attenuation of the photons through the open night air, the use of pure single-photon states yields a measurable advantage over systems relying on weak attenuated laser pulses.

In summary, this focus issue presents a quite complete overview of state-of-the-art single photon generation in 2004, and reports advances with sources of single photons on demand and heralded photons. The articles also describe methods for characterization, enhancement and application of these single photon sources for quantum cryptography and quantum information processing.

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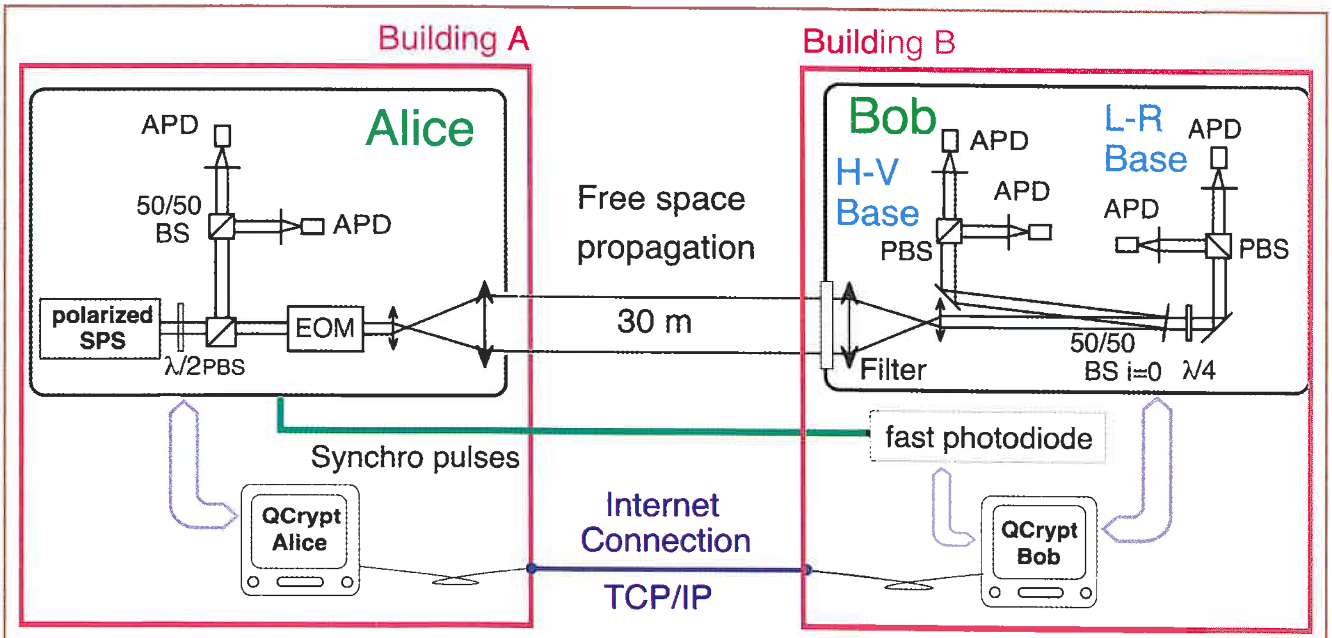
All contributions to the Focus Issue on 'Single Photons on Demand' published in New Journal of Physics (www.njp.org), are free-to-read and may be accessed directly at http://stacks.iop.org/1367-2630/6/i=1/a=E04



▲ Fig. 2: Experimental set-up for our quantum key distribution system based on a polarized single photon source. This system corresponds to the implementation of the BB84 protocol. It was operated at night using a free space quantum channel between Alice and Bob and the internet as the classical channel. APD, silicon avalanche photodiode; BS, beam splitter; PBS, polarizing beam splitter; EOM, electro-optical modulator; λ/2, achromatic half-wave plate; λ/4, achromatic quarter-wave plate. Alleaume et al. *New Journal of Physics* 6, 92 (2004)

The aftermath of Core-Collapse Supernovae

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The lifecycles of stars considerably more massive than the sun show that they end in spectacular events in which the core collapses and the outer parts are ejected in a tremendous explosion. The Rosetta stone for the end states of such stars has been the Crab Nebula and its association with the supernova of 1054 (SN 1054) (Fig. 1). The amorphous radiation from the interior of the nebula was identified as synchrotron radiation from relativistic particles in the 1950's, but the source of the particles was not known until the discovery of a central pulsar, a rapidly rotating magnetized neutron star, in 1968. The spin-down of the central pulsar, with its 33 msec period, was shown to account for the energetic requirements of the nebula. The synchrotron radiation implies the presence of a relativistic bubble of magnetic fields and particles, which are responsible for sweeping the surrounding stellar ejecta into a shell.

In a young (age ~1000 yr) supernova remnant, the pulsar is expected to affect the inner part of the exploded star, while the outer part of the star interacts with the surrounding medium. In the Crab Nebula, we see the inner pulsar bubble, but we have not detected the interaction with the surrounding medium. This has been a long-standing puzzle with the Crab.

For many years, the Crab pulsar and the older Vela pulsar were the only pulsars that could be clearly linked to the explosive remnants of supernovae. That situation has recently changed; the number of pulsars with surrounding remnants is greater than a dozen. A combination of factors has allowed this advance, but particularly important has been the launch of X-ray space observatories with excellent spatial resolution and sensitivity (ASCA, Chandra, XMM-Newton). These observations have shown that a young pulsar in a supernova remnant is typically surrounded by a pulsar-generated nebula of relativistic particles and magnetic fields generated by the central pulsar as in the Crab Nebula. In many cases, the interaction with the surrounding medium is also observed.

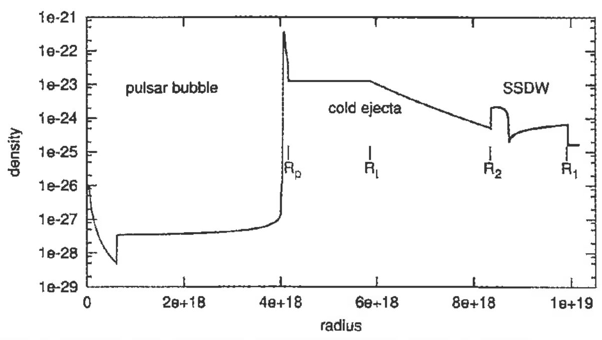
At the same time as these discoveries, there have been advances in our understanding of the final evolution of massive stars and the various types of core collapse supernovae. Core collapse is believed to occur in stars with an initial mass >8 $M_\odot$, where $M_\odot$ is the mass of the sun. Above that mass, the final outcome depends on the rate of mass loss and the core development at the center of the star. Observations of stellar mass loss and evolutionary studies of massive stars show that mass loss rates increase with increasing initial stellar mass (and luminosity). These differences in presupernova mass loss can be linked to the different supernova types and, ultimately, to the different kinds of core collapse remnants. The aim of this paper is to describe these links and the implications for the end states of massive stars. Full details and references can be found in Chevalier (2005).

Supernova types

Stars just above the limit for core collapse are expected to end their lives as cool, extended red stars, with most of their hydrogen envelope intact. The explosion of these stars leads to a luminous supernova over an extended time (100 days) during which the light is from the heated hydrogen envelope. This type of explosion can be identified with Type IIP supernovae, where the II implies that hydrogen is present in the spectrum and the P stands for a plateau in the light curve. Above some initial mass, around 25 $M_\odot$, most of the hydrogen envelope is lost during the stellar evolution, but there is enough left to give an extended envelope at the time of explosion. These objects can be identified with Type IIL (linear light curve) in which there is a more rapid drop from light maximum than in the IIP case. Above a higher mass, around

◂ Fig. 1: Optical image of the Crab Nebula. The reddish, filamentary emission is gas from the exploded star that has been swept out by the pulsar bubble. The bluish, smooth emission is synchrotron radiation from relativistic particles that have been accelerated by the pulsar power (European Southern Observatory, Very Large Telescope).

features



▲ **Fig. 2:** A one-dimensional model for a young supernova remnant (age 500 yr); the density is in gm cm^{-3} and the radius in cm. Starting from radius = 0, there is a freely expanding pulsar wind, a region of shocked pulsar wind (pulsar bubble), a swept up shell of ejecta bounded by a shock front at Rp, a region of cold, freely expanding ejecta, and a region of hot gas (SSDW) bounded by a reverse shock at R_2 and a forward shock at R_1 (from Blondin, Chevalier & Frierson 2001).

35 $M_\odot$, the hydrogen envelope is completely lost during the stellar evolution. These stars are observed as relatively compact, hot stars. The explosions of these stars can be identified with Type Ib or Ic supernovae, which do not have hydrogen in their spectra.

The rate of star formation is dominated by the lower mass stars, so that the expected rate of Type IIP supernovae is about 10 times the rate of Type IIL and 5 times the rate of Type Ib/c. Observational data are not yet sufficiently detailed to determine the relative rates. However, the above results are for single massive stars. A significant fraction of massive stars are in binary systems and mass transfer and loss due to binary effects could influence the relative rates of various core collapse supernovae. The importance and detailed effects of binary evolution remain one of the most uncertain aspects of stellar evolution.

Supernova properties

The central core collapse in a massive star triggers an explosion of the rest of star, by a mechanism that remains poorly understood. A mechanism involving transfer of energy from neutrinos has been favored, but has not yet provided a convincing model for an explosion; this has recently led to the exploration of other possible mechanisms, involving rapid rotation and magnetic fields. In the immediate aftermath of the explosion, the behavior of the layers near the collapsed core depend on the explosion mechanism, but, as one moves out in the star, the shock acceleration of the stellar layers is primarily determined by the explosion energy. The eruption of the explosion shock from stellar surface gives a burst of hard, typically ionizing, radiation. This emission has not yet been directly observed from a supernova, although the effects of such emission can be seen in the nearby supernova SN 1987A.

The time for the shock front to traverse the star is < 1 day, and is followed by a period in which the internal energy of the explosion is converted to kinetic energy. After about a week, the expansion tends towards a homologous, free expansion. The density profile that is set up by the expansion is fairly flat in the central region and has a steep power law profile in the outer parts where the shock front has accelerated through the decreasing density layers of the star. The density of gas at a given velocity drops as t^{-3} due to the 3-dimensional expansion. The typical energy of a core collapse supernova is 10^{51} ergs (10^{22} H bombs).

As described above, the supernova types IIP, IIL, and Ib/c have increasing amounts of mass loss, which has implications for the composition distribution of the freely expanding ejecta. In a Type IIP supernova, most of the explosion energy ends up in the H envelope, whereas in the other types, the energy is in heavy element rich material. If the explosion were strictly radial and spherically symmetric, the explosion would have a set of composition layers, like an onion, with the heaviest elements at the center. Actually, composition discontinuities can be accompanied by strong density gradients; when the denser, interior material is decelerated by the outer lower density material in the explosion, the interface is subject to Rayleigh-Taylor instabilities. The result is that clumps of heavy elements go out to high velocities, while bubbles of light elements move to low velocities. The effects of this redistribution of elements can be seen in the late spectra of supernovae, when the ejecta have become optically thin.

The deceleration of an inner layer is accompanied by a reverse shock wave, a shock front that eventually moves back toward the center of the explosion. Material brought back to the center in this way can be important for fallback onto the central compact object. Some fallback is expected for gas that is marginally bound to the compact object. In high mass stars, including most single stars that are expected to end as Type IIL or Ib/c supernovae, the fallback is expected to be strong, leading to the formation of black holes. In other cases, the accreted mass is <0.1 $M_\odot$. The nature of the fallback can depend on the type of supernova. Even if the neutron star is born with slow rotation, the inward mixing of material can bring higher angular momentum material into the vicinity of the compact object.

Finally, different types of circumstellar medium, built up by stellar mass loss, are expected in the different types of supernovae. The speed of a stellar wind is related to the escape velocity from the star, so that extended red supergiant stars, which are the expected supernova progenitors of stars with hydrogen envelopes, have relatively slow winds (v_w=10-20 km s^{-1}). These stars thus have a relatively high surrounding wind density, Ůw, because in a steady spherical flow $\rho_w=(dM/dt)/(4\pi r^2 v_w)$, where dM/dt is the mass loss rate and r is the radius from the center. The value of dM/dt depends primarily on the luminosity of the star, which is higher for the higher initial mass stars. Thus, for single stars, the Type IIL supernovae are expected to have the densest circumstellar winds, while the Type IIP are at lower density. Binary interaction can also lead to dense winds in Type IIL supernovae. The expansion of the wind is ultimately limited by the pressure of the surrounding medium. The high ram pressure in the denser winds means that they can expand out 5 parsecs (1 parsec = 3.26 light-years = 3.09 x 10^{18} cm) or more from the progenitor star. Type Ib/c supernovae are thought to have more compact progenitors with higher velocity winds, v_w=1000 km s^{-1}. Their mass loss rates are comparable to those expected around Type IIL supernovae, but the high wind velocity leads to a relatively small surrounding density.

These expectations have been borne out by observations of extragalactic supernovae at ages up to a few years. The interaction with the surrounding wind can be observed at radio and X-ray wavelengths, as well as optical in the case of a dense wind. The interaction with the wind gives rise to hot shocked gas and relativistic particles that are probably produced by the shock wave acceleration mechanism. The relativistic electrons radiate synchrotron emission in the magnetic field of the shocked region. The early absorption of radio synchrotron emission and the synchrotron luminosity provide indicators of the circumstellar density. The thermal emission from the hot gas at X-ray wavelengths provides another estimate of the circumstellar density. The new X-ray observatories (*Chandra, XMM-Newton*) have made the detection of nearby extragalactic supernovae routine. The circumstellar densities inferred around the various types of supernovae are roughly in accord with expectations.

Pulsar wind nebulae

The presence of a pulsar inside of a supernova generates a bubble of relativistic fluid inside of the supernova. The spinning neutron star loses rotational energy through a magnetized wind that moves out from the pulsar at highly relativistic velocity. In order to be compatible with the slow moving gas outside of the bubble, the wind must pass through a shock wave that decelerates the wind and converts the wind power to internal energy (Fig. 2). This type of model was first applied to the Crab Nebula, where it was found that the position of the wind termination shock was compatible with the observed position of filaments in the synchrotron emission. A description of the pulsar wind nebula as a bubble of relativistic fluid, with adiabatic index 4/3, provides an initial approximation to the pulsar nebula.

The pulsar wind nebula expands into the freely expanding ejecta of the supernova (cold ejecta in Fig. 2). If the pulsar power input is steady and the inner density profile of the supernova can be described by a power-law in radius, $\rho \sim r^{-m}$ (with m about 1), the interaction is self-similar and the radius of the wind bubble increases as a power law in time, $R \sim t^{(6-m)/(5-m)}$. The radius accelerates because the bubble is sweeping up gas that is expanding away from it. The fact that a light fluid is accelerating a denser fluid gives rise to the Rayleigh-Taylor instability, which is the likely origin of the filamentary structure observed in the Crab Nebula (Fig. 1). The acceleration of filaments in the Crab is directly indicated by the fact that the expansion age of the filaments is less than the age of the parent supernova SN 1054.

If the pulsar maintains its power and the bubble is able to expand into the steeply dropping part of the supernova density profile, the relativistic fluid can break out and fill the volume out to the shell of circumstellar interaction. The energy from the pulsar required to do this is comparable to the kinetic energy of the supernova, $\sim 10^{51}$ ergs, which places an upper limit on the initial rotational period of the pulsar, about 9 msec. No observed nebulae appear to have undergone this rapid expansion, implying that they do not begin building a relativistic bubble at such a high spin rate. If pulsar nebulae do not reach the breakout phase, they are either in an early phase of steady power input (assuming no evolution of the pulsar magnetic field), or the pulsars have spun down from their initial rotation rates. The evolutionary status of a nebula can be estimated by comparing the kinetic and internal energies of the nebula to $(dE/dt)t$, where dE/dt is the pulsar power output and t is the age of the nebula.

Young supernova remnants with pulsars

The presence of a pulsar wind nebula inside of a supernova remnant gives valuable diagnostic information on the nature of the supernova. In the case of the Crab Nebula, the emission from the shell of ejecta shows the presence of hydrogen moving at about 2000 km s^{-1}, as expected in a Type IIP supernova. The outer edge of the Crab Nebula is observed to be in essentially free expansion, as expected for expansion into the supernova ejecta. The observed radius and acceleration of the gas shell are consistent with acceleration by the pulsar wind bubble. No circumstellar interaction around the Crab Nebula has been observed, despite extensive multiwavelength efforts. In a Type IIP model, this can be attributed to expansion into the low density wind bubble left from the main sequence phase of evolution of the massive star progenitor. This is the initial, and longest, phase of evolution for a massive star; the star has a strong, fast wind that can create a low density region around the star. Early interaction with the red supergiant wind would have led to hot gas that adiabatically expands and becomes unobservable. Although this scenario is plausible, a definitive case has not yet been made and deeper searches for emission surrounding the Crab Nebula are needed.

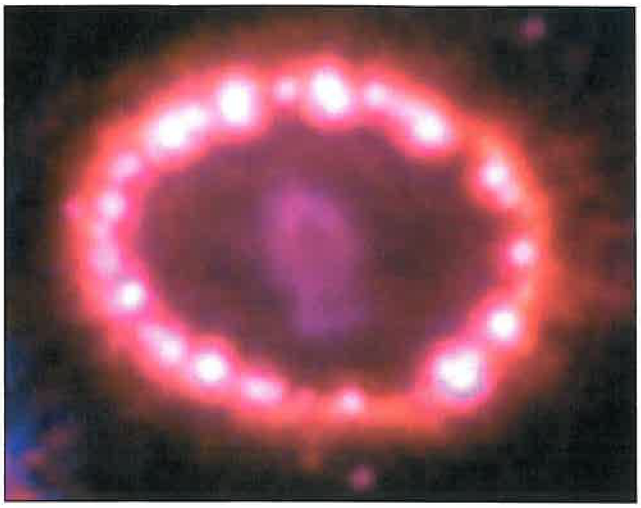
The appearance of G292.0+1.8 is different in that it shows strong circumstellar interaction, as well as a pulsar nebula (Fig. 3). The radius of the emitting region, 7 pc, and the emitting mass, several $M_\odot$, are consistent with a dense surrounding wind, suggesting a Type IIL explosion. Optical observations of supernova ejecta moving at about 2000 km s^{-1} show that it is hydrogen-poor and heavy element rich, as expected for this kind of supernova. The estimated age is 3200 years.

There is enough information on 9 young nebulae that contain pulsars to estimate their ages, initial pulsar periods, and supernova types. The initial periods of the pulsars are inferred to be in the range 10-100 msec, but the periods are not correlated with the supernova type. The same is true for the pulsar magnetic fields deduced from the assumption of spin-down by magnetic dipole radiation. This would be surprising in a single star model for the stellar evolution because the core properties depend on the mass of the progenitor. However, if close binary evolution plays a role in the mass loss determining the supernova type, the lack of correlation is not surprising.

SN 1987A and conclusions

All the objects discussed to this point have ages of about 10^3 years. The best opportunity we have to study the aftermath of a younger explosion is the nearby supernova SN 1987A in the LMC. Neutrinos were detected from the supernova in 1987, showing that a compact object formed in the explosion. However,

▶ **Fig. 3:** X-ray image of G292.0+1.8. The pulsar nebula with its central pulsar (135 msec period) is the blue region to the left of the center. The brighter emission is from gas heated by the interaction with the circumstellar medium. The radius of the remnant is about 7 parsecs. (NASA/Chandra X-ray (Observatory/Smithsonian Astrophysical Observatory)



▲ Fig. 4: Optical image of SN 1987A in the Large Magellanic Cloud, a companion galaxy to our Milky Way Galaxy (taken 28 November, 2003). The ring, believed to be a circular ring with a radius of 0.2 pc observed at an angle, was created by presupernova mass loss. The bright spots on the ring are where the supernova shock front is driving shock waves into the dense ring material. The asymmetric central region is supernova debris heated by radioactive decays. (NASA/Hubble/STScI)

multiwavelength observations since that time have failed to give any evidence for the compact object. The optical emission from the region of the explosion can be attributed to power input by radioactive decays of ^{44}Ti (Fig. 4). Current limits on the luminosity of any compact object are orders of magnitude smaller that the power output of the Crab pulsar, and are lower than expectations for accretion onto a quiet neutron star. Accretion onto a black hole, with low radiative efficiency, is one possibility, but a quiet neutron star with little mass around it cannot be ruled out. Fortunately, the emitting supernova ejecta are becoming more extended and more optically thin with time, so it is just a matter of waiting until the mystery at the center reveals itself.

The increasing power of space and ground-based observatories is giving us the possibility of following through the supernova explosion to the effects of a central compact object and circumstellar interaction around massive stars. These phenomena tell us about fundamental astrophysical issues: the ejection of heavy elements and energy into the interstellar medium and the early evolution of neutron stars. The number of well-observed objects is still small; as it increases, we will have a clearer view of the diverse paths of massive star death.

About the author

Roger Chevalier is W.H. Vanderbilt Professor of Astronomy at the University of Virginia. He is a member of the National Academy of Sciences and was awarded the 1996 Dannie Heineman Prize for Astrophysics for his research on supernovae.

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Lithuanian Physical Society

Zenonas Rudzikas, Rasa Kivilšienė

The history of physics teaching and physics research in Lithuania goes back to the sixteenth century, when in 1579 the University was founded in Vilnius, the oldest university in Eastern Europe. Physics was always taught there together with the other natural sciences. The newest achievements in physics were presented to the students with some delay, mainly caused by low speed of travel of the newest scientific literature to this then remote part of Europe.

In 1773 the Rector of Vilnius University, M.Poczobut-Odlanicki, presented a draft for an Academy of Sciences in Vilnius; however, perhaps due to the complicated political situation in that region at that time, the initiative did not become a reality.

In the 19th century physics was taught in the old Vilnius University in a particularly modern way, because at that time there existed especially good contacts of local professors with their colleagues in France, England and other European countries. It also became common to buy modern equipment from these and other countries. The Vilnius University observatory also had strong links with a number of observatories in Western Europe.

The recent roots of the Lithuanian Physical Society (LPS) originated in the Lithuanian Scientific Society (LSS) founded in 1907, when Lithuania was still the so-called North-West Region of the Russian tsarist empire. The core of the LSS consisted of educated Lithuanians of various specialities, physicists and engineers included, who had the desire to collect and preserve the Lithuanian ethnographical cultural artefacts, to contribute to the education of the people, and to build up the national self-esteem. Much attention was paid to collecting data on geology, botany, zoology and other branches of science, to writing and publishing textbooks and popular scientific literature.

The LSS had its own library, its collection of manuscripts, an ethnographic archive, and museum. It also edited the journal "Lietuvių tauta" ("Lithuanian Nation") (1907-1936).

Special attention was paid to writing and publishing textbooks. During 1915-1920 about 100 textbooks for Lithuanian schools were written and published. When the Vilnius region was occupied by Poland in 1920, the LSS became very active in opening the new university in Kaunas, then the temporal capital of Lithuania.

In 1928 the Society of the Students of Physics and Mathematics was founded at Kaunas University, and in 1931 the Lithuanian Society of Natural Scientists. The latter was active up to 1940. It had about 200 members representing the physical, mathematical, chemical, biological, geological and medical sciences.

◀ Fig. 1: Emblem of LPS

In 1934 a separate section of physicists and chemists was established in that Society. Povilas Brazdžiūnas was elected its chairman. Later he became the first President of the Lithuanian Physical Society. The main goal of this section was to disseminate the most important achievements in the natural sciences among the population and to consolidate the scientists by sharing their experience in research.

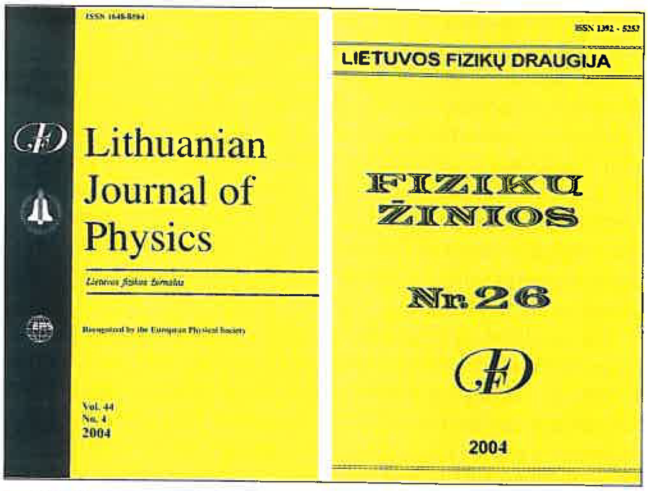
After World War II when Lithuania was incorporated into the USSR, the so-called Republican Meetings of Physicists were organized periodically starting in 1954. Actually they continued the traditions of the former meetings of the Lithuanian natural scientists. Gradually these meetings have become the National Physics Conferences (officially the word "National" was not used...). They were dedicated to the analysis of physics research and teaching as well as to the history of physics in Lithuania. The problems of the foundation of new research institutions, the coordination of physics research, the methodological aspects of physics teaching in secondary and higher schools, the demonstration equipment of physical experiments, the popularization of physics, physics terminology in the Lithuanian language, etc were considered during such meetings.

In 1962, during the 5th National Physics Conference, the idea of the foundation of the Lithuanian Physical Society (LPS) was raised by the founder of the scientific school of modern theoretical physics in Lithuania, Academician Adolfas Jucys, whose centennial jubilee was celebrated in 2004. The LPS was officially founded in 1963, when Lithuania had already been incorporated for 23 years into the Soviet Union. It was the only Physical Society in the USSR, the Union formally consisting of fifteen "independent" Republics. There was no USSR Physical Society, therefore the creation of an official legal Scientific Society, having its own registered Statute, in a separate Republic, was a unique event in the USSR. It had not only scientific, but also certain political significance.

The LPS is older than the European Physical Society (EPS) that was founded in 1968. The first chairman of the LPS was an Academician of the Lithuanian Academy of Sciences, Povilas Brazdžiūnas . He was the founder of contemporary experimental physics in Lithuania and initiated a number of new research directions in Lithuania (semiconductor physics, radiophysics, quantum electronics). He was also the author of a number of physics textbooks in Lithuanian. Under his supervision a very large Lithuanian-Russian-English-German dictionary of physical terms was prepared in collaboration with linguists and published in 1979. Now an updated and even more extended version is under way (including the French language). In it the new achievements in the physical sciences during the last decades as well as the changes in the Lithuanian physical terminology have been taken into account. He has served in this capacity during 1963-1966 and 1968-1986. During 1966-1968 Academician Paulius Slavònas was chairman of the LPS. His main domains of interest were astronomy and history of science.

In 1986-1995 Academician Algirdas Šileika became the chairman of this Society. Under his leadership in 1992 the LPS became a member of the EPS. Since 1995 Academician Zenonas Rudzikas serves as chairman (President) of the LPS.

It may seem that the elected chairmen serve too long. However, it takes time to learn the peculiarities of the activities of such an organization, having no paid staff, and particularly now in the age of globalization and modern information technology that opens new possibilities of international co-operation. However, indeed in future the President must serve not more than two four-year terms.



▲ **Fig. 2:** Title pages of "Lithuanian Journal of Physics" and its supplement "Fizikų žinios"

In 1961 even before the formal establishment of the LPS, "Lietuvos fizikos rinkinys" (Lithuanian Physics Collection) – the only physical journal in Lithuania – was founded. Before that papers on physics research were published in the "Proceedings" of the Lithuanian Academy of Sciences, in publications of Vilnius University, etc. The papers were published in Russian with the Summaries in Lithuanian and (usually) English. Since 1974 the Journal has been translated into English and published by Allerton Press Inc. under the strange title "Soviet Physics-Collection". Since 1989 it became the "Lithuanian Physics Journal".

Since its establishment the LPS has been in charge of this journal and continues its publication. Since 2000 it is published only in English with summaries in Lithuanian. The present title is "Lithuanian Journal of Physics" (6 issues a year, www.itpa.lt/~lfd/Lfz/LFZ.html). Since 2002 it has the rank "Recognized by the European Physical Society".

Since 1990 the LPS publishes the supplement "Fizik˜ Ïinios" ("Physicists News") to the Journal twice a year in Lithuanian (www.itpa.lt/~lfd/fiziku_zinios/FizikuZinios/html/). There are included popular papers on physics, on physics terminology, information on the activity of the LPS and the EPS, jubilees, etc.

LPS also encourages the publication of physical literature, both pedagogical and popular, even 'humorous' physics. Those who would like directly to contact the Board of the LPS are kindly asked to send messages to lfd@itpa.lt.

The Charter of the LPS in the light of the changing political circumstances and the needs of the Society itself was revised and updated in 1972, 1985, 1990 and 1997. These changes were presented to and approved by the majority of its members at LPS conferences. At present the Board of the LPS consists of 21 members. They are grouped into the Organizational, Science, Studies and Publications commissions.

At the beginning of the activity of the LPS physics teachers were among its members, but since 1995 they have established the Association of Physics Teachers. They are organizing separate conferences as well as a number of other initiatives. Nevertheless they coordinate their activities with the Board of the LPS. Moreover, the President of this Association, Saulò Vingelienò, is a member of the LPS Board. Their website is as follows: www.lfma.ivi.lt.

The main duties of the LPS commissions are as follows.

The Organizational Commission is mainly in charge of the documentation of the membership, archives of the LPS, studies of the history of physics in Lithuania, international relations, organization of the Board meetings, contacts with the EPS, etc.

The Science (Research and Development) Commission is concentrating its activity on the organization of the National Physics Conferences (since the first meeting of the physicists of Lithuania after World War II already 35 conferences have been organised), participation in European science projects, international agreements, etc. There are now signed co-operation agreements with the physical societies of Poland, Russia, Taiwan and the UK. Similar agreements with the physical societies of a number of other countries are in progress.

The Studies Commission is paying its main attention to the improvement of physics teaching in secondary and higher schools, to writing textbooks in the national language (teaching in schools and universities of Lithuania even during the Soviet period was as a rule in the Lithuanian language), to the organization of conferences on the methodology and history of physics, etc. Several researchers have obtained their PhD degree while investigating the history of physics in Lithuania.

The Publications Commission is concerned with the edition of scientific and popular physics journals, the popularization of the physical sciences, the development of physical terminology, etc.

One may also mention a few other initiatives of the LPS, which may be of interest to readers.

In 1972 the LPS has established the so-called 'physics school by correspondence'. In 1973 it obtained the name "Fotonas" (Photon). The duration of participation in it is four years (the last four years in secondary school). Twice a year its members receive a number of physical problems, which they must solve. Now they can find them and send the solutions by internet. The most successful pupils are invited to participate in the so-called summer camp of "Fotonas", where they listen to the lectures of known professors, participate in the discussions, etc. After graduating from this school they receive the relevant certificates with the recommendation to study natural sciences (please visit www.fotonas.su.lt/photon.phtml).

The LPS also encourages the organization of the National Physics Olympiads (there have already been organized 52 such Olympiads) as well as participation in the World Physics Olympiads.

Since 1995 there has also been organized the special school of additional training in physics "Fizikos Olimpas" (Physics Olympus), aimed at further improvement in the level of physics knowledge (excellence) of the gifted pupils. Usually the national team of participants in the World Physics Olympiad is formed from the best pupils of this special school.

Every year on the first Saturday of April, Vilnius University Physics Faculty organises the 'Day of Physicists'. Its symbol is Din(o)Saur and its slogan is: "The dinosaurs have become extinct but physicists have survived" (please also visit www.fidi.lt/).

Since 1995 Lithuanian physicists are regularly receiving "Europhysics News". This physics journal is very useful to feel the pulse of European physics, to be kept informed about the activities of our colleagues in other countries, about international conferences, schools or seminars, about new achievements in physics, etc.

The main challenges of the LPS for the future remain the same as they have been formulated at the foundation of the Society, namely,

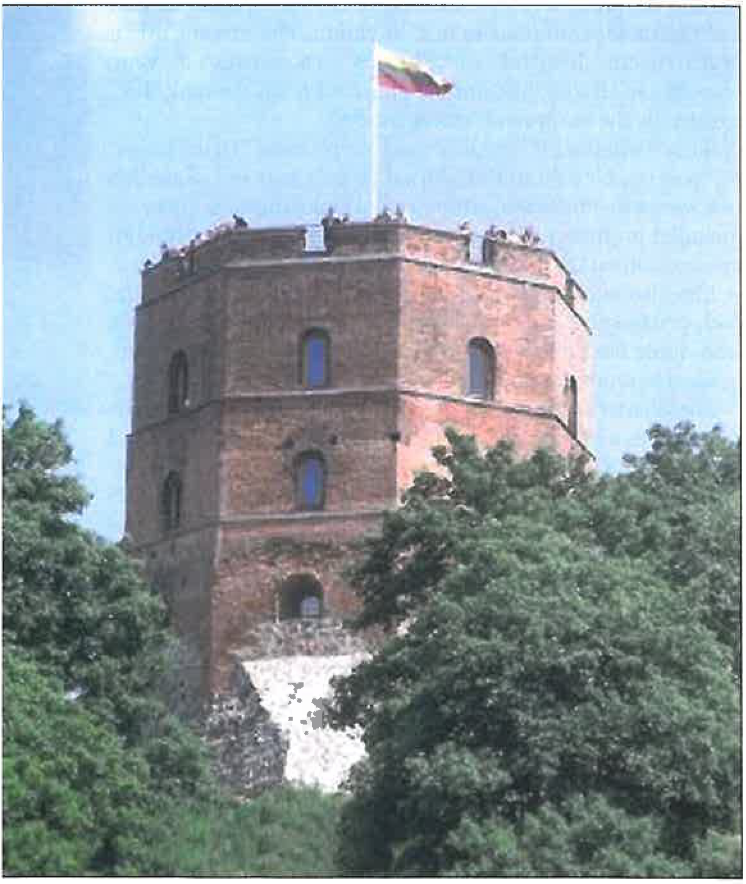
- to contribute to the development of research in physics in Lithuania and to encourage the co-operation of physicists from all research and educational institutions of Lithuania;
- to organize National Physics Conferences with the participation of foreign scientists;
- to monitor the quality of teaching of physics on all levels;
- to popularize the achievements of physics among the population, particularly in schools.

However, in the age of globalization and modern information technologies and with its entrance into the EU and NATO, Lithuania faces new challenges and frontiers. Among these are the need to participate in the creation of the European Research Area, to encourage international scientific co-operation, to contribute to the formation of a critical mass of researchers, to pay more attention to interdisciplinary research, to develop practical applications of the results of fundamental research, to improve contacts with industry, to attract girls to study physics, etc. The LPS is ready and willing to participate in the solution of these problems.

About the authors

Zenonas Rudzikas during 1992 - 2003 was elected the Director of the Vilnius University Research Institute of Theoretical Physics and Astronomy. In 1994 he was elected the Academician of the Lithuanian Academy of Sciences. Since 2003 he has been President of the Academy. His research interests are in mathematical physics, particularly in the areas of plasma physics and astrophysics. He is a member of the EPS Executive Committee and the President of the Lithuanian Physical Society.

Rasa Kivilšienė was awarded her Doctorate in 2000 in the field of the history of physics in Lithuania, and is a Research Associate in the Vilnius University Research Institute of Theoretical Physics and Astronomy. She is a member of the Board of the Lithuanian Physical Society.



◄ **Fig. 3:** Symbol of Vilnius – Gediminas Tower

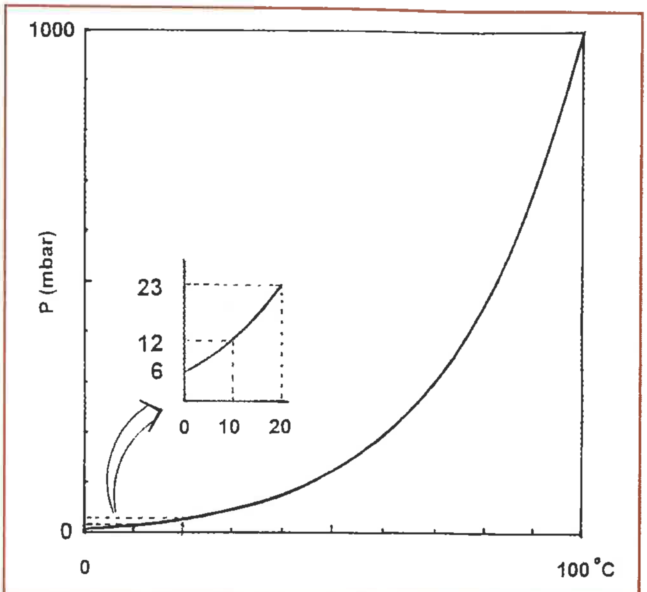
Fresh air

L.J.F. (Jo) Hermans, Leiden University, The Netherlands

Whether at home or in the office: we feel comfortable when the temperature is around 20 °C and the humidity around 50%. There's some interesting physics here, especially in wintertime, when we have to heat and – almost inevitably - to humidify the outside air. The humidity aspect is a trivial consequence of the steepness of the H_2O vapour pressure curve (see figure): at 0°C and 20°C, we find 6 and 23 mbar, respectively, almost a factor of 4 difference. Therefore, when it freezes outside, the humidity cannot exceed some 25% inside, since the water content of the incoming air does not change by being heated. This is so unless we add water to the room. The air conditioning industry does that routinely in our labs and offices.

How hard is it to humidify the air in our home? In the stationary state this depends, of course, on the degree of ventilation. For a back-of-an-envelope calculation we use the rule of thumb that, for simple liquids including water, there is a factor of 1000 between the density of the liquid and that of the vapour if assumed at standard temperature and pressure. A litre of water, therefore, gives roughly 1 m^3 of vapour if it were at 1 bar (it gives 1,244 m^3 at STP, to be precise). Using the above 23 mbar at 20°C we find, for a room of 100 m^3 volume, that it takes about 1 litre to increase the humidity by 50% for a single load of air. If we assume a refreshment rate of once every hour, we see that humidification is effective only if we are prepared to pour a lot of water into our home daily. Or we have to minimize ventilation.

But ventilation is a must, if we don't want to run into health problems. In this context, an interesting physics aspect comes up. Suppose we instantaneously replace the air in our living room by cold outside air while keeping the heating off. Will the room be much colder after we wait for the new equilibrium to be reached? The answer is: very little, and it is easy to se why. It's all a matter of heat capacities, of course. But there are wooden furniture, brick walls, glass, metals, etc. in the room, which seems to make an estimate pretty hopeless. However, if we are only interested in an approximate value, there is an easy way out: If specific heats are taken not per mass but per volume, values for most solids and liquids are pretty much alike (around 2-3 $kJ.l^{-1}.K^{-1}$). The reason is simple. We remember that atoms may differ enormously in mass, but they do not differ so much in 'size': the atomic number densities are rather equal. Moreover, the contribution of each atom to the specific heat is roughly the same (around 3k, where k is the Boltzmann constant). For gases, of course, we have to take the above factor 1000 in the ratio of the densities into account.



▲ Fig. 1: The vapour pressure of water, with an expansion of the 0 to 20°C temperature interval

Conclusion: when estimating heat capacities, a litre of liquid or solid and a m^3 of a gas at ambient temperature and pressure are pretty comparable.

So much for the 'rule of thumb'. We can return now to our room. It is clear that the volume of the 'solid' content of the room is far larger than 1/1000 of the air, even if we are honest and count only half of the wall thickness. This shows that, indeed, the temperature of the room will be hardly affected by a single load of fresh air. This trivial exercise also suggests that opening the refrigerator for a second or so puts about as much heat into the refrigerator as leaving a tomato inside.

About the author

L.J.F. (Jo) Hermans recently retired as professor of Physics at Leiden University, The Netherlands. Main research topics: Internal-state-dependence of intermolecular and molecule-surface interactions, and nuclear spin conversion in polyatomic molecules. In the 1990s he served as a member of the EPS council. Presently he chairs the National Steering Committe for the World Year of Physics 2005.

About the illustrator

Wiebke Drenckhan (26) is currently doing her PhD in the "Physics of Foams" in Trinity College Dublin, Ireland. She has studied and worked in Germany, USA, New Zealand and France, being largely supported by the German National Merit Foundation. Additionally to taking a scientific approach to the world, she likes to capture its oddities in cartoons.

Successful launch conference for the International Year of Physics 2005 in Paris

Christophe Rossel

Entitled Physics for Tomorrow this large international meeting took place at the UNESCO Headquarters on 12-15 January 2005 to officially inaugurate the International Year of Physics 2005. One aim of this conference, open to the general public, was to focus the attention of international media on events and celebrations organized around the world throughout IYP 2005. Organized by the EPS in collaboration with the International Union of Pure and Applied Physics (IUPAP), the French Physical Society (SFP) and the UNESCO it gathered more than 1000 participants from 86 countries thanks to a very attractive program put together by Martial Ducloy, chair of the conference, and his co-organizers. Over 500 young men and women, aged 16 to 21, from over 70 nations had been invited and gratefully financed by the organization committee and its sponsors.

Prestigious invited speakers, among them six Nobel prize laureates in Physics and one in Chemistry, gave outstanding presentations for a general audience and contributed to interesting round tables discussions. The impact of physics on daily life was presented under various headings, outlining its importance on issues such as development, information technology and life science. Spanning from nanophysics to cosmology and astrophysics, the speakers identified the important achievements in their fields and the open challenges for the future. Georges Charpak, in a vibrant appeal, advocated reforms in teaching and education in order to attract more youngsters towards physics and science in general. In a first round table the theme "Physics and the socio-economic challenges of the 21st century" was addressed by the participants. The major problems that we are facing in the future are indeed global warming, climate change, energy production and conservation. With regard to the world population and its growth, more challenges to come are free access to food, health, safety and education. In the second round table "Public perception of Physics and Science" the interdisciplinary aspect of physics being part of our culture and its role in exploring new territories was outlined as a major vector of communication to the public. Through its moral and ethical behaviour, the physicist must continue to play an active role in policy making, and to contribute, with the help of non-governmental organizations, to a better civil society. The sad Tsunami devastation in South-East Asia was a constant concern throughout the meeting and generated constructive debate on the prevention of natural catastrophes.

▲ **Fig. 1:** What can bring physics to the socio-economic challenges of the 21st century? The actors in this debate were from left to right Philippe Camus (Executive President, EADS, France), Carlo Rubbia (Physics Nobel laureate, ENEA, Italy), Alex Taylor (moderator), Sergio Rezende (Director, FINEP, Brazil), Burton Richter (Physics Nobel laureate, SLAC, USA) and Sylvie Joussaume (Director, INSU/CNRS, France)

▲ **Fig. 2:** Among the many delegations present in Paris, representatives of the Sudan shared their views on the role of physics in developing countries.

The success of this conference in bringing young physics students together with older colleagues was evidenced by the lively debates and animated coffee breaks. Next to the speakers and committee members, a major tribute must be given to the conference secretary, Johannes Orphal, for his outstanding engagement and organization. The closing session witnessed addresses by Koïchiro Matsuura, Director General of UNESCO, Marvin Cohen, President of the American Physical Society, Edouard Brézin, President of the French Academy of Sciences as well as by Yves Parlier, the French navigator and godfather of the WYP2005 activities in France.

Inauguration of the EPS building in Mulhouse

The new EPS building in Mulhouse

Finally it has happened on Friday 21 January 2005. The new EPS building located on the campus of the Université d'Haute-Alsace (UHA), 6 rue des Frères Lumière in Mulhouse, was officially inaugurated in the presence of numerous honoured guests. The celebration was also the perfect opportunity to launch in Alsace the International Year of Physics 2005.

Although the idea of a new building to house EPS came as the Society moved from Geneva to Mulhouse in 1997, it took many years of negotiations since1999, to finalize its financing within the Plan Etat-Région for 2001-2007. Upon selection of the winning architectural project in 2002, the construction of the building could start in 2003 and reached its completion in spring 2004, under the professional supervision of Mrs Mangano from the Technical Services of the UHA. This beautiful building, the pride of all those who contributed to its realisation, was handed over to our EPS Secretariat staff who moved in during the warm days of August. Financed at 80% by the French State, 10% by the région d'Alsace, and 10 % by the Département du Haut-Rhin, the city of Mulhouse and the UHA it will certainly fulfill its role in the centre of the campus. As noted by Martin Huber, EPS President, in his opening address 'the EPS building will serve the European physics community, be an encouragement of international exchange among scientists, and be an active interface with the local University and the region of Alsace'.

Further speeches were delivered by representatives of the State and the University, namely by Michel Guillot, Préfet du Département du Haut Rhin, Adrien Zeller Président du Conseil régional d'Alsace, Charles Buttner, Président du Conseil Général du Haut-Rhin, Gérald Chaix, Recteur de l'Académie de Strasbourg and Guy Schultz, Président de l'UHA. The ceremony ended with the official tricolor ribbon cutting and all participants were invited to visit the new construction and raise a toast in honor of the EPS and all its members. Needless to say, the local Alsatian wine was enjoyed with great pleasure but with moderation as the day was not yet over. Indeed, following the inauguration, a public lecture was given by Claude Cohen-Tannoudji, Nobel Prize laureate 1997, on the theme of 'Matter and Light'. In a neighboring auditorium, filled to overflowing with about 600 people, the speaker shared with his audience the history and the fascination of the cooling and trapping of atoms with laser light. It was a fantastic event that once again demonstrated how much physics can be appealing to the general public.

Lastly, but not least, I would like to thank here my colleagues David Lee, EPS Secretary General, Martial Ducloy, past EPS-president, Jean-Paul Hurault and Claude Sebenne of the French Physical Society, Dominique Bolmont, Director of the Laboratoire de Physique et Spectroscopie Electronique (LPSE) at the UHA who shared with me, during my time as Executive Secretary, the unavoidable ups and downs inherent in such a project. A particular acknowledgement goes also to Michèle Leduc who greatly contributed to the successful financing of the building by the French State.

At the ribbon ceremony: Martin C.E. Huber President of the EPS, Charles Buttner, Président du Conseil Général du Haut Rhin, M. Guillot, Préfet du Département du Haut Rhin, Gérald Chaix, Recteur de l'Académie de Strasbourg et Guy Schultz, Président de l'Université d'Haute Alsace (from left to right)

Professeur Cohen-Tannoudji explaining to an enthusiastic audience the recent developments in physics based on Einstein's early ideas on photons.

Opening address of Martial Ducloy,

President of the Kick-off Conference Organising Committee
13 January 2005 – World Year of Physics

It is with great pleasure that I welcome you on behalf of the Organising Committee to this important conference to launch the World Year of Physics/International Year of Physics, held at the UNESCO headquarters.

Why a World/International Year of Physics?

Modern society is marked by greater and greater specialisation, which has led to the increased separation between science and the general public, as well as among the different sciences themselves. This has important consequences and it is necessary to show the impact and the importance of physics in every day life to the general public. Around the world, the number of students in physics is decreasing, because young people tend to choose disciplines that are less demanding and easier. What would modern life be, however, without computers, internet, cellular telephones, lasers, or magneto resonance imagery, all advances made directly possible by fundamental research in physics?

Four years ago, the European Physical Society took this problem under consideration, and in reply to the global disaffection for the physical sciences, global mobilisation was necessary to make the general public, young people, and politicians aware that action was necessary.

At the end of 2000, the EPS proposed that 2005 should be declared the World Year of Physics, in recognition of the centenary of the "miraculous" year of Albert Einstein, when he wrote, at the age of 26, his legendary articles, which opened three fields that revolutionised 20th century science: quantum physics, the theory of Brownian motion, and the theory of relativity, with Science's most famous equation "$e=mc^2$".

Einstein, who is probably the most famous physicist in history, and who was named the "Personality of the 20th century" by Time Magazine will serve as the rallying point to stimulate the public's interest during 2005.

The initiative of the EPS in favour of 2005 as the World Year of Physics was adopted by the International Union of Pure and Applied Physics in 2002, by the General Conference of UNESCO in 2003, and by the UN in June 2004, who officially declared 2005 as the International Year of Physics.

After this long groundwork, to gain the support of the important institutional actors and to plan the events aimed at the general public, 2005 has come at last. The Kick-off Conference that starts today is the beginning of events that will develop two main themes throughout 2005:

• Physics is not a field that is oriented towards the past, but continues to provide answers to questions raised by the infinitely small, in the infinitely big, and the infinitely complex. Physics plays a central role in all fields of science, from chemistry to biology, by bringing its rigorous theoretical and experimental approach, and in developing fruitful interfaces with other fields of science. Physics will make essential contributions to major problems of the 21st century – energy production, environmental protection, health, medicine, etc.

• Physics, because it is oriented towards the future, must be attractive to young people, and remind them of the thrill associated with scientific research, despite the dryness often associated with its methods and with research. Physicists have to leave their ivory tower, where they tend to hide themselves and to explain in simple, accessible language the need for research, particularly fundamental research, where unplanned for discoveries can open the way for technological revolutions.

These are the reasons that this conference is aimed at the general public, and has an international character. It is aimed specifically at young people. Thanks to the efficiency of the Organising Committee, in particular Johannes Orphal, its secretary, and with the active help of the French Minister of Foreign Affairs, a plan was made to invite delegations from around the world composed of high-school students and young college students who had showed their merit in international and national science comptetions. It is my pleasure to announce that over 500 young people passionate about science from 70 countries are in the audience – and more than a quarter of the young people in these delegations are women. We expect a lot from the interaction and discussions of these young people with the famous scientists who have accepted to share their views on the different topics, the great discoveries and questions, of the physical sciences.

In conclusion, I would like to thank the principal organisers of this conference: The European Physical Society, the French Physical Society, the International Union of Pure and Applied Physics, and UNESCO. This conference could not have been organised without the sponsorship and financial support of the French Ministry of Research, the French Ministry of Foreign Affairs, the Eurpean Commission, and Centre Européen de Recherche Nucléaire (CERN), and the French Commissariat à l'Energie Atomique. Finally, I would like to thank the Enterprise Foundation of EADS, and the Foundation Iagolnitzer.

I wish you all a good and fruitful conference, and have a nice time in Paris.

Nominations are requested for EPS Fellow

The rules are below. Exceptionally for 2005, the limit for the receipt of nominations for fellows to be elected in 2005 is 31 March 2005.

Rules for the nomination of Fellows of the European Physical Society. Approved by the Executive Committee • November 2004

Eligibility

• Individuals whose achievements in physics, industry, or education and/or commitment to the SOCIETY warrant specific recognition are eligible to become EPS Fellows.

• No one will be denied EPS Fellowship on the grounds of the person's nationality, sex, or religious beliefs.

• Normally, only those individuals who have been Individual Members of the SOCIETY for at least 5 years are eligible as EPS Fellows.

Nominations

- Only EPS Members (Individual Members, Member Societies, and Associate Members) may make nominations for EPS Fellows.
- No person can be nominated to become a Fellow while that person is a member of the Executive Committee.
- No person may make a nomination while that person is a member the Executive Committee.
- No self-nominations will be accepted.
- Nominations may be made at any time. Nominations must normally be received no later than 15 January of the year of the Council meeting that will decide on the Fellows to be admitted that year.
- All nominations must be accompanied by the following documentation:
  - Support letters from at least 3 EPS Members, including the principal nominator. Support letters originating from different countries are encouraged.
  - A CV, including publication list of the proposed EPS Fellow
  - A brief description (maximum 1 A4 page) describing in detail why the individual nominated merits to become an EPS Fellow. This should include the achievements in physics, industry, or education, and/or service to the physics community that justify the nomination.
  - A proposed short citation.

Elections

- Nominations will be made to the EPS Executive Committee. The Executive Committee will review all nominations. The Executive Committee will prepare a list of recommended candidates for EPS Fellowship for approval by Council.
- Council shall be asked to elect EPS Fellows during its regular annual meetings. A simple majority of Council Members present and voting is necessary to elect an individual to EPS Fellowship.

Rights and Duties of EPS Fellows

- EPS Fellows shall have all rights and responsibilities of Individual Members. In addition, the person may add "EPS Fellow" to his/her title, and use the designation EPS Fellow on business cards, letterhead, etc.
- EPS Fellows shall pay membership fees as an Individual Member.

Revocation

- Fellowship is terminated upon termination of Individual Membership in the SOCIETY.

EPS high energy particle physics prizes 2005

The EPS HEPP Board is calling for nominations for the EPS High Energy Particle Physics Prizes in 2005:

- The High Energy and Particle Physics Prize, for an outstanding contribution to High Energy Physics in experimental, theoretical or technological area, will be awarded to one or more persons or to collaboration(s). In accordance with EPS-HEPP regulations, nominations for this prize are only accepted from a broad list of invited world experts.
- The Young Physicist Prize, for outstanding work by one or more young physicists (less than 35) in the field of Particle Physics and/or Particle Astrophysics. Nominations are open and should be addressed to the HEPP-EPS Chair, Professor Jose Bernabeu (jose.bernabeu@uv.es) before April 15th, 2005.
- The Gribov Medal, for outstanding work by a young physicist (less than 35) in Theoretical Particle Physics and/or Field Theory. Nominations are open and should be addressed to the HEPP-EPS Chair, Professor Jose Bernabeu (jose.bernabeu@uv.es) before April 15th, 2005.
- The Outreach Prize, for outstanding outreach achievement connected with High Energy Physics and/or Particle Astrophysics. Nominations are open and should be addressed to Professor Jorma Tuominiemi (jorma.tuominiemi@cern.ch) before April 15th, 2005.

The Prizes will be awarded in a ceremony on July 25th, 2005, during the International Europhysics Conference on HEPP, Lisbon.

Detailed regulations and the List of previous Prizes may be found in the web page of the HEPP Division of EPS: http://eps-hepp.web.cern.ch/eps-hepp/

King Faisal Prize 2005 awarded to Anton Zeilinger

The King Faisal International Foundation has announced the winners of the 2005 King Faisal International Prize for natural sciences, a cash prize of 200,000 dollars donated annually by the Foundation. This renowned distinction for natural sciences was this year awarded in physics to three physicists for their outstanding achievements in the field of quantum physics. The LAUREATES (in alphabetical order) were: Professor Capasso, Harvard University, Professor Wilczek, MIT (Nobel Laureate, physics 2004) and Professor Anton Zeilinger, University of Vienna. The committee's decision in recognising Zeilinger was based on the significance of his extensive scientific work for mankind and on his numerous scientific publications which range from epistemological and foundational research to the forefront of modern quantum technology. Above all, the committee emphasized Zeilinger's achievements in the fields of quantum teleportation and quantum cryptography. Zeilinger's association with his co-laureates Professor Capasso and Professor Wilczek underlines his remarkable profile on an international scale. Zeilinger himself considers the distinction as recognition of the accomplishments of his research team. The official award ceremony will take place in Riyadh in late March 2005.

King Faisal Foundation:
www.kff.com/english/kfip/bfull-winners.html.

The Plasma Physics Division Reports...

Scientists at the National Institute for Fusion Science (NIFS) in Japan took an important step towards demonstrating the practicality of fusion power plants recently by sustaining a 20 million degree (2KeV) plasma for 30 minutes in the billion-dollar-class Large Helical Device (LHD).

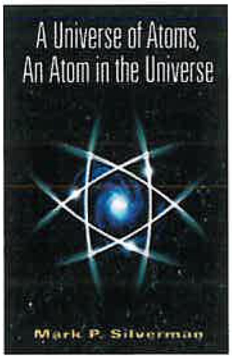
The plasma density was around 8 trillion particles per cubic centimeter.

During the 30 minute run, 1.3 billion joules of energy was poured into the plasma, setting a new world record in this regard. As part of the demonstration, the scientists demonstrated the successful application of sophisticated radio-frequency power technologies to heat and sustain the plasma for the full duration of the run.

Approximately 700 kW of power was continously applied at the electron and ion cyclotron frequencies.

Details are posted at www.nifs.ac.jp

BOOK REVIEWS



A Universe of Atoms, An Atom in the Universe

Mark P. Silverman, Springer, 2002, ix + 417 pages, Price: € 40.00

This collection of essays is the second edition of the And Yet It Moves, updated and enlarged by several additional chapters. It is based on the publications of the author, but is not a mere personal account of original research, for this would tell just a part of the story. It is the choice of themes and their arrangements that makes it more than a collection. Besides the personal note that threads throughout the book, which conveys the author's wish to convince readers how physics is an enjoyable subject, the book displays an ascending note both in subjects and the level of scientific inference to the mysteries of Nature.

It starts with mechanical phenomena in a down-to-earth manner, or as the French would put it, 'mains a la pate'. The following chapters deal with the most intriguing subjects in physics, from quantum interference phenomena, quantum beats, exotic atoms, etc. Particularly enlightening is the subject of optical phenomena, where those unfamiliar with the field, such as myself, can learn about most unexpected effects, such as enhanced reflection and nonlinear optics in general. Another curiosity is treated in the next chapter – a comparative and interactive treatment of earthly and atomic phenomena. (This is the chapter, which most justifies the title of the book). Chapter 8 attempts to answer the question which the majority of physicists never ask - do radioactive nuclei decay randomly. Another chapter presents the author's recent preoccupations (the latest reference from 2002) with cosmological puzzles, such as the issue of dark matter.

The book concludes with meditations on the science paideia, the issue of making young people learning not so much to accumulate facts, but to enjoy revealing nature's secrets, developing and pursuing their own curiosity.

Another important feature to be noticed, although not explicitly displayed, is the passage from everyday experience both natural and artificial, through the most perplexing phenomena and theoretical interpretations, to the latest, most advanced subjects, such as modern field-theoretical and cosmological ideas. This passage illustrates the difference between interpretative difficulties, such as those pertinent to quantum phenomena (epistemological aspects) and hypothetical modeling, as in cosmology (ontological aspects).

The book is difficult to find a niche in the scientific library, nor is it easy to locate the aimed target. Perhaps, the best choice is advanced level students and the general research and teaching readership in physics and related fields. Those interested in the epistemology of science, such as myself, will find a lot of points helpful in clarifying and systematizing. A number of original ideas, such as that of inferring the possibility of extraterrestrial life by observing the light polarization coming from distant celestial objects, are surely refreshing for stereotypical research people.

My only objection, which refers to the majority of books I read, is the use of endnotes, instead of footnotes. It is really annoying to go to the end of chapter to read, otherwise instructive and necessary, supplementary information. The book is well written, with a mild touch of humour. Each chapter ends with references, and the book concludes with the relevant bibliographies and index of authors. Mathematical expressions do appear, but at an illustrative level.

I liked the book's witty cover illustration, designed by the author's son (who plays a role in the book itself, both within the research and pedagogical context), although I am not sure everybody will join in.

Professor Petar V. Grujic, Institute of Physics, Belgrade

Books available for review

Capillarity and Wetting Phenomena. Drops, Bubbles, Pearls, Waves
P.-G. de Gennes, F. Brochard-Wyart, D. Quéré; Springer, 2004

Chaos and Time - Series Analysis
J C Sprott; Oxford, 2003

Computational Physics (Fortran version)
S. E. Koonin; D. C. Meredith; Westview Press, 2002

Cosmology and Particle Astrophysics
L. Bergström, A. Goobar; Springer, 2004

Design of High Frequency Integrated Analogues Filters
Y. Sun; The Institution of Electrical Engineers (IEE), 2002

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