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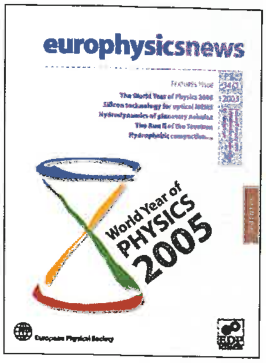

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Silicon technology for optical MEMS

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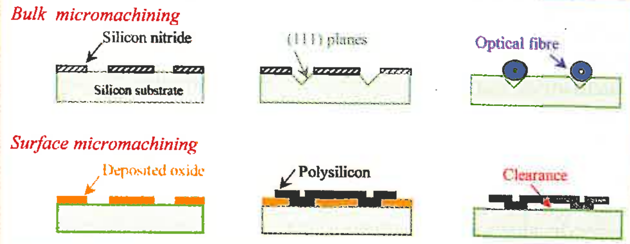
Micro-electro-mechanical systems (MEMS)

Components fabricated with the emerging technologies of micro-electro-mechanical systems (MEMS) are being incorporated in an increasing number of sensor and actuator applications [1,2]. There is rapid progress in optical systems for telecommunications to meet the needs for increased bandwidth, for optical networks with terabit capacities per fiber link, and for local area networks [3]. Some applications require precise features for optical alignment while others involve the precise movement of small optical parts to achieve advanced functionality. In the MEMS approach accurate, low-loss, optical connections are made between different guided wave optical components including fibres, waveguides and lasers. Mechanisms to allow motion and structures to provide electrical actuation are combined in micro-opto-electro-mechanical systems (MOEMS). Many MOEMS components process light in miniature free-space optical beams, and the performance scaling laws are often different from those for guided wave optical systems. This paper surveys MEMS with an emphasis on the outstanding challenges for Physicists and Engineers. The silicon and other materials and technologies used to create MEMS devices are discussed in detail, as are example applications in packaging such as fixed and demountable connectors and methods for hybrid integration.

Fabrication technologies for MEMS

The sets cross-sectional diagrams shown in Figure 1 illustrate the two main processes used for micromachining. The first established process is silicon bulk micromachining using alkaline solutions which have a much smaller etch rate of the (111) crystallographic plane in Si compared with other planes. In this process, a mask is first patterned in an etch-resistant surface layer such as thermally grown SiO_2 or deposited Si_3N_4, as shown in Row 1 of Fig.1. The silicon is then etched. Since the (111) planes etch the slowest, V-shaped grooves are produced by etching standard (100) oriented substrates to termination. V-grooves can be used for the precise positioning of optic fibres as shown in Figure 2. The features may be hundreds of micrometers deep and precisely defined by the initial planar lithographic process. Even grooves with diamond shape cross sections are made, although the range of possible shapes is restricted by the characteristics of the etch process. Encapsulated structures are made by fusion bonding of glass to bulk micromachined wafers, and multilayer structures are built up by bonding several silicon wafers together. Suspended structures can also be made by undercutting of etch-resistant features.

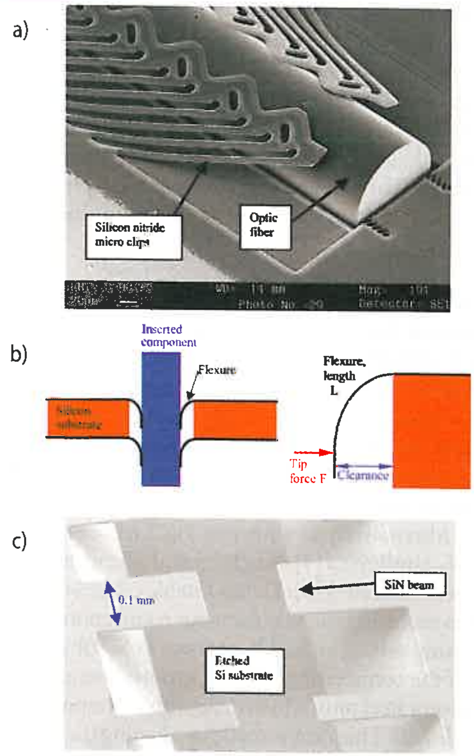
Polysilicon surface micromachining, exploits differences between deposited polysilicon and silica layers to form three-dimensional features as seen in Fig.1 row 2. The process is adapted from conventional silicon integrated circuit technology, and the chemical vapour deposited (CVD) polysilicon mechanical layer is typically 2 µm thick. The underlying silica sacrificial layer is later



▲ Fig. 1: Sequences of schematic cross sections showing bulk micromachining and polysilicon micromachining for MEMS.

wet etched away to produce a free-standing polysilicon MEMS layer. The polysilicon layer can be incorporated into a wide variety of sensors and actuators such as electrostatic comb drives. By careful control of the CVD process conditions, the stress in the polysilicon can be made reproducibly low. However, the thickness of the deposited layers is limited to a few tens of micrometers by cost considerations, and by the mechanical and electrical properties of deposited polysilicon which are inferior to those of single crystal Si. The cycle of deposition, patterning and etching of each material can be repeated several times to build up multilayer structures, and feature shapes can be arbitrary. Foundries operate semi-standard processes with several levels of polysilicon.

Figure 3 shows more advanced micromachining processes which are under development. When the fabricated structures must be thicker than is achievable using polysilicon, an alternative surface micromachining process is to use lithographic exposure



▲ Fig. 2: Elastic fixtures for optical components: a) secondary electron micrograph showing silicon nitride clips holding an optic fibre in place in a silicon V-shaped groove; b) schematic of a proposed new approach to fixtures which avoids V grooves; c) silicon nitride beams made by bulk silicon micromachining.

of thick photoresist, followed by electroplating, to form the mechanical parts as illustrated in Fig.3 row 1. The original Lithographie, Galvanoformung, Abformung (LIGA) process uses synchrotron radiation to expose the resist. The short X-ray wavelength allows deep (up to 1 mm) resist layers to be exposed without significant diffraction effects, and high aspect ratio structures are made. The released metal layer can be used in a variety of MEMS applications including packaging. Cheaper alternatives under development use ultraviolet mask aligners to exposure special resist and achieve features several hundred micrometers thick with aspect ratios of order 15. Parts are usually electroplated in nickel and, after removal of the resist, they can be replicated in other materials. Only low temperatures are needed, so LIGA can be used as post processes to add microstructures to CMOS (Complementary Metal Oxide Semiconductor technology).

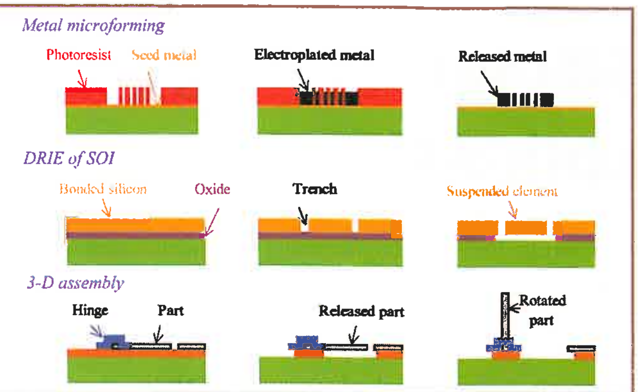
A recently developed process for forming suspended single crystal silicon structures is based upon the use of bonded silicon-on-insulator (SOI) starting material, which is available as a by-product of the high-performance silicon integrated circuit industry. As shown in Fig.3 row 2, the starting material is a silicon wafer that is thermally bonded to an oxidised silicon substrate. The bonded wafer is polished back to the desired thickness, usually in the range 5 μm - 200 μm. The bonded layer is then structured by deep reactive ion etching (DRIE) using an inductively coupled plasma etcher and specific gas chemistry to obtain high etch anisotropy. Movable structures may be made by removal of the buried oxide. There are many MEMS applications including micromechanical shutters for optical switching.

All of the above processes involve surface patterning and the resulting structures are quasi three-dimensional. Fully 3-D microstructures are made in polysilicon and in SOI by rotating surface micromachined parts out of the wafer plane, and latching them into position as seen in Fig.3 row 3. The parts are held by micromachined staple hinges. Assembly is usually manual, but mass-parallel powered assembly has been demonstrated by differential shrinkage of a polymer due to surface tension forces. Surface micromachined engines are also used to push parts out of plane. The many potential MEMS applications include components for free-space MOEMS.

MEMS packaging in optoelectronics

It is well known that passive alignment features for connecting single-mode optical fibres can be made by anisotropically etching single crystal Si. As shown in Fig.1, etching of (100) oriented Si through an appropriate mask is used to make V-shaped grooves which act as kinematic mounts for optic fibres. When two fibres are aligned in a groove and then butt-coupled together, all degrees of freedom except uniaxial motion are fixed. The assembly may then be epoxied. Alternatively, as shown in Fig.2, a fibre may be held by flexible Si_3N_4 cantilevers [4]. Single crystal silicon cantilevers have also been demonstrated [5]. Demountable connectors for ribbon optical fibres requiring the simultaneous connection of many cores are made using sets of etched V-grooves in Si substrates. On the male half of the connector, two large grooves are used to locate a pair of precision steel pins, which mate with corresponding grooves on the female half. The joint is made by aligning the pins, and sliding the connector halves together. V-grooves can also be used to construct simple subsystems known as opto-hybrids such as the connection between an optical fibre and a photodiode. Systems with detectors, lasers and high speed interconnects are used as transceivers.

Precision mechanical components are also used to connect different types of waveguide. Particular attention has been given



▲ **Fig. 3:** Cross sections showing metal microforming using thick resist; deep reactive ion etching of silicon on insulator starting material; and three dimensional microassembly processes for optical MEMS.

to the optic interfaces between fibre and silica-on-silicon integrated optical components. Silica-on-silicon has several major advantages over the earlier technologies such as ion-exchanged glass, Ti : $LiNbO_3$, GaAlAs and InGaAsP. Because of this, silica-on-silicon components are likely to find widespread application in low-cost systems such as fibre-to-the-home. A typical device comprises a single-crystal Si substrate with fibre alignment grooves, a thick buffer layer of silica to isolate the guided mode from the substrate, channel guide cores formed from doped silica, and a thick over-cladding to bury the cores. When combined with MEMS fabrication, devices may be constructed with a large number of ports.

Silica-on-silicon is also being used as a platform for the hybrid integration of optical subsystems containing components such as lasers and detectors that cannot be fabricated in the glass itself. Buried silicon terraces or other precision features are used to locate the components accurately in the vertical plane, and mesas are etched into the glass to provide lateral location. For example, a hybrid-integrated 1.3 μm / 1.5 μm transceiver based on a terraced silica-on-silicon platform is now available commercially. The chip contains waveguide circuitry, an embedded dielectric filter for demultiplexing, a photodiode receiver, and a laser diode source with monitor photodiode.

Many new assembly techniques are under development. One proposed geometry is shown schematically in Fig.2 where a substrate carries elastic flexures on both sides to secure an inserted component in position [6]. In this arrangement the flexure length L is much greater than the clearance α and the force F acts essentially at the point of initial contact. The precision with which an optical component can be located is determined primarily by the lithography and etching technology used for the deposited thin film flexures. In contrast to V-groove technology, the precise geometry of the etched substrate is of secondary importance. A possible candidate for the microclip material is silicon nitride. A micrograph of chemical vapour deposited SiN beams 3 μm thick is shown in the lower part of Fig.2 where the silicon substrate has been wet etched to form a V-groove. Silicon carbide is another possible material which has the required large Young's modulus and low stress. Preliminary experiments on 5 μm thick CVD SiC carbide films and etched Si substrates indicate that the material is suitable [6]. In the longer term, active flexures would be useful to allow for the adjustment of inserted components.

An alternative alignment method exploits LIGA to construct complex components such as multi-axis flexures in Ni metal.

Several flexures soldered to a breadboard provide individual mounts for components in an optical component train. For example, Figure 4 shows a flexure for an optical fibre and a collimating lens. After assembly, the optical throughput is optimised by adjusting the position of each component in turn, using plastic deformation of the flexure by an assembly robot. Complete optical systems such as a channel monitor based on a tunable Fabry-Perot filter have been assembled.

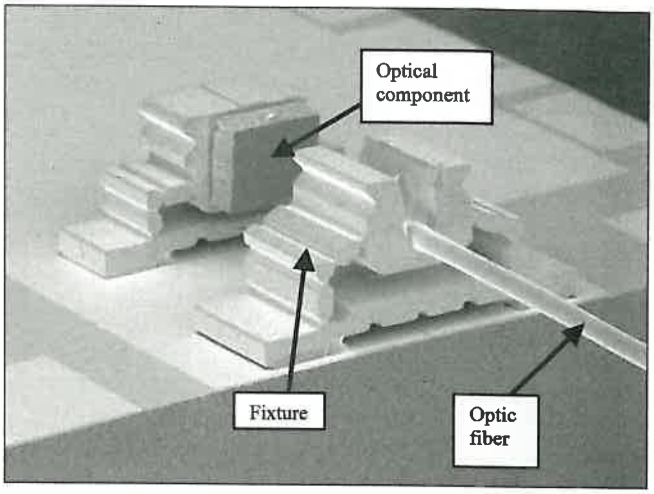
Optical breadboards are also constructed using components that are fabricated flat by surface micromachining and then rotated out-of plane. Small, free-space optic beams propagate parallel to the surface of the chip through fixed and movable lenses and gratings, and reflect off micro mirrors. The structures are hand-assembled using precision micromanipulators. Other systems have been assembled by using surface-micromachined engines to push hinged devices out of the wafer plane. A typical assembly engine is a scratch-drive actuator which acts as a controllable linear translator, allowing dynamic component positioning. Fully automatic techniques are also being developed for assembly of 3D MOEMS. One process based on surface tension force simply requires the melting of small pads of material to rotate parts out-of-plane [7], as shown in Figure 5. This method allows angular positions to be set to an accuracy of minutes of arc. Demonstrated devices again include fixed and movable mirrors, and lenses. Surface tension has been used to position and fix the parts of the bonded silicon support frame in Fig.5. The lenses are formed simultaneously by using reflow moulding of photoresist which gives optical surfaces.

MEMS optical devices

Applications for MOEMS in telecommunications were inspired by the emergence of a successful device in a different field: the digital micromirror projection display. On the display chip an array of more than a million electrostatically actuated torsion mirrors rotate to-and-fro against a system of end-stops to reject or accept individual pixels for the display. The advantages of MOEMS are small size, low cost, and the ease with which large-scale systems may be integrated. Compared with interferometric guided wave devices, the advantages are low loss, low cross talk, scalability and insensitivity to process variations. These advantages can outweigh disadvantages such as the relatively slow speed of a mechanical switch or tuning structure. Most MOEMS devices have been constructed either in polysilicon or in single-crystal silicon using bonded silicon-on-insulator, although III-V MOEMS are now being developed. The advantages of polysilicon surface micromachining are the existence of foundry-standard processes and the ease with which complex multi-layer devices may be constructed. The advantages of SOI are often improvements in structural thickness (and hence the flatness of released surfaces) and low surface roughness.

Switches can be based upon the electrostatic deflection of a waveguide for integrated optics. 1 x 2 silica-on-silicon moving waveguide switches have been demonstrated with the input channel guide fabricated on a cantilever suspended over an etched cavity. Using surface electrodes, the cantilever is deflected electrostatically from side-to-side, to allow connection to either of the output waveguides. The switching time of the order of milliseconds is long compared with the data rate, but is sufficient for network reconfiguration.

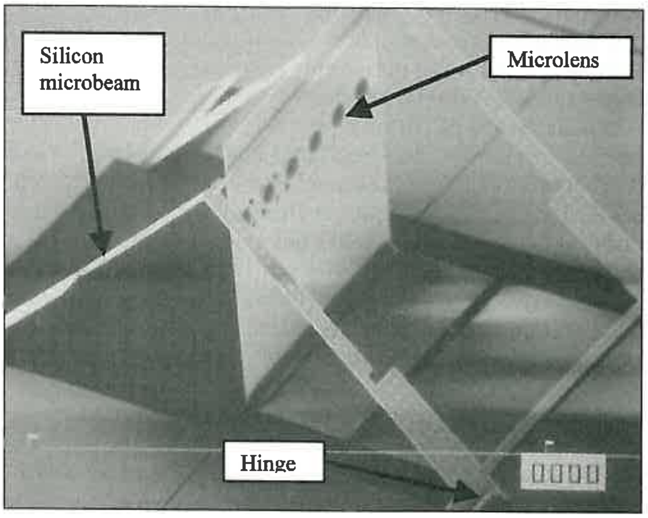
Other switches are based on the insertion of small mirrors into the nodes of a classical cross-point geometry. Suitable devices can be fabricated by deep reactive ion etching silicon. DRIE can simultaneously form vertical mirrors, fibre alignment grooves



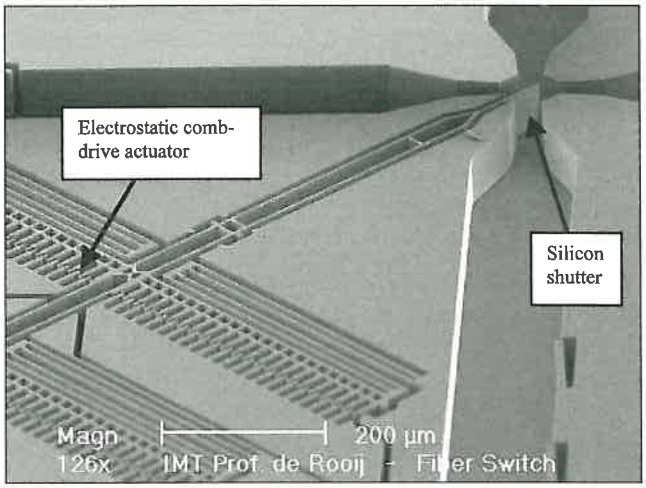
▲ Fig. 4: Electron micrograph showing the hybrid integration of optical components using a LIGA-type flexure (www.axsun.com).

and a simple electrostatic drive to remove or insert the mirrors into the regions where the optical axes intersect. A typical structure is shown in Figure 6. Switching times are also of the order of milliseconds, and optical isolation is excellent. However, the devices are only scalable to small-size switch arrays.

Dynamically assembled 3D MOEMS are being used to construct larger mirror insertion cross-connects. A commercially available polysilicon switch uses an 8 x 8 array of small mirrors to form a 64-node cross-point. The mirrors are driven between two states by an electrostatic drive acting through a linkage. Switches of this type are now well developed and reliable, despite their apparent mechanical complexity. Two-dimensional mirror farms can suffer from increasing diffraction losses as the size of the array is increased. Alternative mirror plane switches with a larger number of ports are now under development. Instead of using deflection between a set of single-axis mirrors, whose positions are effectively binary, the devices operate by routing beams between two arrays of continuously adjustable, dual-axis mirrors. Using surface micromachining Lucent Technologies Inc./Bell



▲ Fig. 5: Scanning electron micrograph of a microlens array after surface tension self-assembly [7].



▲ Fig. 6: Electron micrograph showing a linear translation mirror switch fabricated by deep reactive ion etching (www.sercalo.com).

Labs have recently reported a large (238 x 238) switch fabric with a mean fiber-to-fiber insertion loss of 1.33 dB [8]. The maximum insertion loss for the 56644 possible connections was only 2.0 dB. Two fiber arrays with collimating microlenses attached are used to project and receive beams from two 2-dimensional arrays of micro-mirrors. Figure 7 shows an electrostatically actuated 2-axis tilt mirror similar to the mirrors used in the large array [8].

▲ Fig. 7: Two axis beam steering micro-mirror built using surface micro-machined technology [8], (Lucent Technologies Inc./Bell Labs)

Mirror insertion devices are also being used as variable optical attenuators, for example for channel equalisation in dense wavelength division multiplexed systems involving erbium doped fibre amplifiers. A small mirror on a cantilever is inserted into the optical path to block part of a collimated beam, the reflected component being dumped into an absorber. Alternatively, switches may be based on a microfluidic systems and the controlled movement of gas bubbles in liquid channels.

Linear arrays of tilt mirrors have also been used to construct ADD-DROP multiplexers. A lens is first used to collimate the output from a fibre carrying a number of different wavelengths. A diffraction grating is used to disperse the wavelengths into a fan of beams, which are then passed through another lens to form spatially separated foci. The mirror array is placed at the focal plane, so that each wavelength falls on a separate mirror. Each mirror may then either retro reflect the light back through the multiplexer, or redirect it to a second multiplexer and fibre. Consequently, the spectral compositions of two output channels may be arbitrarily selected.

When an electrostatically-deflectable membrane mirror is combined with a second, fixed mirror, the result is a mechanically tunable Fabry-Perot cavity. This structure forms the basis of the mechanically actuated anti-reflection switch used as a modulator and filter. A more complex structure with a segmented drive electrode is used as a deformable membrane. This device has been used as a spectral plane filter, controlling the reflectivity as a continuous function of wavelength to achieve spectral equalisation of the gain of a fibre amplifier.

MOEMS components have been used as the basis of tunable external cavity lasers. Gain is provided by a conventional semiconductor optical amplifier, frequency selection is achieved using a reflection grating, and tuning is carried out by rotating an external mirror about a remote pivot. The actuator is a comb drive structure formed by deep reactive ion etching of bonded silicon-on-insulator material.

Highly integrated vertical cavity semiconductor lasers with an external cavity formed by a small movable mirror are also under development. They may be optically pumped with a membrane as the external mirror. Another electrically pumped device is grown in one step and etched to create a cantilevered tuning arm. Tuning is achieved by applying a small voltage to the top mirror, which causes the cantilever to move up or down, the cantilever motion altering the laser cavity length and changing the wavelength of operation.

Future prognosis

This review has considered the present technology for silicon-based MEMS and some future telecommunications applications. The key to new developments in optical MEMS is to successfully apply the underlying physics and develop cost-effective processing to make high-precision components. New materials are being used in the silicon integrated circuit industry where there is a huge on-going investment, and the much smaller MEMS activity can benefit from these developments. Examples are (i) SOI technology as seen in Fig.3 whereby low stress mirrors and other MEMS components are made with reproducible mechanical properties and excellent control of planarity, and (ii) low stress Si_3N_4 which has a high Young's modulus and has promising applications in packaging as seen in Fig.2. The current MEMS product containing the largest number of micromechanical components is the mircromirror projection display.

As integrated circuit lithography and reactive ion etching techniques improve in accuracy, the necessary precision for optical MEMS can be obtained in a manufacturable way. There is a strong incentive to stay with silicon substrate technology for MEMS packaging to piggyback on this further investment, but within this paradigm there is great scope for applied physicists in both the invention of device structures and the development of materials processing.

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The Run II of the Tevatron

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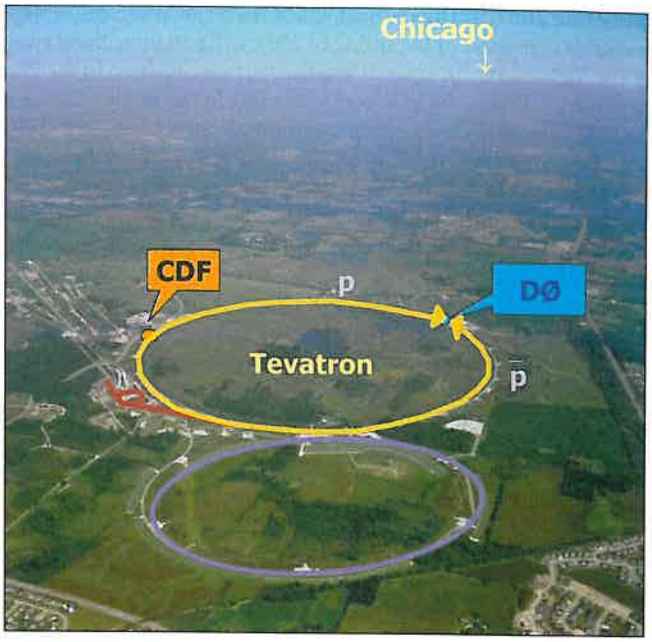
High energy physics is the denomination commonly used to designate the physics of elementary particles, the branch of physics which deals with the building blocks of matter (quarks and leptons, as it presently seems) and their interactions. The reason for this denomination is that high energy beams are necessary to probe short distances, which is why higher and higher energy particle accelerators have been and continue to be built. As of today, the particle accelerator providing the highest energies is the Tevatron, a proton-antiproton collider located at Fermilab [1] (the Fermi National Accelerator Laboratory) near Chicago, Illinois (Fig. 1). Bunches of protons and antiprotons circulate in opposite directions in a 6.28 km long ring, and collide head on at specific locations where two large and complex detectors, named CDF [2] and D0 [3], register the outcome of their interactions. The Tevatron collider operated from 1992 to 1996, at a centre-of-mass energy(1) (twice the beam energy) of 1.8 TeV, delivering to each experiment an integrated luminosity(2) of 120 pb^{-1}. The main achievement of this period, known as Run I, was the discovery of the long sought top quark [4], with a mass of 174 GeV, in 1995.

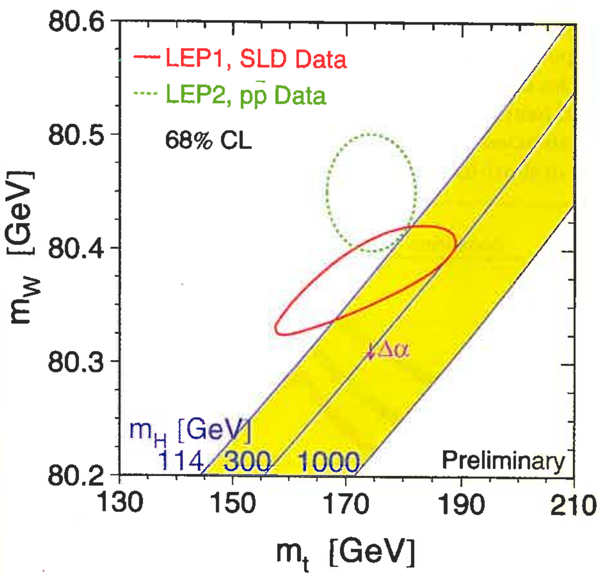
With the discovery of the top quark, the only missing piece in the highly successful Standard Model of electroweak interactions(3) is the Higgs boson, a very peculiar object since all other particles, which would otherwise be massless, acquire their mass through their interaction with it. Its discovery would therefore be of paramount importance. Essentially all of the current experimental knowledge on the Higgs boson was obtained at CERN, the laboratory of the European Organisation for Nuclear Research near Geneva, where the LEP electron-positron collider was in operation from 1989 to 2000 at centre-of-mass energies up to 209 GeV. Until 1995, data on the Z boson, the neutral mediator of the weak force, were accumulated, allowing precision tests of the Standard Model to be performed. Consistency within this framework of the results thus obtained(4) required a top quark mass in the range 155 to 185 GeV, precisely where it ended up being found at the Tevatron. Together with the measurements of the mass of the charged weak boson W performed both at LEP and at the Tevatron, and of the top quark mass at the Tevatron, the same consistency requirement of the Standard Model now predicts that the mass of the Higgs boson should be lower than 190 GeV [5] (Fig. 2). Finally, direct searches for the Higgs boson [6] performed at the highest LEP energies exclude it for masses below 114 GeV, however with tantalising hints around 116 GeV.

> The successor of LEP at CERN will be the LHC (Large Hadron Collider).

The successor of LEP at CERN will be the LHC (Large Hadron Collider), a 14 TeV proton-proton collider which was essentially designed in view of the discovery of the Higgs boson or of new particles predicted by theories beyond the Standard Model, for masses all the way up to 1 TeV. The construction and commissioning of the LHC and of the associated detectors will however not be complet-



▲ **Fig. 1:** An aerial view of the Fermilab site. The main components of the accelerator system are highlighted: in yellow, the Tevatron, a 2 TeV proton-antiproton collider; in red the initial injection system; in blue the newly constructed main injector and recycler. The locations of the CDF and D0 detectors are also indicated.



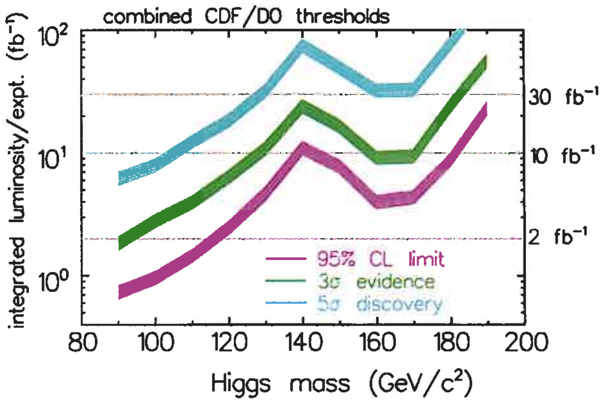
▲ **Fig. 2:** Masses of the W boson and of the top quark as measured directly at LEP and at the Tevatron (in green), and as indirectly predicted, based on precision measurements at the Z resonance (in red); the contours drawn correspond to a confidence level of 68%. The yellow band represents the Standard Model prediction for various Higgs boson masses. Direct and indirect measurements are in agreement, and point toward a light Higgs boson. (From Ref. 5.)

ed before 2007, at the earliest. Until then the Tevatron, which resumed operation in the spring of 2001, will remain without rival at the high energy frontier. It was furthermore realised in the late nineties [7] that a Higgs boson with mass in the range indicated by LEP direct and indirect searches, i.e. between 114 and 190 GeV, could well be within the reach of the Tevatron, provided that a sufficient integrated luminosity is delivered (Fig. 3).

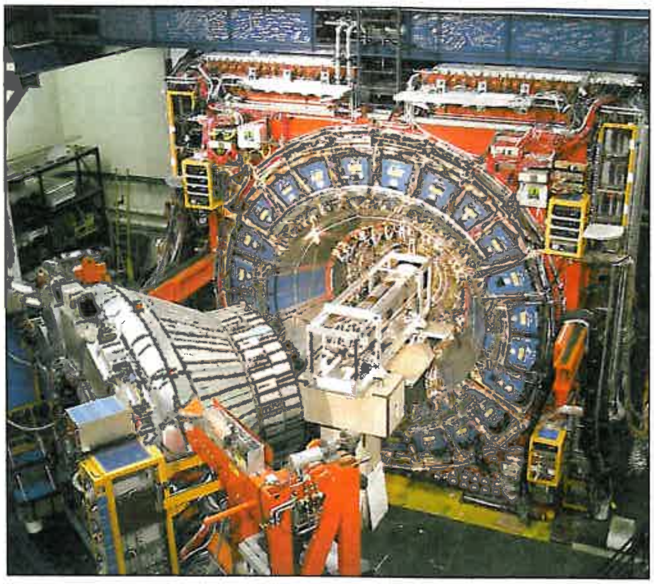
Both the Fermilab accelerator complex and the CDF and D0 detectors were substantially upgraded for this new phase of operation called Run II. On the accelerator side, two entirely new rings, the Main Injector and the Recycler, were constructed, with the goal of increasing the antiproton intensity which had been the main luminosity limitation during Run I. Together with other challenging beam optics improvements, these upgrades should allow the instantaneous luminosity to be progressively increased by a factor of five in a first phase, possibly of up to fifteen in a second one. This would lead to an integrated luminosity of 2 fb^{-1} (i.e., 2000 pb^{-1}) collected by the end of 2005 (Run IIa), and then of up to 3 fb^{-1} every year thereafter (Run IIb). In addition to these luminosity improvements, the proton-antiproton collision energy has been increased to 1.96 TeV.

Both the Fermilab accelerator complex and the CDF and D0 detectors were substantially upgraded for this new phase

The CDF and D0 detectors had been initially optimised in quite different ways. In the case of CDF (Fig. 4), the emphasis had been put on an excellent detection and measurement of charged particles in a large volume tracking chamber. Silicon detectors placed near the beam pipe allowed secondary vertices to be reconstructed. Such vertices may arise in particular from the decay of short-lived particles such as those containing a bottom quark. The D0 collaboration had decided to rather emphasise precise, homogeneous and hermetic calorimetry (Fig. 5). For Run II, the CDF central tracker was entirely rebuilt, and both the calorimetry and muon detection coverage extended. In the case of D0, the muon coverage was also improved, but the main modification has been the introduction of a superconducting solenoid inside the calorimeter, and within it of a totally new tracking system. In particular, silicon detectors were also installed in D0, so that the intrinsic capabilities of the two experiments are now much more similar than they were during Run I. With the anticipated luminosity, and therefore interaction rate, increases, the silicon detectors of both CDF and D0 will have to be replaced at the end of 2005 by new "radiation hard" ones.



▲ **Fig. 3:** Reach of the Standard Model Higgs boson search at the Tevatron. The curves represent, as a function of the Higgs boson mass, the luminosity which has to be delivered to each of the two experiments in order to allow an exclusion at 95% confidence level (in purple), a 3σ evidence (in green), or a 5σ observation (in blue) to be achieved. (From Ref. 7.)



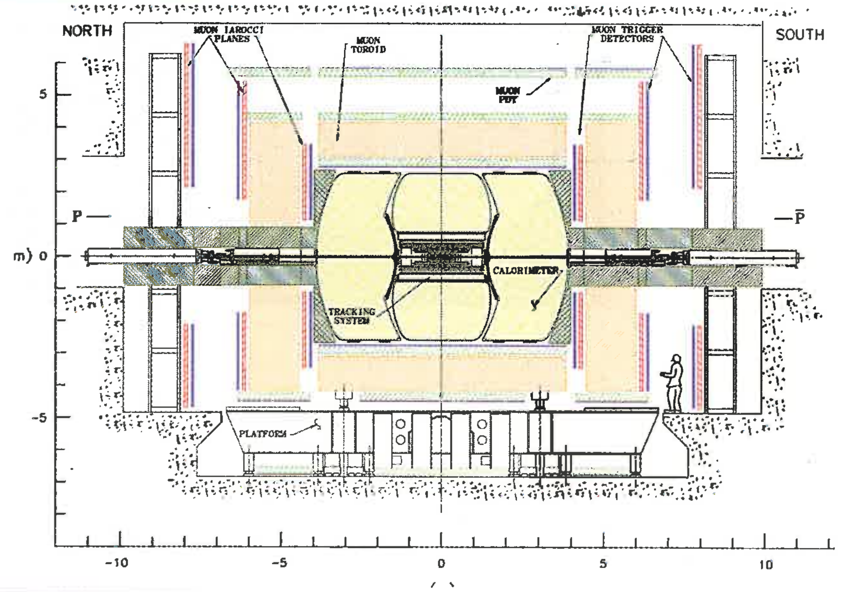
▲ **Fig. 4:** A photograph of the CDF detector, opened during the installation of the silicon detector. From the inside to the outside, the tracking chamber, the calorimeter and the muon chambers can be seen.

The Run II of the Tevatron will offer a broad range of physics opportunities:

- The higher luminosity and the increased production cross section will allow a large sample of top quarks to be collected. Because of its large mass (forty times the mass of the second heaviest quark), the top quark properties are quite unusual, and their detailed investigation will become possible. In particular, the uncertainty on its mass could be reduced to ± 2 GeV.

- It should also be possible to reduce to ± 30 MeV the uncertainty on the mass of the W boson. As can be inferred from Fig. 2, this improved precision of the top quark and W boson masses would allow the mass of the Standard Model Higgs boson to be much better constrained. It could even well be that these indirect constraints conflict with the mass lower limit obtained at LEP, which would point to some new physics beyond the Standard Model.

- Direct searches for phenomena beyond the Standard Model will also be pursued, greatly benefiting not only of the higher



◀ **Fig. 5:** A schematic cut view of the D0 detector, showing the various components. Inside out starting from the beam pipe: the silicon and scintillating fiber tracking systems, the superconducting solenoid, the uranium-liquid argon calorimeter, the iron toroid with the muon detectors.

luminosity but also of the higher energy, compared to Run I. For reasons which cannot be addressed in this short article, it is commonly expected that the Standard Model, even if it is experimentally very successful, will break down at a scale not much beyond the few hundred GeV presently probed, therefore possibly within reach of the upgraded Tevatron.

- A huge number of bottom quarks will be produced, which will allow very difficult, but unique, measurements to be performed. In particular, it will be possible to study hadrons containing both a bottom and a strange quarks, which cannot be efficiently produced at the current "b-factories" (5), thus providing additional constraints on the CKM (Cabibbo-Kobayashi-Maskawa) quark mass matrix [8].
- Detailed studies of QCD (quantum chromodynamics, the theory of strong interactions) at the TeV scale will be performed, not only interesting by themselves, but also possibly revealing a quark substructure.

While the above topics can already be addressed with an integrated luminosity of 1 or 2 fb^{-1}, corresponding to Run IIa, the search for the Standard Model Higgs boson will really need the 10 fb^{-1} or more anticipated for Run IIb, as can be seen in Fig. 3. With such an integrated luminosity, it should be possible to exclude at 95% confidence level the whole mass range suggested by LEP precision studies. More optimistically, a 3σ (three standard deviation) evidence, perhaps even a 5σ discovery, could confirm the LEP hint at 116 GeV.

At the time of writing (November 2002), both CDF and D0 are essentially fully commissioned. Since the beginning of Run II, the Tevatron luminosity has been steadily increasing, and has already reached half the Run IIa design value. The current goal is to accumulate before next summer two to three times the integrated luminosity collected during Run I, which, together with the energy increase and with the improvements brought to the detectors, should provide the first harvest of many years of forefront results.

Footnotes:

(1) Energies and masses are measured in electron-Volt (eV) units. One MeV is worth 10^6 eV, one GeV 10^9 eV, and one TeV 10^{12} eV.

(2) Instantaneous interaction rates are proportional to the luminosity of the collider, measured in $cm^{-2}s^{-1}$, and to the cross section of the process considered, measured in cm^2, or rather in pico- or femtobarns (10^{-12} or 10^{-15} barns, where one barn is worth 10^{-24} cm^2). For an integrated luminosity of N pb^{-1} (N fb^{-1}), N events are produced by a process with a cross section of 1 pb (1 fb).

(3) The Standard Model of electroweak interactions is based on the gauge group SU(2)×U(1), with three generations of quarks and leptons. The gauge symmetry is spontaneously broken by the Higgs mechanism.

(4) The SLC (SLAC Linear Collider of Stanford, California) also contributed to these results.

(5) PEP II at Stanford (California), and KEK-B at Tsukuba (Japan)

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Hydrodynamics of planetary nebulae

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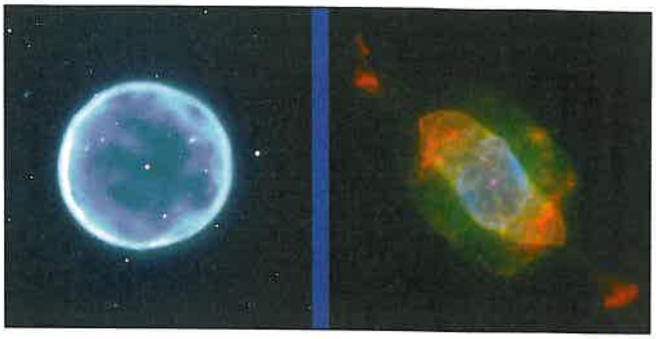


▲ **Fig. 1:** Left: the spherical planetary nebula Abell 39; image courtesy of G. Jacoby and Kitt Peak National Observatory. Right: the bipolar NGC7009, observed by B. Balick with WFPC2 on the Hubble Space Telescope.

Stellar evolution

Stars do not go gently into that dark night. Those with masses above eight times the mass of the Sun explode as supernovae, outshining for a few weeks their parent galaxy. But even low-mass stars make a show of their departure. Because they are so much more numerous than the heavies, the remains of defunct solar-type stars litter the galactic landscape. Known as *planetary nebulae*, they appear so frequently that many of them are found quite nearby; with apparent sizes of many minutes of arc, these are excellent objects for viewing with an amateur telescope. The moniker 'planetary' has nothing to do with planets; it means 'planet-like', because an emission line of doubly ionised oxygen gives these nebulae a greenish glow, reminiscent of a planetary disk.

Stars shine due to the nuclear fusion of hydrogen, producing helium, carbon, and heavier elements. The central temperature in low-mass stars is too low to produce much beyond the CNO-group. When the hydrogen in the core is exhausted—which takes about 10 billion years for the Sun—the core contracts. The temperature is, as in Wien's Law, inversely proportional to a length, in this case the core radius. The luminosity is proportional to the fourth power of the temperature and the second power of the radius, so that the core increases a hundredfold in brightness for every factor 10 it contracts. Thus, when the core contracts, the stellar atmosphere is heated from below and puffs up, ultimately reaching a size comparable with the orbit of Venus. The luminosity of the cooling core is radiated away through this enormous surface, so that the effective temperature of the star is low, of the order of 2000 K or even less. In its final ten million years, the star has become a *red giant*.

During the initial stages of this process, some fusion still occurs in a shell around the core, but this state is overstable. Ultimately, *thermal pulses* of increasing amplitude drive off the outer shell, leaving behind a naked core with a surface temperature up to several hundred thousand kelvin. Radiation pressure from this brilliant pinpoint, soon to cool down and become a *white dwarf*, drives a supersonic wind into the departing outer shell. It is the collision between these two winds—a dense shell at tens of kilometres per second, hit by a tenuous gas at a few thousand km/s—that produces the beautiful planetary nebulae.

Colliding winds

Originally, it was thought that most PNs are spherical (Fig.1, left). After all, that is what their parent stars are likely to be, and the physics of the formation of such shells was well understood. The outer 'slow' wind expands with a velocity of about 20 km/s and a density of 10^{10} atoms per m3. The inner 'fast' wind races outward with speeds up to 2000 km/s, and a much lower density, typically 10^7. The interacting winds produce a typical shock/contact-discontinuity/shock configuration. Seen from the central star, and following a radial flow line, the gas is very supersonic, and moves outward with a Mach number of 40-100. Then the gas passes through a strong shock, which converts most of the kinetic into thermal energy. This creates a thick layer of very high temperature and pressure, which pushes against the 'slow' gas at a contact discontinuity where the gas density jumps upward but the pressure and the velocity are continuous. Further out, the slow gas runs into whatever external medium there is, and a second shock is formed.

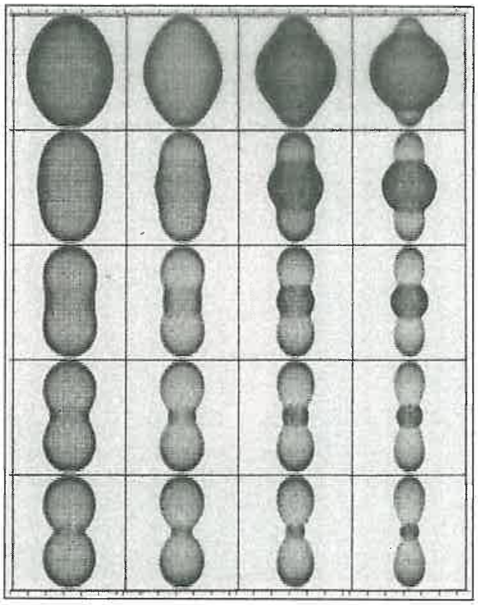
Using standard hydrodynamic conservation laws, these configurations were readily analysed (e.g. Kwok 1982), and compared well with the observations of spherical PNs. The fast wind is almost unobservable, and the region beyond the inner shock, having a temperature in the millions of kelvin, is properly observed only in X-rays, which has only recently become possible with the advent of satellites that can observe X-rays with large collecting area. The shocked slow wind, which forms the archetypical 'planetary nebula', stands out clearly in the light of various emission lines, most notably Hα, [N$^+$] and [O^{2+}]. The nebular spectrum is dominated by the reprocessed ultraviolet radiation of the central white dwarf.

Kompaneyets revisited

But the spherical textbook cases turned out to be a minority (Fig. 1, right). Many planetaries even have an extreme dumbbell shape (Fig.2; for detailed reviews, see Schwarz 1993 or Sahai 2002). In 1987 Bruce Balick (University of Washington, Seattle) published a classification scheme in which, for the first time, the whole range of shapes was taken seriously, all the way from purely spherical (Fig.1) to completely double-lobed (Fig.2). In addition, Balick (1987) supposed that the shaping of bipolar nebulae was due to a hypothetical aspherical shape of the outer slow shell, even though a mechanism for producing this was—and is—unknown.

When Balick visited Sterrewacht Leiden on a sabbatical leave, he asked me to think about the hydrodynamics of interacting

◄ **Fig. 2:** Bipolar planetary nebula Hubble 5, observed by B. Balick, V. Icke and G. Mellema with WFPC2 on the Hubble Space Telescope. Colour channels indicate three emission lines: red, [O]; green, [N$^+$]; blue, [O^{2+}].



▲ Fig. 3: Analytical models for bipolarplanetary nebulae. From left to right, the pole/equator density contrast increases; from top to bottom, time increases. Images have been scaled to fit the boxes.

aspherical winds. The main problem, as I saw it, was finding a suitable approximation for the propagation of a very strong shock through an inhomogeneous atmosphere. Of course I knew the elegant analytical solution that Kompaneyets (1960) had found for the evolution of a strong shock in an exponential atmosphere, and I formulated the PN problem in the same approximation. The shape $r(\theta, t)$ of the outer shock can be found analytically from the equation

$$\frac{\partial r}{\partial t} = \left\{ \frac{(\gamma+1)P}{2\rho} \left[1 + \left(\frac{1}{r} \frac{\partial r}{\partial \theta} \right)^2 \right] \right\}^{1/2}$$

Here P is the pressure behind and ρ the gas density ahead of the shock. In the PN case, the density ρ in the outer atmosphere is far from exponential. Instead, it is cylindrically symmetric, with a distribution dictated by the flow of the slow wind. The velocity of this gas is almost constant, so that the density can be approximated by $K(\theta)/r^2$, where K is an arbitrary function of the polar angle θ and r is the radial distance to the star. To my surprise and delight, I discovered that this equation can be solved exactly by separation of variables. The solution is

$$\rho(r, \theta) = r^{-2}\, K(\theta);\ \log r = Et - \int \sqrt{E^2\, K(\theta) - 1}\ d\theta + g(E)$$

with separation constant E and arbitrary function $g(E)$. This form allows the easy generation of predicted shock shapes for a great variety of confining density distributions (Fig.3).

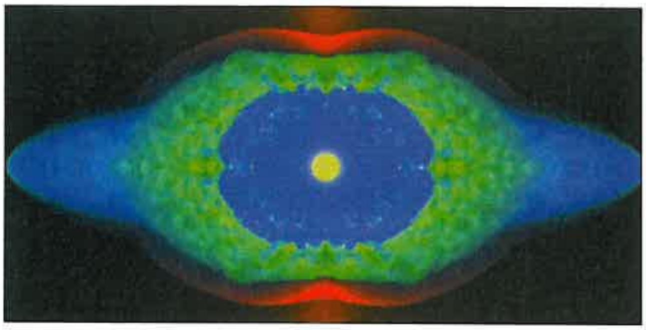
The sequence of bipolar shapes generated by this analytical solution matched Balick's classification scheme almost perfectly (Balick 1987; Icke 1991, and references therein).

Numerical hydrodynamics

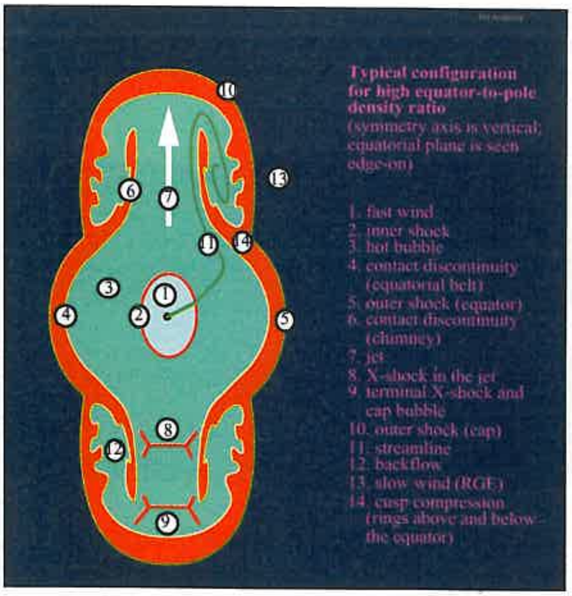
But the analytic solution said nothing about what is perhaps the most intriguing part of a PN, namely its interior. To solve that part of the flow, numerical hydrodynamics was necessary. The difficulty here is, that the gigantic jumps in pressure and density in PNs present severe difficulties to ordinary, diffusive numerical methods (Soker & Livio 1988). Using my 'LCD' variant of Boris & Book's robust flux-corrected transport code, I managed to keep the diffusive effects of numerical hydrodynamics within acceptable bounds (Fig.4).

Subsequent work by Mellema and co-workers, using Roe's approximate Riemann solver, greatly refined these results. Finally, Mellema completed the picture by including radiative transfer and ionisation effects in the equations of motion (Mellema 1995 and references therein).

In the early investigations of bipolar nebulae, the hydrodynamical models concentrated on disk-wind interactions that are 'energy driven'. A central star blows a spherical wind into a toroidal nebula; the wind has such a low density and high speed that the surrounding (inner) shock generates a very hot, pressure dominated layer that then drives the outer shock. Because flow in the high pressure region is very subsonic, inhomogeneities in



▲ Fig. 4: Snapshot of adiabatic PN model. Symmetry axis horizontal, equatorial plane vertical. Red is the density, green temperature, blue the absolute value of the velocity.



▲ Fig. 5: the Identification of features discovered in numerical models for bipolar planetary nebulae. Most of these have now been identified in observed images.

features

this layer are mostly smoothed out, so that the outer shock and the nebular shape are well rounded.

These computations showed a wealth of structures in the interior of the PN (Fig.5), most of which were subsequently identified in observed images, especially those obtained at the European Southern Observatory and with the Hubble Space Telescope. It was even discovered that disk-wind interactions can produce sharply collimated supersonic jets (Icke *et al.* 1992).

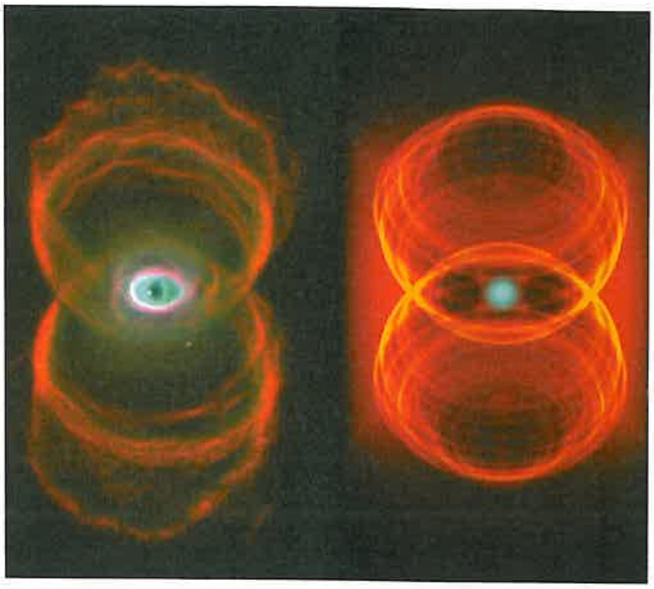
Cooling flows

If the flow is strongly compressible, a thick high-pressure smoothing shell does not develop. This regime is often called 'momentum driven'. In such flows the gas still has considerable momentum after passage through the inner shock, and thereby shapes the outer nebula by direct impact rather than by a mediating pressure. Strong cooling can provide the requisite compressibility, and instabilities and other interesting effects will certainly occur. In order to allow dimensionless scaling of the simulations, the high compressibility can be mimicked by picking a small value of the Poisson constant (usually $\gamma = 1.1$). A typical result is shown in Figure 6. When these computations are used to generate images as they would be observed, the similarity with actual nebulae is particularly striking (Fig.7).

It is expected that stars of higher mass (in the range 2-8 solar masses) produce nebulae that do not cool quickly, and are therefore 'energy driven', whereas the stars that have smaller masses produce the highly compressible, 'momentum driven' PNs. This prediction remains to be verified.

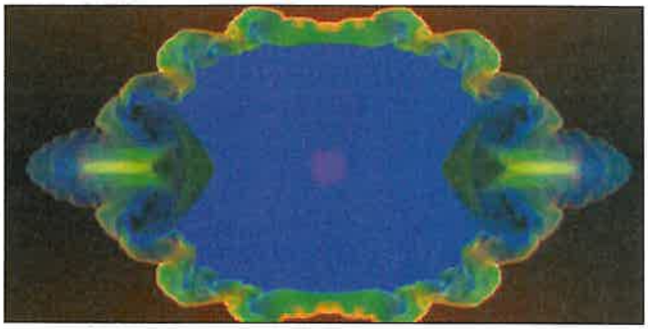
Apotheosis: the Red Rectangle

Astronomy is great, if only because there are always objects that look so strange that they seem to defy explanation. One of these is the 'Red Rectangle' (Icke 1981 and references therein), a nebula looking just like what its name says on the Palomar plates on which it was discovered. New observations (Van Winckel, priv.comm.) clearly show that the Red Rectangle flow is biconical, but it also seems to *pulsate*: the stream is intermittent, which at first sight would be very difficult to produce in the interaction between a steady spherical outflow and a stationary surrounding disk. However, the central star is a binary, which could modulate the flow.

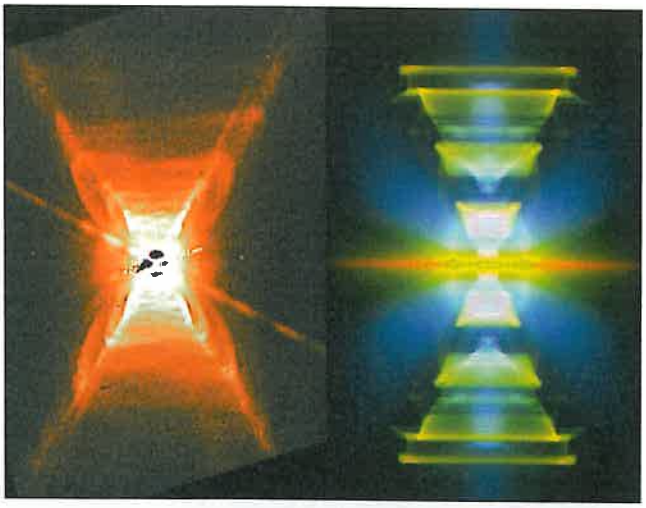


▲ Fig. 7: Bipolar planetary nebula MyCn18, as observed by R. Sahai & J. Trauger with WFPC2 on the Hubble Space Telescope, compared with hydrodynamic pseudo-cooling model.

In the case of momentum-driven flow, the instabilities that occur in the inner flow regime make the outflow far from stationary. In some cases, the gas is focused into a double cone, when it passes through the aspherical inner shock (cf. Fig.5). The density of the Red Rectangle is so high, and the central star(s) so cool, that radiative losses will be considerable, and highly compressible 'momentum driven' outflow is almost guaranteed. Focusing of the primary gas through the inner shock may create a biconical outflow pattern that can produce the characteristic X-shape of the outer nebula.



▲ Fig. 6: Snapshot of a highly compressible PN model (pseudo-cooling). All parameters are the same as in Figure 4, except that the value of the adiabatic index is 1.1 instead of 5/3. Symmetry axis horizontal, equatorial plane vertical. Red is the density, green the temperature, blue the absolute value of the velocity. Notice the collapsed shock-contact configuration, and the instabilities of the outer shock front.



▲ Fig. 8: Left: Observed image of the Red Rectangle, courtesy of Van Winckel. Right: Pseudo-observation of a hydrodynamic simulation with $\gamma = 1.1$. Symmetry axis vertical, equatorial plane horizontal. The image was produced by computing the scattering of white light in the density field produced by the hydrocode. Note the 'Mach stems' at the place where the recurving bow shocks intersect on the symmetry axis.

Observations such as those by Van Winckel can thus be modelled in great detail. Computational experiments show that a specific set of features is common to a wide range of compressible biconical flows. Key features are (Fig.8): (1) cup-shaped density ridges close to the central source, which become ragged rings at higher altitude; (2) the recurving bow shocks ahead of the gaseous rings that are shot upwards from the centre; (3) intersecting shocks on the symmetry axis, forming Mach stems ('X-shocks'); (4) the gradual widening of the effective cone opening angle at higher altitudes, due to the outward pressure behind these shocks. One feature that I initially thought to be problematic for my interpretation, namely the occurrence of X-shocks on the axis, turned out to be present on closer inspection of Van Winckel's $H\alpha$ image.

Conclusions

Bipolar nebulae are due to an interaction between two winds: a slow, dense outflow deposited during the time immediately after the red giant phase, and a very fast, tenuous wind driven by radiation from the dying white dwarf. Analytical and numerical calculations allow the identification of almost all flow features. Notable exceptions are the so-called 'FLIERs' (fast, low-ionisation emission regions). These many forms of mass loss fertilise the interstellar plasma with the materials of life, and show the admirable ways in which low-mass stars rage against the dying of their light.

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Full colour-coded versions of some of the flow patterns shown here will be kept as long as disk space permits on www.strw.LeidenUniv.nl/~176icke/, from which they can be downloaded. QuickTime movies of some of my simulations can be obtained on request from icke@strw.LeidenUniv.nl .

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Hydrophobic compaction, curvature of space and deciphering protein sequences*

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In the July 2000 issue of the *Bulletin de la SFP* [1], Yves-Henri Sanejouand and Georges Trinquier presented an overview of the surprising ability of simple topological models (cubic nets) to explain the fundamental three-dimensional (3D) folding properties of the polymers that we call proteins, those essential components of life. Here, through a number of different examples, I will illustrate another equally surprising aspect of another apparent "simplicity", that relating to hydrophobic compaction, which governs the folding of these macromolecules and which directly serves as a useful tool to decipher genes, thereby opening new prospects in this "post-genomic" era.

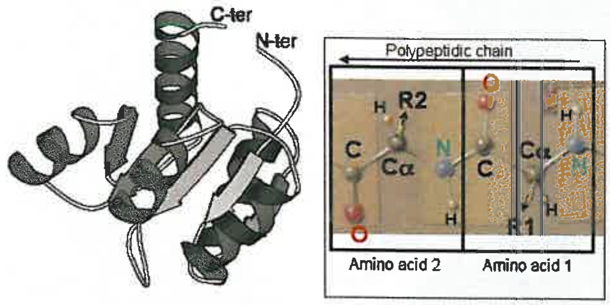
A protein is a linear, unbranched polymer consisting of anywhere from a few dozen to a few thousand links. Nature has limited the chemical diversity of proteins, with the occasional exception, to twenty different types (the twenty common amino acids). All amino acids share the same backbone, differing in terms of their side chains (Fig. 1). Seven amino acids have an aliphatic or aromatic side chain, making them strongly hydrophobic: V (valine), I (isoleucine), L (leucine), F (phenylalanine), M (methionine), Y (tyrosine) and W (tryptophane). Six have a strongly hydrophilic side chain: D (aspartic acid), E (glutamic acid), N (asparagine), Q (glutamine), K (lysine) and R (arginine), while the other seven have intermediate properties: A (alanine), C (cysteine), T (threonine), G (glycine), P (proline), S (serine), and H (histidine). This distribution of hydrophobicity/hydrophilicity offers a clever range of blocks with which to build macromolecules exhibiting remarkable physicochemical properties.

Under normal conditions, any fairly long polypeptide (from a few dozen to a few hundred amino acids) folds spontaneously in the presence of water into globular domains with a stable three-dimensional architecture; some can also fold specifically (often in helical form) within lipid membranes. It is the dichotomy between hydrophobicity/hydrophilicity that acts as the driving force for these processes (e.g. [2]), as it does for many other physicochemical situations in the world around us.

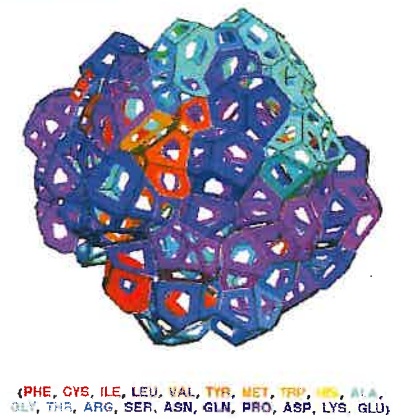
The succession of different types of amino acids along the polymer, which is specific to each protein, is called the primary structure, or sequence. This information is sufficient for the polypeptide chain to adopt a stable and unique three-dimensional structure in a suitable medium (mainly water), with the occasional exception (Fig. 1). Yet not all the positions of a given sequence have the same influence on the cooperative process of folding. As a result, ancestral proteins have undergone considerable modification during evolution, amino acid after amino acid, without altering their resulting three-dimensional structure nor affecting their associated biological function(s). Thus, it is not infrequent that proteins with only a very low number of chemically conserved homologous positions along the polypeptide chain (cf. Fig. 4A), i.e. a very low level of sequence identity (10 % for example), are in fact close cousins within a same structural or functional family.

The result is that, while the number of natural sequences in the biosphere is undoubtedly very large (perhaps more than 10^{12}), the number of distinct 3D folds found in nature is much smaller. Recent estimates [3] put the number at approximately 10^3 and, interestingly, about half of these (≅ 600) have already been precisely characterized at the atomic level through X-ray crystallography or NMR studies over the past four decades (the first x-ray structure of a protein dates back to 1958). Thus, a protein domain encoded on a gene currently has a roughly one in two chance of being closely related in structure (and often in function) to a previously characterized protein fold. This favorable situation can only get better in the future, considering the ever growing number of known protein folds and the even faster rise in the number of whole genomes being sequenced.

The major obstacle to uncovering the underlying correlations in this expanding bulk of data is to recognize the relatedness between evolutionarily divergent proteins sharing low sequence identity, solely on the basis of the available data, i.e. the sequences themselves. We shall see below how topological considerations alone, which directly reflect the physicochemical principles governing polypeptide stability, can meet this challenge by going one step beyond the classical methods of statistical and lexical sequence analysis, which rapidly lose their sensitivity as sequences



▲ **Fig. 1:** Simplified "ribbon" illustration of an experimentally determined protein structure, depicting the regular secondary structures [α helices (helices) and β strands (arrows)]. The positions of the two ends, N-ter (for NH2-terminal) and C-ter (for COOH-terminal) of the polypeptide chain (128 amino acids – PDB 3CHY) are indicated and, in this case, are close to one another, as frequently observed. The insert shows a peptide segment (from [15]) composed of two links, two amino acids whose backbone (main chain) are linked through a planar peptide bond (CO-NH). The side chains (R1, R2) are carried by the alpha carbons (Cα) of the main chain and vary according to amino acid (20 different side chains; e.g. the side chain of methionine (hydrophobic) has the structure –CH2-CH2-S-CH3). The NH and CO groups of the backbone form hydrogen bonds with the CO and NH groups, respectively, of distant amino acids in the sequence to form regular secondary structures such as a helices and β sheets (assemblies of β strands).



▲ Fig. 2: Voronoi tesselation of the same protein Che Y (PDB: 3CHY shown in Fig. 1). The colors of the cells correspond to the hydrophilic/hydrophobic properties of the amino acids. Black and white lines respectively depict faces specific to a single cell and those common to several cells. Only the surface of the protein is shown (source: B. Angelov and J.F. Sadoc).

become more divergent. But first, let us take a look at this topological environment.

Voronoi tesselation of common protein globular domains

Consider the geometrical barycenters of each amino acid and, starting from these few dozen to few hundred points, let us build contiguous polyhedral cells for which any point inside their volume is closer to their associated barycenter than to any other barycenter. These are Voronoi cells, characterized in particular by their mean number of faces and edges per face (Fig. 2). In a representative sample of proteins, these values are in almost perfect agreement with what would be expected for a compact packing of spheres [4]: the protein domains behave like condensed matter, at least in this regard. The advantage of this cell-building method is that it gives "absolute" access to the concept of neighbors, i.e. among others and without arbitrary numerical cutoffs, to concepts as important as, for instance, the mean burying of such and such a category of amino acids, by direct counting of the Voronoi cells at the core and at the surface. This concept, widely employed in condensed matter physics, opens new perspectives into the world of proteins.

Proteins as flowers

Compilation of the geometrical distances between peptide links along a protein sequence reveals that segments separated by some 20 to 30 amino acids are sometimes in close proximity to one another [5]. This heretofore unnoticed property is also revealed in the physics of certain nonbiological polymers [6] (such loops are formed of segments of chains which are about 4 persistence lengths). Thus, like the edge of a daisy petal which loops around before returning to the center of the flower, proteins can be thought of as a "disorderly bouquet" occupying the volume of the folded protein globe (Fig. 3). The recent demonstration of these "closed loops" sheds new light on the origin of proteins, suggesting that they arose from the concatenation of primordial peptide fragments having the right length to self-stabilize by pseudo-closure [7].

Two-level micelles

In a typical protein globular domain, about one-third of the amino acid side chains are strongly hydrophobic while the other two-thirds are polar or neutral. The first type clusters within the protein core, insulated from the solvent (water) by a layer of neutral or polar amino acids. However, not all the positions in the sequence (and the resulting 3D structure) occupied by hydrophobic amino acids have the same properties. Two categories may be distinguished: positions at which, for all sequences coding for a same fold, strong hydrophobicity is always conserved ("topohydrophobic positions") [8], and those at which this hydrophobicity is not conserved between sequences ("non-topohydrophobic positions"). The first account for about 1/3 of all positions in a sequence occupied by hydrophobic amino acids (or about 1/9 of the sequence) and display remarkable properties. They are buried deep within the core and therein constitute a network of mutually interacting amino acids, very largely coinciding with the amino acids which, very early during the folding process, are experimentally found to be in contact ("folding nuclei" [9]).

Moreover, it was recently shown that the ends of the closed loops described above are frequently occupied by these topohydrophobic positions [10]. One advantage, and not the least, is that these topohydrophobic positions can be predicted from a limited number of sufficiently divergent sequences coding for a same fold.

Sequences, or the game of chance and time

A protein sequence is only very rarely stable. Over the course of evolution and during long periods of time, certain amino acids might be substituted by others, while others are added and still others deleted. This game of musical chairs (with a variable number of chairs!) lasts for as long as the modifications do not cause unfavorable, or even lethal, effects to the organism, i.e. for as long as they remain compatible with conservation of the fold and its resultant biological function. Yet these geological periods are much too short, by far, to allow this game to explore more than just a tiny fraction of the possibilities. Nevertheless, the result is that a sequence coding for a protein with a given biological function may become unrecognizable: its length may have varied considerably (by addition or deletion of amino acids in any number or position) as well as the identity of the amino acids that make up the polypeptide chain (Fig. 4).

Therefore, comparing sequences and ordering them on the basis of homology into families within genomes is no simple matter. Below a certain level of conserved homologous positions, corresponding to about one quarter of the amino acids, it is very difficult, if not impossible, to succeed by using common automated lexical methods that statistically compare sequences like strings of independent letters. This methodological obstacle is of major importance because it is encountered in a great many genomes, substantially hindering their analysis and use.

▲ Fig. 3: Reduction of the urate oxidase tetramer into closed loops, some of which from this viewpoint are clearly visible at the periphery (in yellow, orange and pink) (source: M. Lamarine). These closed loops should not be confused with the usual loops found in proteins, which are normally shorter (segments of the polypeptide chain joining two successive regular secondary structures – thin segments in Fig. 1).

features

We shall see below that this obstacle can now be often overcome, but for the moment the price to pay is a loss of automaticity and, consequently, an inability to process massive amounts of genomic data.

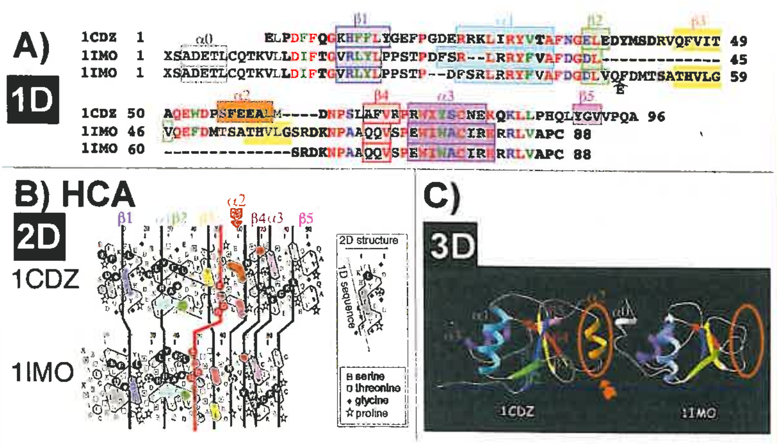
Sequences are more than just strings of letters, or how giving them curvature can help decipher them

A natural polypeptide chain folds upon itself to give the compacted polymer its biological property or properties (Fig. 1). In principle, to "mimic" this compaction, one must obviously and necessarily curve the polypeptide chain which, in the symbolic representation of its sequence, i.e. a string of letters, is considered to be fully extended. This string might be thought of as a straight line (1D). In 2D space, the ideal, uniform curvature of this line is the circle (in which the two ends of the chain – canonically called N and C – touch). Transposition into ordinary 3D space turns this isotropic curve, by continuity, into a helix. Starting from these intuitive principles, it can be shown that with a suitable pitch, the sequence so curved into a uniform helix gives direct information about the local hydrophobic compactions associated with the typical regular secondary structures of polypeptide chains (a helices and β strands) (Fig. 1). Hydrophobic Cluster Analysis (HCA) is based on such an approach [11]. Fig. 4B illustrates in two-dimensional form the result of helical curvature of a sequence, supporting the analysis and the HCA sequence comparison.

This strategy thus makes use of this curvature of space of sequences and also takes into account a suitable separator of information [the "connectivity distance", equal to the number of amino acids, for a helix of given pitch, separating amino acid i from its farthest near neighbor j (e.g. 4 for the common α helix of proteins)]. For the usual sequence, this connectivity distance is simply equal to 1 (amino acid i and its neighbors $i \pm 1$). Using these ingredients, HCA reduces the sequence into protein "words" that make physicochemical sense: they form the internal hydrophobic faces of the regular secondary structures of the polypeptide chain and appear as hydrophobic clusters on the helical representation of the sequence (Fig. 4B). This works in much the same way as blanks and spaces give meaning to a text by separating it into words and sentences: a given string of letters does not have the same meaning in the presence and absence of these punctuation marks. Geometrically speaking, the internal hydrophobic surfaces of these secondary structures are like strips of velcro which, by sticking together, form the hydrophobic core of the domain and constitute the signature of its fold.

It is these "words", these cores of molecular compaction, that allow one to compare and classify highly divergent sequences, because during evolution these clusters have been much more resistant to the shuffling of amino acids than the amino acids considered in isolation. Currently, this can still only be done by dint of a largely multifactorial, context-dependent human expertise comprising both structural and functional data, much like a police investigation. However, more powerful automated methods may one day become feasible, opening a vast field of study.

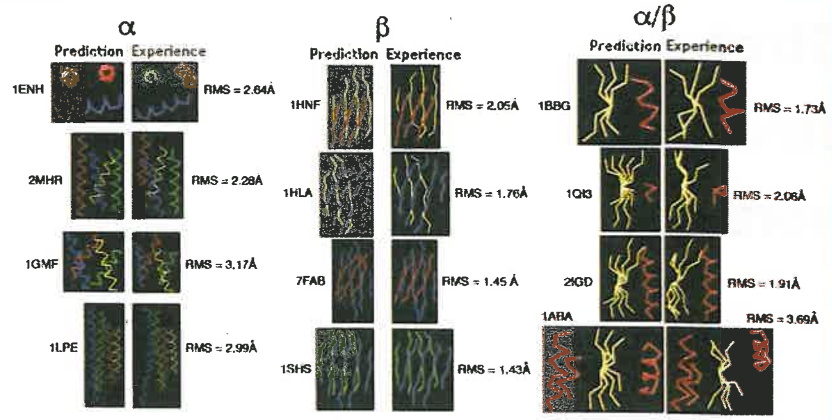
Proteins are compact, and the first HCA curvature of space of the sequence, which exploits the intrinsic properties of helical compaction (e.g. the Coxeter helix as a continuous assembly of tetrahedra attached by their faces [12]) gives information about local compaction nuclei, which serve as building blocks of global hydrophobic compaction. This makes it tempting to explore the potentials of a higher dimension, i.e. a second curvature in topological space to four dimensions, with the aim of revealing, even in a roundabout way, the global compaction, i.e. the 3D fold itself, based solely on sequence information (the so-called *ab initio* fold, an approach developed in collaboration with Jean François Sadoc (Laboratoire de Physique des Solides ,Orsay)) and which, with the occasional exception, is still outside of our reach, though substantial progress has been made through the use of structural fragment banks (e.g. Rosetta [13]).



▲ **Fig. 4A:** Alignment of two protein sequences sharing a same fold and a common ancestor (belonging to the BRCT family, a family of domains found in several proteins associated with DNA repair and cell cycle control, among which the breast cancer- associated BRCA1 protein [16]). The sequences have considerably evolved and share only less than 30 % amino acid identity (red) in homologous folding positions, whereas conservative substitutions of the principal physicochemical properties (green for hydrophobic amino acids, blue for the others) and non-conservative substitutions have occurred at other positions in the alignment, in addition to insertions or deletions of amino acids (hyphens). Secondary structures, as observed experimentally (panel C), are reported in coloured boxes. The alignment shown on the two first lines, based solely on lexical comparison of the two sequences, can be refined by HCA (see panel B) and the characteristic profiles of this family of sequences [16] (first and third lines). The result is a displacement of the insertion. Strands β3 are not aligned correctly by the lexical procedure between the first and second lanes, as well as the begining of helix α1. The cluster of identical (Q, E, D) or similar (W or F) amino acids, depicted in white on a red background on panel B, has wrongly attracted the automatic lexical procedure of alignment (red line of correspondence on the HCA plots – panel B), shown on the first and second lines of this panel.

▲ **Fig. 4B:** Comparison of the HCA plots of these same two sequences, revealing the conservation of the internal faces of the secondary folding structures (hydrophobic clusters shaded, according to the corresponding structures). The orange arrow shows a large insertion comprising a typical hydrophobic cluster with regular secondary structure. The HCA hydrophobic clusters depicted in this figure represent a broken and transposed 2D image of the local nuclei of hydrophobic compaction within the 3D core of the protein.

▲ **Fig. 4C:** Comparison of the three-dimensional structures of these two proteins, illustrating the overall conservation of folding and the presence in one of the sequences of a large insertion in a loop, including a "decorative" regular secondary structure (orange arrow).



▶ **Fig. 5:** Representative sample of the RUSSIA procedure to predict the folding of small protein domains, based on a topological search for optimal compaction of hydrophobic side chains. Only regular secondary structures (helices and strands) are shown (long chains). Loops (in the usual meaning of the term) are not depicted. The mean quadratic distances in Å (RMS) between the positions of homologous alpha carbons in actual structures (experience) and the predicted ones are indicated.

RUSSIA

RUSSIA (Rigid Unconnected Secondary Structure Iterative Assembling) [Znamenskiy D., Le Tuan K., Chomilier J. and Mornon J.P., submitted for publication] is a topological procedure to predict the folding of small to intermediate size globular domains based solely on seeking the maximal compaction of hydrophobic amino acids. The starting data consist of the sequence, the nature and the limits (approximate) of secondary structures, a helices and b strands, predicted by multiple sequence alignments. Helices are modelled as rigid cylinders and assemblies of β strands (β sheets) by helical surfaces with a predefined pitch. The simplicity of this description allows an exhaustive study and an efficient sorting of all possible conformations, as long as the global hydrophobic barycentric description of the domain under study can be considered small (ideally a single point) (Fig. 5).

The success of this procedure has encouraged an approach based on both geometry and topology, which has the advantage of implicity taking into account a description and energy minimization that is still directly (formally) out of reach for such large molecular systems, considering the extreme complexity and lack of contrast in energy states.

Proteins never form knots

A glance at the many protein three-dimensional structures that have already been elucidated reveals that the two ends of the polypeptide chain are often in proximity to one another (Fig. 1); statistically this should be true even if the exercise is not straightforward. This observation might perhaps be related to another solidly established fact ([14]: except in rare circumstances, during the normal folding process polypeptide chains never form knots in the usual meaning of the term (a shoelace, for example – topologically speaking, only closed curves can contain irreducible knots). This might explain why, in contrast to the case of DNA for which topoisomerases exist, there appears to be no molecular machinery to prevent formation of potentially disastrous topological situations, such as knots, apart from the chaperone protein complexes which assist in polypeptide chain folding, perhaps in part by "holding" the two ends of the chain together. This question, which has not yet been widely addressed, once again underscores the importance of geometrical and topological considerations in the molecular machinery of the living world.

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About the author

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Stretching of a vortical structure: filaments of vorticity[1]

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Vortical structures are commonly formed in flows: One has noticed a bath tub vortex, or a vortex formed with a kitchen mixer. The largest vortical structures can be observed in Earth's high-atmospheric flows where cyclones or anti-cyclones can reach up to 1000 km diameter with typical velocities of the order of 100 km/h. Large structures can also be seen in oceans with typical diameters of 100 km with velocities of few tens of km/h. On the other side of the spectrum, the smallest vortices also have a limit, which is not due to the size of the planet, but to viscosity: below a certain size, viscous dissipation does not allow for an organized coherent structure. Its whole energy is dissipated as heat in the flow. On an intermediate scale, tornados are spectacular illustrations of vortical structures or vortices (Fig. 1).

▲ Fig. 1: Picture of a tornado.

Intuitively, one understands that a vortex can be described by two parameters: Its size, and its circumferential velocity. The size of the core of the vortex is defined as the distance r_0 from the vortex axis where the azimuthal velocity V_θ is maximal $V_\theta(r_0) = V_{\theta max}$. For distances larger than r_0, the rotationel velocity decreases and goes to zero at "infinity". Below this diameter $2r_0$, the vortex is approximately in a state of solid-body rotation, as shown in Figure 2a.

Another important parameter is the vorticity ω which is the curl of the velocity $\omega = rotV$. Alternatively, it can be written as twice the angular velocity Ω of the vortex. In the case represented in Figure 2a, the vorticity has only a non-zero component in the direction along the vortex axis. This vorticity is represented in Figure 2b.

In this example, one observes indeed that the vorticity is concentrated in the vortex core. A flow with $V_\theta \sim 1/r$ outside the core has been chosen. This gives a zero vorticity outside this region. Note that such a velocity field depends on r although its axial vorticity is zero: $\omega_z = 1/r\,[\partial/\partial r(V_\theta/r)r - r\partial V_r/\partial\theta] = 0$. In a similar way, a non-zero vorticity does not mean that a vortex is present: A shear flow such as a boundary layer flow[2] on a flat wall can be stable until large Reynolds number ($Re=UL/\upsilon$). For all vortical flows, vorticity is a very important parameter since it locates vortices and gives their "intensity".

An important mechanism that enhances the vorticity is the stretching. Stretching a vortex along its axis will make it rotate faster and decrease its diameter in order to maintain its kinetic momentum constant. This is analogous to the kinetic momentum conservation law in solid mechanics. A well known example is the ice-skater who turns faster as she brings her hands near her body, and vice versa. An example in fluid mechanics is the bath-tub vortex that rotates faster and becomes smaller as it goes from the fluid surface to the exit. More precisely, a stretching γ is an acceleration of the axial velocity along the vortex ($\gamma = \nabla V$). The vorticity equation is obtained from the curl of the Navier-Stokes equation:

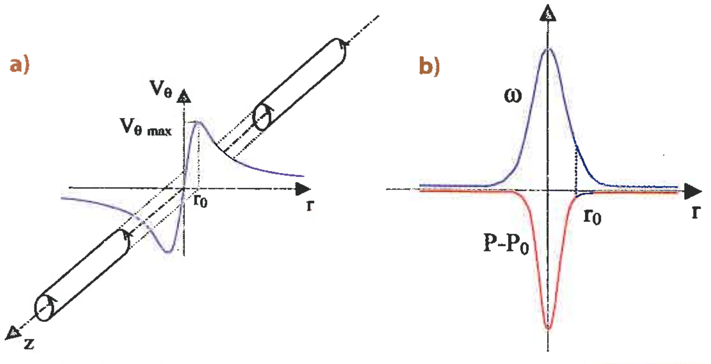
$$\partial\omega/\partial t + (V.\nabla)\,\omega = (\omega.\nabla)\,V + \upsilon\Delta\omega.$$

The first term represents the temporal evolution of the vorticity, the second is an advection term, the third is the stretching term and the fourth represents the viscous effects. When stretching is parallel and in the same direction as the vorticity, the term $(\omega.\nabla)$ is positive and amplifies the vorticity $(\partial\omega/\partial t)$. The vorticity increases and the viscous term $(\upsilon\Delta\omega)$ becomes large enough to exactly counter balance the amplification term $(\omega.\nabla)V$. An equilibrium is then reached which imposes the diameter of the vortex $\gamma.\omega = \upsilon\omega/r_0^2$, hence $r_0 \approx (\upsilon/\gamma)^{1/2}$. From the general perspective of view, the stretching of the vorticity in the flow leads to its amplification and its confinement. Note that it is not the vorticity which is conserved, since it is amplified by stretching, but the circulation $\Gamma = \oint_C U.dl$. Circulation around a curve C is the total vorticity inside this curve.

Vortex stretching is a very important mechanism in fluid dynamics: it usually corresponds to the presence of vortical structures which are much more intense that those produced by simple shear or rotating flows. In particular, it is now well known that local stretching of vorticity in turbulent flows produces very intense vortices called "filaments of vorticity". A large part of the scientific community working on turbulence believes that these structures are very important in the dynamics of turbulent flows, although their structure, their dynamics or their instabilities are not fully understood. The study of these structures of intense vorticity is hence extremely important for both fundamental research and applied science (flow control, ...).

▶ Fig. 2a: Example of azimuhtal velocity of a vortex $V_\theta(r)$.

▶ Fig. 2b: Vorticity $\omega(r)$ and pressure $(P\text{-}P_0)$ profile of the velocity profile (Fig. 2a).



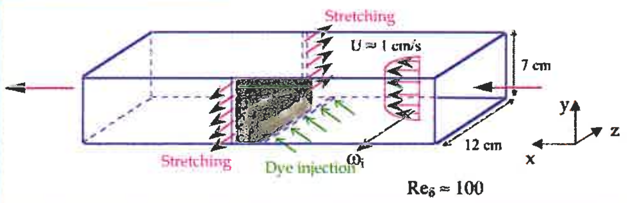
Two experiments have been built to produce filaments without turbulent flows. Only the fundamental ingredients have been kept, i.e. initial vorticity and stretching. These set-ups allow the study of the filaments of vorticity with a control over various parameters of the experiments. In that way, an isolate "standard" vortex is produced for a study of its structure, its dynamics, its instabilities and its turbulent burst.

The two experiments allow a direct study of the mechanisms behind a vortex structure along with its dynamics. Note that the vortex structure is much more complex than models such as Burgers' vortex.

The first experiment corresponds to the stretching of the vorticity of a laminar boundary layer flow in a water channel. The second produces a stretched vortex between two co-rotating discs. In the latter experiment, filaments of vorticity of stronger intensity are produced as the injected vorticity is much larger with rotating discs than with a boundary layer flow. These two experiments cover a large range of vorticity.

Experiment in a water channel (stretching of a boundary layer)

A vortex is generated by stretching the vorticity of a stable laminar boundary layer flow which, under natural conditions, does not produce a vortex. The initial vorticity sheet occurs in the laminar boundary layer ($Re_\delta \approx 100$). Figure 3 shows a sketch of the channel section where the study is performed. On the right hand side of the figure, the flow develops boundary layers on each wall. The boundary layer on the lower plate has, for instance, a non-zero component of the vorticity ($\partial U/\partial y \neq 0$). This "initial" vorticity ω_i will be artificially enhanced to a powerful single vortex. To enable this, a stretching, along this initial vorticity is carried out through suction from slots located in lateral walls. The suction generate a stretching, i.e. an acceleration or a transversal velocity gradient ∇V, parallel to the initial vorticity ω_i. When the stretching is large enough, a strong vortex is produced between the two suction slots.

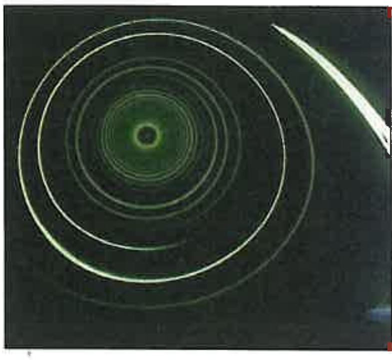


▲ Fig. 3: Experimental set-up.

As the mean flow is laminar and the velocities are slow (0 to 10 cm/s), the study of a stretched vortex becomes easier compared to a study in a turbulent flow. Some examples of flow visualization are shown in photographs of Figures 4, which were obtained from either the injection of fluorescent dye in conjunction with argon laser lighting or from the injection of food colour dye upstream.

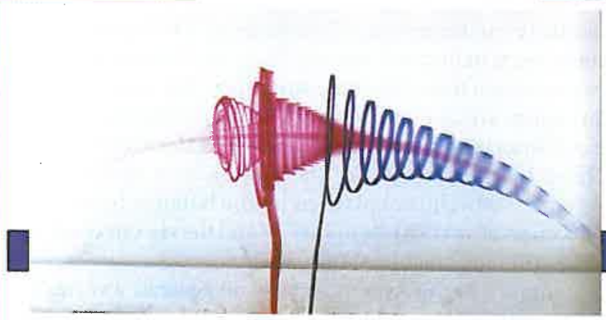
If the whole flow goes through the suction, a permanent vortex is produced. In that case, its structure is studied with velocity measurements as well as its eventual instabilities. If only a part of the flow goes through the suction slots while the rest goes downstream (on the left hand side of the Figure 3), the vortex tends to be advected by the flow while the suction tends to keep it attached. Depending on the ratio between these two mechanisms, the vortex can remain attached or can explode as a turbulent spot. The vortex cannot persist after detachment from suction slots since it lost its stretching, leading to an interruption of the axial flow. It will therefore break up. Another vortex is produced that follows the same dynamics and so on with a very well defined frequency.

Mechanisms behind the formation of vortices have been determined through visualizations. It has been observed that vorticity filaments were generated by the roll-up of a fluid sheet around the vortex core.



◀ Fig. 4a: Visualization of the cross-section of a stretched vortex (plan x,y on Figure 3). A sheet of fluorescein is injected just before stretching. Vortex formation by roll-up of fluid sheets on themselves is observed (image size: 3 cm, vortex core diameter: 0.3 cm).

An important point that has been studied is the structure of the vortex (Fig. 4). Indeed, the localization of the stretching does not allow a simple model for this vortex, such as what has been proposed when the stretching is uniform (Burgers' vortex). The axial component of the velocity must depend on the distance to the vortex axis r (Fig. 4b). A model will be proposed very soon.

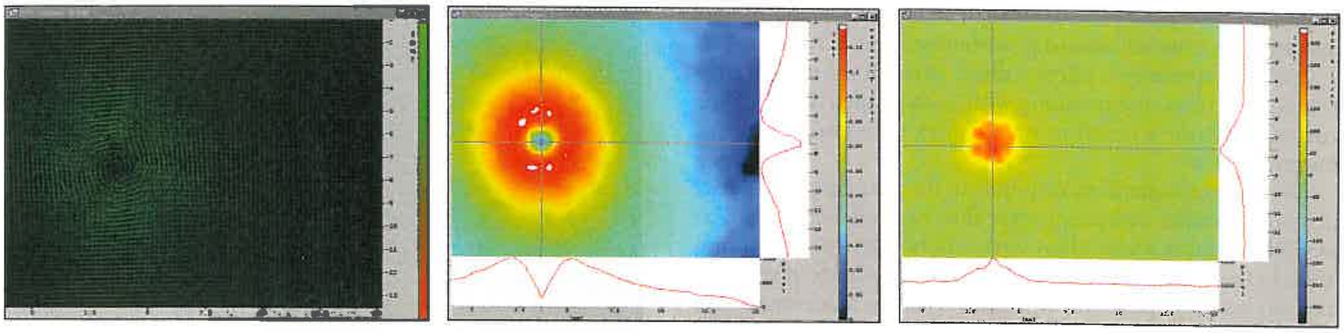


▲ Fig. 4b: Visualization of a vortex by injection of two small dye jets. Top view (plan x,z of Figure 3;. Flow comes from the bottom of the image towards the top and is stretched through suction represented as two small rectangles on the image (size of the image: 12 cm).

PIV technique (Particles Image Velocimetry) was used for measurements of the velocity field in a transverse cross section of the vortex (r, θ). This technique consists of seeding the flow with small particles that are traced for the determination of the velocity fields. Two successive images of the 2D cross-section of the flow are recorded with a video camera. These images are usually obtained thanks to a laser sheet illuminating only particles within its light sheet. The velocity field is then evaluated from the two successive images by following the displacements of particles.

Figures 5 gives an example of what can be obtained with this technique.

◀ Fig. 4c: Visualization of a vortex by injection of two small dye jets. Front view (plan x,y of Figure 3;. Flow comes from the right of the image (size of the image: 4 cm).

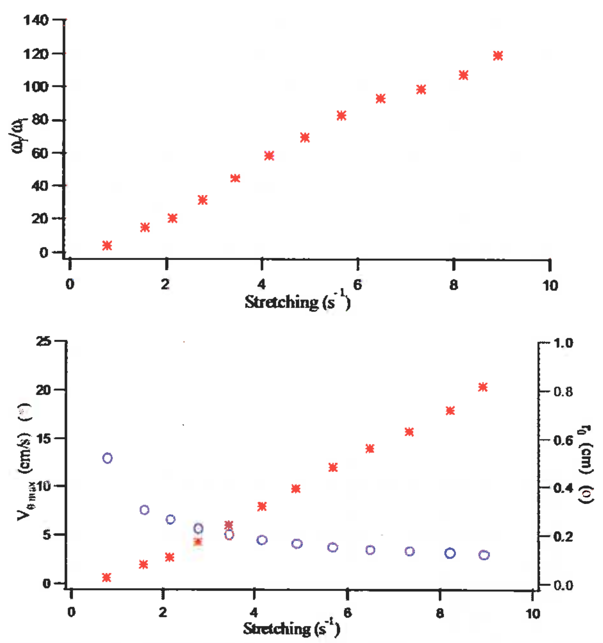


▲ Fig. 5a: **(left)** Velocity field obtained by PIV on a cross-section of the vortex (plan x,y). Fig. 5b: **(centre)** Velocity modulus that is approximately the azimuthal velocity V_θ the radial velocity V_r being much smaller than V_θ. The shape of the vortex (its ellipticity) can be determined with these measurements. Red color coresponds to the largest velocity ($v_{\theta\,max}$) that is reached for $r \approx r_0$, while blue color correspond to the slowest velocity. Modulus of velocity profiles are shown on the sides of the image, with maxima at $r \approx r_0$ for $v \approx v_{\theta\,max}$ and a minimum at the center of the vortex where radial and azimuthal velocities are almost zero. Fig. 5c: **(right)** The curl of the velocity gives the axial vorticity. Particularly, one observes that vorticity is concentrated in the vortex core, and that the flow is quasi irrotational around. This calculation has been performed after a Gaussian-type filtering of the velocity field of Figure 5a.

Thanks to different experimental techniques available in our laboratory, we were able to measure quantitatively the evolution of the vortex characteristics as a function of the stretching γ. Main results are summarized in the following figures:

Figure 6a plots the amplification of the initial vorticity ω_f/ω_i as a function of the stretching. The initial vorticity ω_i was deduced from the velocity profile just before stretching and the final vorticity ω_f is evaluated from the velocity profile of the vortex. This experiment enables a large range of parameters to be explored as the vorticity can be enhanced by a factor of 100! Figure 6b shows the maximum azimuthal velocity $V_{\theta max}$ and the mean radius of the vortex r_0 as a function of the stretching. The results presented in this figure are obtained from PIV measurements technique. One can observe that r_0 strongly depends on the stretching and is not fixed by the diameter of the suction hole. It follows that $r_0 \propto (\upsilon/\gamma)^{1/2}$ which is explained by the balance between the amplification of vorticity term $(\omega\nabla)V$ and the viscous dissipation term $\upsilon\Delta\omega$ in the equation of the vorticity.

In summary, in this experiment we can generate a vortex with characteristics of $V_{\theta max} \approx 1$ cm/s and $2r_0 \approx 1$ cm for a stretching just large enough to produce a vortex. For maximum stretching, just before the vortex becomes too unstable and explodes in a turbulent burst, the vortex characteristics become as large as $V_{\theta max} \approx 20$ cm/s with a diameter $2r_0 \approx 0.2$ cm.



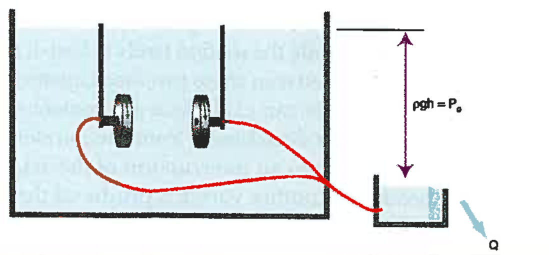
▲ Fig. 6a: **(top)** Amplification of the initial vorticity ω_f/ω_i as a function of the stretching. Fig. 6b: **(bottom)** Mean azimuthal velocity (*) and radius (o) of the vortex (at the center of the channel) as a function of the stretching.

Indeed, we observe that the more the vortex is stretched, the more its vorticity is amplified, the more its diameter decreases, and the faster it rotates; the circulation being the only quantity that is conserved. However, note that in this experiment, the circulation increases, but for another reason: when stretching is increased by increasing the flow rate of the suction, entrance conditions are modified as well, and the injected initial vorticity becomes more important.

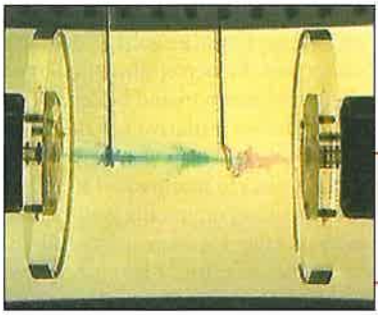
When the flow rate downstream is not zero, a different dynamics is observed. In that case, the flow tends to advect the vortex. Above a threshold, the vortex is unstable and explodes as a turbulent burst. Mechanisms leading to this turbulent explosion are very complex and depend on different kind of instabilities.

Experiment between two co-rorating discs

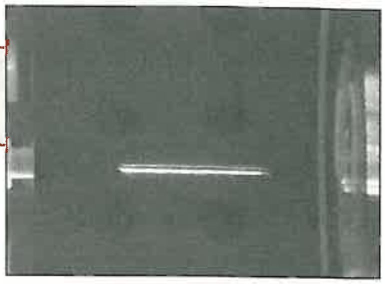
Another experiment devoted to the study of stretched vortices consists of stretching the vorticity of a flow between two co-rotating discs: The discs of diameter $2R$ (5, 10, or 15 cm) are positioned in front of each other with a gap d ($0 < d < 20$ cm) between the disc surfaces. The discs can rotate at identical speeds



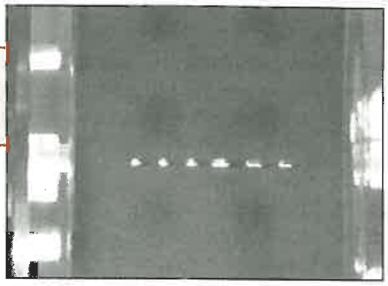
▲ Fig. 7: Experimental set-up.



◀ Fig. 8: Visualization of a vortex. The diameter of the discs is here 10cm.



▶ Fig. 10a: Long bubble into the vortex.

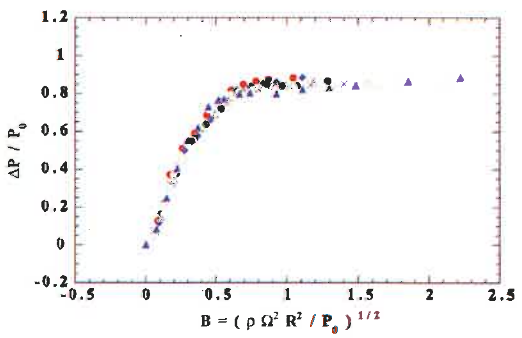


▶ Fig. 10b: Chain of bubbles.

Ω ($0 < \Omega < 1200$ rpm). At the centre of each disc, a 0.5 cm diameter hole allows for suction thanks to a pressure drop (see Fig. 7). This set-up is placed in a water tank whose walls are at least 20 cm away. A vortex is then produced through the vorticity injected by the rotation of the discs and enhanced by stretching (Fig. 8).

Unlike the experiments of the straight channel, the two main control parameters (rotation and stretching) are independent here. Furthermore, the injected vorticity is much larger than in the experiment of the straight channel. These two experiments represent then a very large range of situations.

Pressure is an important quantity that is very difficult to measure in a vortex. We have shown that a probe, even very small (200 μm diameter) strongly destabilize the vortex. The mean pressure in the vortex has been deduced from the measurements of the feedback of the rotation on the stretching: As illustrated in Figure 8, the stretching is produced by a suction system based on a pressure drop between the water level in the big tank (that is maintained at a constant level), and the water level of a small tank connected to the suction slots. The flow rate is measured when the discs are at rest and there is no vortex. A vortex is generated a few seconds after the discs start to rotate with the conditions that the stretching, the distance between the discs, the rotation speed etc are suitable. One observes a flowrate drop in the small tank. This is explained by the presence of the vortex which induces a pressure drop in its core. This pressure drop counterbalances the suction and the stretching, hence the flowrate of the small tank. From the flow rate drop, we evaluate the mean pressure drop in the vortex core: The flow rate with a vortex and a difference of water-level $h1$ between the two tanks, is the same as that without a vortex but with a smaller difference of water-level $h2$. The pressure drop P in the vortex core is given by the relation $Pv = \rho g \Delta h$, where $\Delta h = h1 - h2$. This pressure drop is measured as a function of the initial stretching (i.e. $h1$), the size R of the discs, the distance d between the discs and the rotation velocity Ω (Fig. 9). This study has been performed with F. Moisy and B. Guard.



▲ Fig. 9: Pressure drop into the vortex P/P_0 where the initial pressure drop P_0 is imposed by the difference between the water level in the two tanks when there is no vortex (Ω=0) as a function of a parameter B that represents the ratio between the pressure drop generated by the rotation and P_0. Saturation proves that above a threshold, rotation lost its efficiency.

The pressure drop in the vortex can be large enough to trap micro bubbles naturally present in the water of the tank. This can lead to the formation of a long bubble that stays along the vortex core (Fig. 10a). The bubble is observed to break up into regularly spaced smaller bubbles along the vortex axis (Fig. 10b). This break up is due to the Rayleigh instability.

An interesting point is that, even if the flow rate in the suction holes is of the order of a few l/min, with an axial velocity of a few m/s, the pressure drop in the vortex core is large enough to maintain the bubbles.

Note that it is not cavitation that is observed, as it would require the pressure in the vortex core to be smaller than the vapor pressure of the water. The observations show only concentration of micro-bubbles naturally disolved in water.

The study of stretched vortices is a challenging research topic that presents lots of experimental difficulties due to large velocity gradients, three dimensionality and unsteadyness. However, we believe that mechanisms studied in these "standard" vortices are the same as those of filaments of vorticity in turbulent flows. We hope in that way to contribute to a better understanding and modeling of turbulence, with flow control and prediction as our main objectives. Flow control is indeed an important challenge for the future, in order to reduce the energy losses in turbulent flows (drag reduction, better efficiency in mixing,...). Prediction is also an important challenge for instance in flow control (better prediction leads to better control), or in weather forecasting.

Footnotes

[1] This article is based on an original version published in the Bulletin de la SFP (French Physical Society), 132, p.4, 1 dec. 2001

[2] A boundary layer is a thin layer that develops over a wall and connects the wall where the velocity is zero and the free-stream flow. It is inside this layer that viscosity plays a role whereas it has a much smaller effect in the rest of the flow. This region corresponds to the zone where the velocity gradient produces vorticty.

When physics meets the arts

Signatures of the Invisible

M.Jacob, CERN/Geneva

Signatures of the Invisible stands for a joint project of the London Institute, the largest school of art, design and communication in the world, and of CERN, well known to all physicists. It has produced a travelling exhibition of modern art, which, starting with the Atlantis Gallery in London, in March 2001, has already travelled to Beijing, Rome, Geneva and Lisbon, each time meeting with a great success. Special to this art exhibit is the fact that all the pieces thus presented result from the inspiration which 11 well known artists collected from a visit to CERN which they paid separately in the spring or summer of 2000. Through discussions with physicists at CERN, they were presented with the concepts which are used to described the properties of the fundamental building blocks of Nature, the elementary particles, but they could also see the large and highly sophisticated pieces of equipment through which these particles can only be detected and analysed, since their infinitely small size make them invisible . Some of these pieces of art also result from the discovery by the artists of the very efficient tools available in the CERN workshops, which made possible artistic constructions which some of them had dreamt of realizing but which looked as out of reach with usual means.

A screenshot from the 'Shadows of the Infinite' website: www.infinite.linst.ac.uk/

The different artists expressed themselves in different ways: 2 and 3 dimension paintings, sculptures, mobiles, arrangements of objects, short films projected... all that appears side by side in the exhibition.

The mastermind of the project is Ken McMullen, from the Art Institute. I had the pleasure to first meet him at the end of 1996. We talked about art and science and the different but, to some extent, complementary approaches which they represent in human culture. This prompted him to visit CERN and the idea for the project sprang from this visit. In his words, the project was to encourage "a free flow of ideas between groups of people each concerned in their own way with the mystery and the reality of what makes us who we are and, as much as we can, to achieve an understanding of the universe of which we find ourselves a part." There was definitely a big challenge in starting with particle physics which deals with entities which can be followed and analysed only through a sophisticated mathematical formalism and which can be detected only with highly complex equipment. Nevertheless this physics teaches us the way the world works in its innermost way, forcing us to follow new ways of thinking. Even though it could seem that art had no way to seize all that, it was a great and worthwhile challenge to try to confront it, extracting representations which could trigger interest from a public much wider than the specialized physicists. Physics should not stay a separate corner of human culture and the perception of talented artists could help in making it better known to and better appreciated by a wider public. The McMullen initiative has met with success.

It took about two years for the project to mature and to collect the necessary support and funding and convincing well known artists to participate, but an early meeting between artists and scientists held at CERN had shown that a fruitful dialogue looked possible and even promising. The Director General, Luciano Maiani , showed interest for the project and the director of the press office, Niel Calder and his staff took it up with enthusiasm and efficiency organizing the visits of the artist. The strong support of the London Institute was instrumental, with Michael Benson as project manager. Everything was ready by 2001 for the first London exhibition. It was great to see there, at the opening, science directors and Art school managers in the UK having an extraordinary and fruitful encounter. It has been a much applauded event. Quoting again Ken McMullen to illustrate its content, the artists could " make original pieces of art which repond to, rather than illustrate, the preoccupations of theoretical physics". The many visitors responded to it, discovering that particle physics was not such a foreign venture, restricted to specialists, but something which could trigger emotions beside its providing new knowledge.

Bridging the gap between art and science is not an easy matter but, whereas there are obvious differences between the approaches of the scientists and the approaches of the artists, there are also some similarities. This can be illustrated with quotes from the famous physicist Viktor Weisskopf, taken from his essay on "Art and Science"[1]. He starts saying " What could be more different than science and art ? Science is considered a rational, objective, cool study of nature ; art is often regarded as a subjective, irrational expression of feelings and emotions" .But he quickly continues adding "One can just as well consider scientific discoveries as the products of imagination, of sparks of sudden insight, whereas art could be viewed as the product of painstaking work, carefully adding one part to the other by rational thinking". A passionate advocate of Bohr's complementarity extended to different walks of life and thinking, Weisskopf continues with his essay stressing the complementarity rather than the opposition of the artistic and scientific approaches. He finally concludes on an emphatic note saying " There may come a day when scientific and artistic meanings will combine and help bring forth that ground swell of meaning and value for which there is so great a need. The growing awareness of this need is in itself an important element that brings people together and creates common values and even elation."

We are not there yet but "Signatures of the Invisible" has contributed in bringing together artistic and scientific expressions in front of the greatness and beauty of the world and in developing a lively dialogue. Beauty is indeed highly valued by both the artist and the scientist. Science has of course to work more than it has to look beautiful . It has to be predictive in order to have any value. Nevertheless, as emphasized with strength by many great scientists, from Poincaré to Dirac, the quest for beauty appears as a precious guide in formulating the new concepts and theories which elucidate the inner working of the world. One may also thrill at the beauty of an equation or at that of the principle of an experiment.

We witness at present a dangerous decline in the number of students taking physics as major when entering university. This is a very dangerous trend in a world where technologies coming from new scientific insights play a very important role in everyday life. We should imperatively increase the number of those who can appreciate and understand what science is all about and be in a better position to judge the ethical questions which some of its applications may bring. We should avoid that physics remains a "close book" for so many. This precious and successful encounter between artists and scientists should help in opening the book of physics to others or at least entice them to open it. The artists have magnificently expressed their thinking and emotions when discovering the world of particle physics. They could pass it on to a wider public.

The response met by "Signatures of the Invisible" has been at the origin of a larger endeavour, still under the auspices of the London Institute. This first collaboration is now extended to the worlds of textile, theatre and music, with five projects developed over Europe under the name of "Shadows of the Infinite" [2].

References

[1] "Art and Science"-Gregory lecture-CERN Yellow report (1979)

[2] "Shadows of the infinite" website: http://www.infinite.linst.ac.uk/

EGAS 34

Kiril Blagoev, Chairman of the 34 EGAS
Institute of Solid State Physics, Sofia, Bulgaria

The regular 34 Conference of the European Group of Atomic Spectroscopy was held in Sofia, Bulgaria from 9 to 12 July 2002. Organisers of the conference were the Institute of Solid State Physics, Bulgarian Academy of Sciences and the Faculty of Physics, Sofia University, and the Union of Physicists in Bulgaria was a coorganizer. The conference was attended by 169 participants from 31 countries. Besides the participants from the European countries there were colleagues from NIS (New Independent States) India, USA, Brazil, Egypt, South Arabia. Almost half of the participants were young scientists below the age of 40. Most of them (60 participants) were supported by EC in the framework of the EC Program Human Research Potential—"High Level Scientific Conferences" (contract No: HPCFCT-2001-00338). The EPS supported the participation of 9 young scientists from NIS. The largest group of participants was from Bulgaria (the conference organisers), followed by the groups of Poland, NIS, Ireland, etc. The conference continued the tradition as a meeting of scientists from EC states, the associated states and the rest of the Eastern European states and NIS. Due to financial problems not all colleagues from NIS, who had presented their contributions in the book of Abstracts, had the opportunity to participate in the conference.

At EGAS-34 14 invited lectures, 4 "hot topics" talks, 37 oral and 137 poster contributions are presented. The problems of quantum optic were thoroughly discussed during the conference. Cold and ultracold molecules were the topic of Prof. P.Pillet (Laboratory Aimé Cotton) lecture. New experimental approaches in continuous atom laser were presented by Dr. D. Guéry-Odelin (Laboratory Kastler Brossel). Coherent manipulation of quantum systems with rapid adiabatic passage as well as line shapes at two-photon excitation were discussed in Prof. K. Bergmann (University of Kaiserslautern) lecture. Quantum information processes with trapped laser cooled ions were presented by Dr. J. Eschner (University of Insbruck). Prof. L. Moi (University of Sienna) discussed the cooling of heavy atoms. The Bose-Einstein condensate was the subject of a number of theoretical presentations. Prof. E. Aleksandrov (Vavilov Optical State Institute - St. Petersburg) made a review of the application of quantum optics for measuring weak magnetic field by different types of optically pumped magnetometers.

The different aspects of theoretical and experimental investigations of atomic structure and constants as well as their applications to astrophysical problems were the main topic of a large group of invited lectures, oral and poster presentations. In his lecture Prof. E. Biemont (University of Liege) focused on the present status of theoretical calculations of heavy (in particular rare-earth) atoms and ions. Modern experiments using synchrotron radiation for observation of doubly excited He was the subject of the lecture of Prof. K.Taylor (University of Belfast). Investigation of atomic structure and discovering new energy levels of heavy elements by measuring of hyperfine structure of spectral lines were the topics of the invited lecture of Prof. G.Guthohlein (University of Hamburg) and the "hot topic" talk of Prof. L.Windholz (Technical University of Graz). Dr. H.Nilsson presented the recent achievements in transition probability by branching ratio from FTS UV spectrometer in Lund and FTS VUV in Imperial Colleague, and radiative lifetimes obtained by Laser Induced Fluorescence. In the same field was the lecture of Prof. S.Mannervik (Stockholm University) dedicated to the problems of determination of radiative constants of metastable excited levels. The high resolution IR spectroscopy using diode lasers was discussed in the lecture of Prof. A.Sasso (University of Napoli). Dr. W.Wiese (NIST - Washington) summarised the experimental and theoretical achievements in atomic structure and atomic constants. VUV spectroscopy was reported by the Ireland group. There were many interesting theoretical results for atomic structure and constants presented by Vilnius group and the colleagues from Poland Universities

The behaviour and characteristic of free atoms and their properties near to the dielectric surface was discussed in the lecture of Prof. M.Ducloy (Institute Galillee, University of Paris).

The application of atomic spectroscopy in low temperature plasma and light sources was discussed in the lecture of Prof. R.Gijbels (University of Antwerp) and "hot topic" talk of Prof. G.Pichler (Institute of Physics-Zagreb). A number of oral and poster presentation were in the field of atomic spectroscopy of low temperature plasma.

Generation of ultrashort, attosecond electromagnetic pulses was the subject of Prof. D. Charalambidis lecture, in which proposed schemes and recent achievements were reviewed.

Most of the invited lectures and the "hot topics" will be published in a special issue of Physica Scripta.

The wide field of topics discussed at the 34 EGAS makes this conference unique among the large number of high-specialised conferences. As Prof. P. Lambropoulos (Greece)—Chairman of EGAS Board pointed out at the closing session, the variety of modern topics discussed at the EGAS conferences attracts the interest of young scientists. The EGAS conferences contribute to confirming leadership of the European atomic physics community in this field of science.

The World Year of Physics is on track!

Martial Ducloy, EPS President

For nearly two years, the European Physical Society has been engaged in making 2005 the "World Year of Physics" (WYP), getting support of international organisations for its realisation and success (Europhysics News 33, p.40). This initiative was endorsed by the council of the EPS and its member societies in 2001. It was recently voted unanimously by the General Assembly of IUPAP in October 2002 (Resolution 9 in http://www.iupap.org/resolutions.html). It is also backed by UNESCO. The next step is to get a resolution voted by the Assembly of the United Nations, declaring 'The International Year of Physics' in 2005.

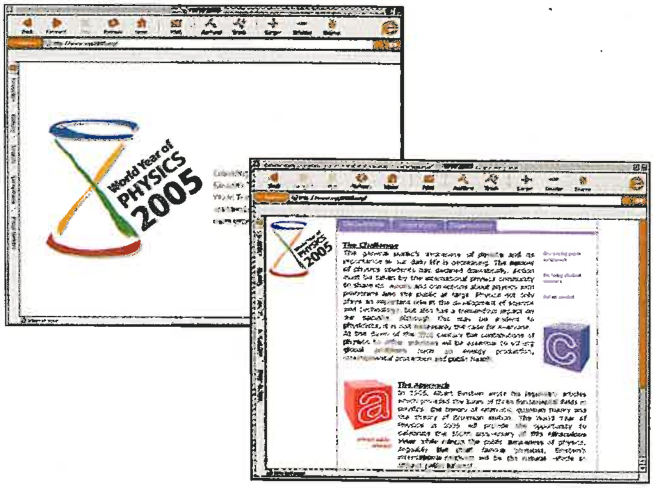
The main purpose of the WYP is to raise world-wide public awareness of physics and, more generally, of physical sciences. The perception of physics and its importance in our daily life has decreased in the eyes of the general public to such a low level that the number of physics students in high schools and universities has dramatically declined over the past few years. In order to address this problem, it is important that Physics Societies all over the world become more active in sharing their visions and convictions about physics with politicians and the public in general. The great contributions of physics to the development of Science and Technology and its impact on our society might still be evident to us physicists, but no longer to everybody. At the dawn of the 21st century the interdisciplinary role of physics will further increase, and help solve crucial problems arising in our world such as: energy production, environmental protection and public health.

The illustration of physics, physical sciences, and their achievements, must be a major axis of the WYP, and should be the object of numerous and multiform activities aimed at raising the interest of the general public: radio and television programmes, articles in newspapers and specialised magazines, books, action in schools and universities, general colloquia on physical sciences and the physical view of the world, local and itinerant exhibits, action "in the street", posters, stamps, advertising in mass transport systems, etc. (see the home page: http://www.wyp2005.org/). Some of these activities could be included in general programmes already existing and aimed at public awareness of science: the European Science Week, "Cienca Viva" in Portugal, the science programme "La main à la pâte" for pupils in French primary schools, "Physics on Stage"....

Along with those outreach activities, scientific debates should also represent another important part of the actions to be planned in 2005. This includes debates on the great challenges of physics in the 21st century, the cultural character of physics and the need for education in physics in high schools and universities, the ethical responsibilities of physicists, the strengthening of physical sciences in developing countries and the influence of physics on development, the interdisciplinary character of physics and its impact on the emergence on new scientific and technological fields, the strong links of physics with technology and industry. Some more basic issues for physicists could include the relations between the various sub-fields of physics, the sense of unity of physics, the importance of maintaining pure physics research at a high level, the relative place of "big" and "small" physics, the relations between basic and applied physics, between theoretical and experimental physics.... Some of the issues discussed above, along with the legacy of Einstein's groundbreaking discoveries on the 100th anniversary of his "Annus mirabilis", will be the object of the 13th General Conference of the European Physical Society, "Trends in Physics", which will be held in Bern, on the 11-15 July 2005.

In view of the WYP success, what are the immediate tasks of Physics Societies?

Establish a WYP national committee, send out WYP announcements and make sure that every scientist in their country is aware of the World Year of Physics; start planning events at the local and national level; contact national political authorities and governments in order to inform them, get their sponsorship and obtain the active support of their representatives in international organisations (UNESCO, UN...); start a regular newsletter in their bulletin or home page with a link with the WYP web site; transmit all information on activities and ideas to the EPS and Europhysics News, for its WYP section.



http://www.wyp2005.org/

The success of the World Year of Physics lies now in the hands of every physicist and relies on the determination of Physical Societies!

Physics in life sciences

Per-Anker Lindgård, Risø National Laboratory, Roskilde, Denmark

The American Physical Society (APS) has a very active division called Division of Biological Physics. Have a look at their web-page http://www.aps.org/DBP/index.html. They organise among other many things a whole series of symposia at the APS-March meeting. Also, they organise a nice newsletter informing about activities in the emerging field of Biological Physics. I was asked to write something about the European initiatives in that direction and have submitted the following, which may be of interest also to the readers of Europhysics News.

A new division, in many ways an analogue to the APS division of Biological Physics, has been created by the European Physical Societies (EPS). It is called the Division of Physics in Life Sciences (DPL).

A lot of physicists feel tempted—rather than scared—by the challenges and possibilities offered by 'life systems'. It could be the challenge to understand 'just' the properties and functions of a single bio-molecule like a protein, RNA or DNA—or the organisation of a cell - or of individuals in a society—or of a feed back control mechanism etc. There seems to be no limit to what new fields or disciplines physicists feel they may contribute to. The traditional boundaries between physics/chemistry/biology/medicine/sociology/economics/... are over flown. Yet, they generally stay in their physics departments and feel at heart like physicists. (That is why they naturally belong to the physical societies). So why do physicists not stay with their reasonably well-defined—or perhaps rather self-defined - problems and develop tools or theories to quantitatively understand these to the very bottom.

If physicists are useful in other fields, why do they not just move there (some do)—or why do new students not go directly into those other fields (many do). The reason, I believe, is the peculiar attitude physicists tend to have: Rather build a new instrument than buy one, rather develop a new theory than apply one, or rather make a new computer code than buy one, rather understand a small corner, a principle, than know a lot of facts. A waste of time in many cases perhaps, but it is that attitude, which counts, I believe. A field like biology in a broad sense is more and more in demand of new quantitative techniques, new visualisation techniques, new simulation techniques etc. That is where the physicist can help in many cases. What counts is that peculiar attitude. And to nurse that is why the students should go through physics training and the physicist should keep their contact with physics colleagues in the Physical Societies.

All right, it may not be necessary to tell the members of DBP that—they may even not agree with it.

But there is a danger going 'inter-disciplinary'; at least so far. That shows up in peer reviewed funding systems. There is a natural human tendency to look after ones own babies—the others may be left to play the role of lonely wolfs or sharks. A division in a physical society can perhaps make a family for those creatures. Another danger is that it may be quite un-rewarding to 'go basic'. The public does not understand the importance of a new principle, but can much better relate to results: for example a visualisation made by NMR spectroscopy of some effect of a disease—or a magneto-encephalic visualisation of activating parts of the brain after some stimulus—or visualising lungs with ^{3}He. It is the visualisation and the subject, which count, not the techniques (invented by the physicists). The experts understand and appreciate the importance of the technical advances, but hardly the public or the politicians. That is an area where a division in a physical society may help in keeping up the visibility of the contributions made by the physicists.

However, when it really comes down to the crux of the matter for us, it is the subject, the physics that is interesting. Therefore making meetings, summer schools and workshops on interesting new stuff and getting inspiring, innovative people together, that is probably really the 'raison d'être' for a Division dealing with physics and biology. For example, I find it fascinating to hear about the rapid developments in isolating and in measuring on single bio-molecules—measuring precisely the forces needed to pull a protein apart or to stretch DNA—not to speak of the possibilities offered by big physics machines: neutron scattering, synchrotron and free electron laser facilities. Also, I find it great that by computer simulation it is now beginning to be possible realistically to study the protein folding process. The progress is so fast, interesting and promising.

Last year I was vice president of the European Physical Society http://www.eps.org/. It has more than twice as many members as APS: 80.000 belonging to the National societies of 37 European countries. So although it is rather loosely organised, it should include many biologically oriented physicists. But we had no such division. Science funding at the European level is made by the European Union (EU). Although it amounts to only 5% of the total science funding, it has a much larger influence - also on the national funding strategies. Therefore it is important that the learned societies are heard for advice and for providing experts for evaluation panels etc. Last year EU decided that nano- and bio- science/technology should be two of very few high priority areas in the next funding round, the so-called framework 6. In response to this, and because we felt biological physics was a new expanding field, the executive committee of EPS set up a 'reflection committee' to see if the idea of creating a new division was generally supported. You may see more details on the web page DPL.risoe.dk.

We gave it the more general name of the Division of Physics in Life Sciences because we foresee that sections in for example physics in medicine etc. could be coming soon. But we start out with very much the same scope as the APS Division on Biological Physics. And we will be very happy to collaborate in any way. After all physics is worldwide. The EPS council approved the new division in 23 of March 2002. I was asked to be the first chairman to get it going. We had a first meeting of the board and guests in connection with a workshop on 'Nano Physics in Life Systems' 21-22 of June in Copenhagen. We are pleased to have collected a board of very good physicists, many of whom you would know, see DPL.risoe.dk, covering a broad range of fields and nationalities. We were furthermore very pleased to have the DBP chairman Bob Austin as a guest at our first board meeting. One common project for DBP/DPL could be to offer to help in the organisation of a rather large meeting on Biological Physics in Gothenburg August 2004, planned by IUPAP.

The scientific part of the June workshop was very interesting and collected about 80 participants—rather more than we had planned for. There will be proceedings published in J.Phys.C. around March 2003. That gives a very good occasion to present the scope of the new Division of Physics in Life Sciences. Furthermore, it marks the beginning of new trend in J.Phys.C. They offer to welcome and publish papers in biological physics, recognising this (or part of this) to be an important emerging field of

activities

physics closely related to condensed matter physics. As another activity of the division we had a workshop on 'Dynamics of Biological Molecules and Networks' 10-17 of August in Krogerup, Denmark organised by NORDITA. Organisers of future meetings are most welcome to contact me p.a.lindgard@risoe.dk, if they wish their meeting to be included in the EPS/DPL activities and enjoy the benefits of that.

I may finally mention that we have made good contacts also with our colleagues in Biophysics, namely with EBSA, the European Biophysical Societies Association. A collected effort to establish contact with EU will be attempted.

As you can see, we have just started, but we hope to grow fast as the DBP division has done. Anyone interested is welcome to join. I am sure many physicists from Europe look at the excellent DBP web page and the present newsletter. Therefore let me say: If you are a member of a Physical Society associated with EPS it is for free to join DPL. The more members we get, the more activities and influence we may get—and the better we can, together with DBP and other similarly interested groups, further the interest in and of the field.

J. Devreese: CMD Pioneer

Angiolino Stella, University of Pavia, Italy

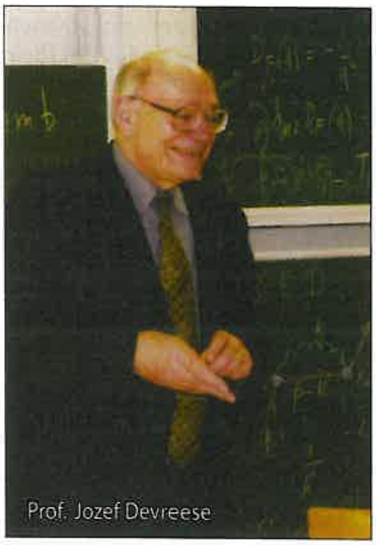
On November 6 of last year about 350 people (coming from Japan, USA and many European countries) attended the celebration meeting of the 65th birthday of Prof. Jozef Devreese at the University of Antwerpen. Several guest speakers gave their impressions on his personality and work, including the professors R. Evrard (Université de Liège), Y. Bruynseraede (Katholieke Universiteit Leuven), J.P. Leburton (University of Illinois at Urbana-Champaign), A. Lagendijk (Universiteit Twente), A. Stella (Università degli Studi di Pavia), P. Wyder (MPI für Festkórperforschung/LCMI CNRS), H. Kleinert (Freie Universität Berlin), G. 't Hooft, Nobel laureate in Physics 1999 (Universiteit Utrecht).

In addition, congratulations from many colleagues and friends were read to the audience: among them professors G.F. Bassani (President of the Italian Physical Society), M.H. Cohen (Rutgers University), M. Cardona (MPI Stuttgart) etc..

Jozef started his academic career as a full professor at the University of Antwerpen in 1969 where he taught Quantum Mechanics, Solid State Physics, Superconductivity and Superfluidity, Feynman Path Integrals and Mathematical Methods in Physics and where he initiated in 1966 the research group "Theoretical Solid State Physics" (TFVS: Theoretische Fysica van de Vaste Stoffen).

Devreese and his school obtained seminal results in the discipline of polaron physics. He and his co-workers are among the leading contributors to incorporate polaron physics in the modern physics of mesoscopic and nanosize systems. According to M. Cardona, the work on polarons "placed Jozef as one of the top authorities worldwide in the field of polarons". K. von Klitzing wrote in his message that "everyone in the world working in solid state physics knows [Devreese] as Mister Polaron". And, I must add, we all know the impact of the concept of polaron, for instance, on the first steps and developments of high Tc superconductivity.

However, this should not lead us to underestimate the contribution of Jozef Devreese and his associates to other fields, like the theory of path integrals. In 2002 Jozef Devreese was scientific director of the 7th International Conference "Path Integrals From Quarks to Galaxies" in Antwerpen, which attracted leading specialists in the field. A key recent result achieved by Jozef Devreese and colleagues is the derivation of an exact analytical path integral for N (few or many) harmonically interacting fermions or bosons in a harmonic confining potential. It is the first time that a non-trivial interacting many-body system could be completely described in closed form. The method is highly systematic and constitutes a remarkable alternative approach to the many-body problem. This innovative approach has been applied to physical systems like Bose-Einstein condensates with a realistic calculation of specific heat, internal energies etc., and many-electron quantum dots.


Prof. Jozef Devreese

I would stress his role as the founder and first chairman of the EPS Condensed Matter Division. A huge and extremely important job, where the authoritative figure of Jozef was essential in reaching results beneficial to the European Physical Society.

In terms of a scientific European reality, also related to the stimulating aspects of a comparison/competition with correspondent realities in the US and in other countries, we needed to have not only a general and well coordinated view, a general scheme to fill in, but especially a stimulating and strongly interacting environment primarily designed for young researchers, in order to

- strengthen scientific collaborations also in terms of research projects
- elaborate common initiatives concerning education as well as new perspectives for research jobs.
- think and start to move towards a unifying view concerning high level European journals.

Much excellent work has been done since those days, but this was made possible or easier by the inspired and intense efforts involving Jozef and many colleagues in that period (starting from the early 1980). We must not forget: it is nice to remember here today the merits of our friend in that respect.

I would like to close by recalling what is a very rare identifying character of Josef: his personal and original way of mixing science and humanities. He has always been ready to give a personal touch of culture in examining or commenting any kind of event. I say "culture" because he always saw it (and worked in that direction) as a unique entity. This is totally in contrast with different views or opinions, summarised in the title of a non-trivial book well known in the sixties of the last century: "the two cultures".

Dear Jozef, thank you for all that you have done and for all that you are going to do.

Murray Gell-Mann remembers the greatest of Irish Scientists

William Rowan Hamilton

Pauric Dempsey, Royal Irish Academy

On Monday 16th October 1843, while walking to the Royal Irish Academy along the Royal Canal in Dublin, the idea of quaternions (sets of vectors involving imaginary numbers), the first non-commutative algebra, finally crystalised in the mind of Irishman, William Rowan Hamilton.

And here there dawned on me the notion that we must admit, in some sense, a fourth dimension of space for the purpose of calculating with triples ... An electric circuit seemed to close, and a spark flashed forth.

He stopped, took out his penknife and on the stone parapet of Broome Bridge scratched out the fundamental formula of his quaternion algebra: $i^2 = j^2 = k^2 = i\,j\,k = -1$. Hamilton believed this discovery would revolutionise mathematics and mathematical physics.

I still must assert that this discovery appears to me to be as important for the middle of the nineteenth century as the discovery of fluxions [the calculus] was for the close of the seventeenth.

Hamilton's quaternions influenced the work of many others. They played a seminal role in the invention of vector analysis and have found many applications in various branches of physics. They were central to James Clerk Maxwell's theory of electromagnetic waves in 1864 and also helped Erwin Schrödinger develop his theory on quantum mechanics. Hamilton's quaternions are in regular use in today's computer graphics and in the guidance systems of spacecraft.

To commemorate Hamilton's discovery the Royal Irish Academy and the Irish Times will host the inaugural Hamilton lecture on 16th October 2002. Nobel prize winning physicist, Professor Murray Gell-Mann will give the lecture entitled *On Bridges, Hamilton and Contemporary Science* in the Burke Theatre, Trinity College, Dublin. The lecture is sponsored by DEPFA BANK plc. Such was the demand for tickets, that within two hours of information on the lecture being published in the Irish Times, the 500 seats on offer were all snapped up and the Academy began compiling a cancellation list.

We want the 16th October to be known annually as Hamilton Day

'We want the 16th October to be known annually as Hamilton Day to celebrate the genius of Hamilton as Blooms Day (16th June) celebrates the genius of James Joyce's novel *Ulysses*' says Dr James Slevin, Science Secretary of the Royal Irish Academy. 'At a time when Ireland is establishing itself as a centre of research excellence, it is entirely fitting that we remember the inspirational figure of William Rowan Hamilton'. Echoing this sentiment is Science Foundation Ireland (SFI) which is commemorating the 1951 Nobel Prize winning Irish physicist, Ernest Walton through its establishment of the E.T.S. Walton Visitor Awards Programme. It is awarding twelve research awards of up to a maximum of 200,000 Euro per annum to attract leading scientists to Ireland for periods of up to twelve months. Its focus is those areas of science, mathematics, computer science, software engineering and engineering that underpin Biotechnology and ICT. For further information see www.sfi.ie .

Murray Gell-Mann looks at Joyce manscripts in the National Library of Ireland.

The choice of Murray Gell-Mann for the inaugural Hamilton lecture is especially fitting given that he has been for over four decades one of the most inspirational and important figures in the world of theoretical physics. When Hamilton was appointed the first foreign Associate of the American National Academy of Sciences in 1863, he was considered by the Academy to be the greatest of living scientists. Moreover Gell-Mann's celebrated Joycean connections make him especially suitable choice for the inaugural lecture in Dublin. According to Gell-Mann's biographer, George Johnson, Gell-Mann liked to pour over the pages of his brother's first edition copy of *Finnegan's Wake* and it was from these pages that he came up with the idea of labelling the fundamental subatomic particle as a 'quark'. On his last visit to Dublin in June, Gell-Mann visited the National Library of Ireland to view a hitherto unknown collection of Joyce manuscripts that had just been purchased by the library. In this collection were inscribed proof copies of *Finnegan's Wake*. Moreover the contrasts between the lives of Gell-Mann and Hamilton are striking and extend beyond the realm of mathematical physics. Both were child prodigies and polymaths, and each had an extraordinary gift for languages as well as a keen interest in literature.

Other events on Hamilton Day include the annual walk from Dunsink Observatory to Broome Bridge organised the Mathematics Department of the National University of Ireland, Maynooth and the presentation of the Royal Irish Hamilton Awards to the top mathematics students in each of the nine universities in their penultimate year of undergraduate study. These s tudents will be presented with a 1,000 Euro award by the Irish National Committee for Mathematics. The Awards are sponsored by a generous grant from DEPFA BANK plc, the Academy's Conference Sponsor.

While Hamilton will be always remembered for quaternions he first came to international notice when he predicted theoretically, in 1832, that light would be refracted in an unusual way through a specially cut crystal of Iceland spar—a form of the naturally-occurring mineral, calcite. He calculated that it would be refracted in the form of a hollow cone of light. It was also Hamilton who introduced the terms 'vector' and 'scalar'.

The 2003 Royal Irish Academy / Irish Times Hamilton Lecture, sponsored by DEPFA BANK plc will be given by Professor Andrew Wiles celebrated for his proof of Fermat's last Theorem.

activities

noticeboard

The EPS Quantum Electronics and Optics Prizes, *sponsored by NKT*

These two prizes, each endowed with 10.000 EURO by NKT, are awarded on an annual basis, for outstanding contributions to quantum electronics and optics. One prize is for Fundamental Aspects, the other for Applied Aspects. Nominators should be members of the EPS, however this is not a requirement on the nominees.

Nominations should be sent to the Selection Committee, Quantum Electronics and Optics Prize, EPS, 34 rue Marc Seguin, BP 2136, F-68060 Mulhouse, Cedex. The closing date for receipt of nominations at the Mulhouse office is March 31, 2003. Details of the nomination procedure, and of the material that must be submitted in support of the nomination are given below. Nominations will be treated in confidence, and although they will be acknowledged, there will be no further communication. Nominations that are unsuccessful on their first submission will be automatically resubmitted in the following two years.

The Fresnel Prizes

These two prizes are now awarded on an annual basis, for outstanding contributions to quantum electronics and optics. One prize is for Fundamental Aspects, the other for Applied Aspects. The prizes are awarded to candidates whose work has been published or accepted for publication before the age of 35, and who have not reached the age of 37 before January 1 in the year of the Award (1/1/03 in this case).

Nominations should be sent to the Selection Committee Fresnel Prize, EPS, 34 rue Marc Seguin, BP 2136, F-68060 Mulhouse, Cedex. The closing date for receipt of nominations at the Mulhouse office is March 31, 2003. Details of the nomination procedure, and of the material that must be submitted in support of the nomination are to be found at the EPS web page: www.eps.org . Nominations will be treated in confidence, and although they will be acknowledged, there will be no further communication. Nominations that are unsuccessful on their first submission will be automatically resubmitted in the following two years provided that compliance with the age rule still applies.

FP6 Call announced

The first call for proposals under the FP6 programme has been announced. You may find the full texts at http://fp6.cordis.lu/fp6/calls.cfm. The call concerns the following areas: Life sciences, genomics and biotechnology for health, Information Society Technologies, Nanotechnologies and nanosciences, knowledge-based multifunctional materials, and new production processes and devices, Aeronautics and space, Food quality and safety, Sustainable development, global change and ecosystems, Citizens and Governance in a knowledge-based society, Policy-orientated research, Horizontal Research activities involving SMEs There are also specific programmes to support international co-operation, for support of actions at the national and regional level, and for fellowship and training programmes

Nominations Open

Nominations are now open for the EPS QEOD and Fresnel prizes. The call text is below, and full information on the prizes can be found at http://cardener.upc.es/QEOD/.

Physics on Stage 3

Physics on Stage is a unique European-wide programme for physics teachers and those in fields related to physics to assess the current situation in physics education and raise the public awareness of physics and related sciences. The first Physics on Stage was organised at CERN in November 2000, and was a combined effort of CERN, ESO and ESA, with the help of the EPS and the EAAE. Physics on Stage is an educational outreach initiative for European physics educators. Physics on Stage 2 was organised in April 2002 in Noordwijk (NL) at the headquarters. Following on the success of these first two events, Physics on Stage 3 is to take place again in Noordwijk, Holland in November 2003.

Nobel Prize 2002

Alexander Hellemans, Napoli, Italy

The Nobel Prize for Physics 2002 was awarded to three pioneers who opened up new windows to the universe. The Royal Swedish Academy of Sciences awarded half the prize to Raymond Davis from the University of Pennsylvania and Brookhaven National Laboratory and Masatoshi Koshiba of the University of Tokyo "for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos." The other half of the prize was awarded to Riccardo Giacconi, president of Associated Universities, a non-for profit organisation in Washington "for pioneering contributions to astrophysics, which have led to the discovery of cosmic-ray sources."

The Solar neutrino problem

Davis was the first to systematically observe neutrinos produced by nuclear reactions in the Sun. Already in 1964, Davis and John Bahcall of Princeton University proposed that it would be possible to detect such neutrinos. However, neutrinos barely interact with matter—only one in a million neutrinos travelling through the Earth collides with an atomic nucleus, and therefore they are extremely difficult to detect. So the size of the detector is important, and in 1967 Davis installed his detector, a huge 400,000-litre tank almost 1500 meter deep, out of the reach of cosmic rays, in the Homestake Gold Mine in Lead, South Dakota.

For the illustrated presentation visit: www.nobel.se .

"This was a groundbreaking new field of astronomy," comments Nick Jelley of Oxford University, who is the UK co-spokesman of the Sudbury Neutrino Observatory (SNO) in Northern Ontario, Canada. At that time no one was sure that it at all would be possible to detect neutrinos from the sun. "Davis was able to detect them, which was amazing, it was an incredible experimental feat," says Jelley. For detecting the neutrinos Davis used the occasional interaction of neutrinos with chlorine atoms, forming radioactive argon atoms that were extracted with helium every two months. Davis reported already in 1968 that he detected a much smaller amount of neutrinos than predicted by theory, to the surprise of astrophysicists who had a quite detailed idea of the amount of neutrinos that should be produced in the solar interior, "This gave rise to the 'solar neutrino problem,' which has taken us thirty years to untangle," says Jelley.

For Davis the first years of data taking was not an easy time, since he was dealing with very small numbers, typically the detection of about 30 argon atoms after a run of two months, missing a few argon atoms would have had a large impact on the results. Davis refined and continually tested his detection method, and astrophysicists went back to the drawing boards and came up with precise amounts of neutrinos that the sun should produce. It increasingly became clear that the problem was caused by the neutrinos themselves.

That the neutrino deficit observed by Davis was real became confirmed when other underground detectors became operational that used different techniques for detecting neutrinos. In Japan Koshiba pioneered the use of Cherenkov radiation produced when particles pass at high velocity through water. He first set out searching for proton decay in an underground tank filled with 2,140 tonnes of water and scrutinised by 1100 large photomultiplier tubes. Although Koshiba could not find any decaying protons, he turned his attention to the detection of solar neutrinos, and verified the neutrino shortage observed by Davis. "They had the great fortune to see the supernova in 1987, where you saw neutrinos coming from our neighbour galaxy—a fantastic distance," says Jelley.

The search for solar neutrinos lead ultimately to the solution of one of the most intriguing questions in physics: do neutrinos have mass? "Now we know that from their work, and also from the work SNO has been doing, that both problems are associated, and can be understood in terms of neutrino oscillations," says Jelley. According to the 'Standard Model,' the current theory describing particles, fields and their interactions, neutrinos have zero mass. However, already in 1957 Bruno Pontocorvo suggested that neutrinos could change from one type into another—this phenomenon is called oscillation. According to quantum mechanics, neutrino oscillation is only permitted if the particles have mass.

Experimental evidence of three types (or "flavours") of neutrinos—electron, muon and tau neutrinos—became soon available. The neutrino deficit can now be explained by the fact that neutrinos change flavour on their way to the detector and thus escape detection.

Most physicists are now convinced that neutrinos have mass. "Certainly the Standard Model has to be changed," says Koshiba. And not just physics profited from these neutrino experiments, but also observational astronomy. "Neutrinos have a much larger penetrating power than any electromagnetic wave...Neutrinos can probe deep into the stellar body, even gamma rays can only see the surface of a star," says Koshiba.

X-raying the Universe.

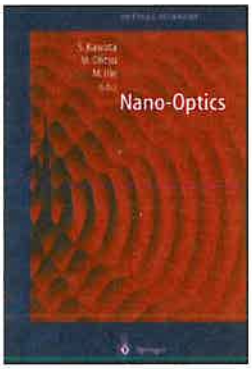
X-ray astronomy started 40 years ago when Giacconi and his colleagues at American Science and Engineering, contracted by NASA, placed three Geiger counters aimed at different directions aboard an Aerobee rocket. Besides a omnidirectional background they detected radiation from Scorpius X-1, a source later identified with a binary star. "The surprise with Scorpius X-1 was that the ratio between x-rays and visible light was thousand to one, no x-ray source on Earth can match this efficiency. This discovery pointed to some very strange object whose existence we didn't know," says Giacconi. It soon became clear that the x-rays were produced in such sources by matter from a companion star falling onto a neutron star or a black hole—the infalling matter heats up to incredible temperatures, emitting the x-rays. "We had no idea at all that these things occurred in nature...," says Giacconi.

Giacconi was the driving force behind the development of the first x-ray space observatory placed in Orbit. UHURU (Freedom in Swahili) was launched in 1970 and by 1972 Giacconi could report 339 x-ray sources, which included neutron stars and black holes. Two space observatories followed in 1977 and 1978, HEAO-1 (High Energy Astrophysics Observatory) and HEAO-2. The Einstein x-ray Observatory, with a telescope a 1000 times as sensitive than that of UHURU, made observations of millions of x-ray sources.

Giacconi and Harvey Tananbaum proposed in 1976 an even larger x-ray telescope, equipped with grazing-incidence x-ray optics. After delays the telescope was launched by NASA in 1999 as Chandra, while Europe launched a similar x-ray telescope, the XMM-Newton, the same year. And with some satisfaction Giacconi mentions that the extragalactic x-ray background that he observed during the early rocket flights is now resolved with Chandra. "Last year I had about ten days of observation with Chandra and we could resolve this background into individual sources, which turned out to be active galactic nuclei, quasars, and galaxies."

Giovanni Bignami of the University of Pavia wholeheartedly agrees with the identification of Giacconi by the Nobel Committee as the central figure in the development of x-ray astronomy. "Giacconi is the first complete combination of experimentalist, theorist, and manager," he says.

BOOK REVIEWS



Nano-Optics

Kawata, Ohtsu and Irie
Springer verlag, 2002
335 pages

The aim of "Nano-Optics", one of the newest members of the Springer's series in the optical sciences, is to give a concise and thorough introduction to the emerging field of near-field optics and near-field optical microscopy. Based on a national research initiative in near-field nano-optics in Japan, the editors Satoshi Kawata, Motoichi Ohtsu and Masahiro Irie have assembled an impressive amount of information on both theoretical and experimental issues concerning near-field optical microscopy (NSOM) techniques and applications. The wider editorial board consists of a who-is-who in the physics of near-fields.

The editors have chosen to base the book on ten rather independent chapters, each written by a different group of researchers involved in the initiative. While this ensures a rather diversified introduction to the field, the quality of the presentation style clearly differs from chapter to chapter. In some of the chapters, the wealth of information presented suffers from a surprising amount of grammatical mistakes in the use of the English language.

Of the ten chapters, the first two introduce theoretical concepts of nanoscale light-matter interactions, followed by three chapters of NSOM probe design. The rest of the book highlights different applications of near-field optics such as optical memories, biological imaging applications and quantum and semiconductor devices. Over all, the chapters present an impressive amount of information on the topic, making the book suitable for a wide audience.

The first two chapters describe the concepts of near-field optical microscopy from a classical and quantum mechanical point of view. The amount of inside knowledge and mathematics used makes these two chapters clearly tailored for a relatively narrow physics audience, and researchers from other fields interested in applications of near-field optics might very well be put off by the complicated descriptions and discussion.

The three chapters on probe design bridge the gap from the theoretical descriptions to applications of near-field microscopy and gives a good overview of the different probe designs used. For the wide majority of the audience though, the value of the book will lie in the remaining five chapters focusing on applications of near-field microscopy.

Researches from a variety of backgrounds in the physical and biological sciences as well in engineering interested in using NSOM techniques for their specific applications will be delighted by the amount of different applications presented in the second part of the book. From semiconductor structures to biological molecules, the authors present the advantages and intricacies of near-field optical investigations in considerable detail.

Over all, "Nano-Optics" is a valuable addition to the current literature on near-field optical microscopy. Designed as a collection of rather independent research descriptions, the book will find its readers from a wide variety of fields and backgrounds. The major wish for the next edition would lie in a more careful proofreading to allow for a more fluent reading.

Stefan Maier,
Pasadena, CA 91125, USA

Books for review

From Semiconductors To Proteins : beyond the average structure
S.J.L. Billinge, M.F. Thorpe, *Kluwer Academic/Plenum Publ*, 2002, 287 pages

Information And Measurement (Second Edition)
J.C.G. Lesurf, *IOP Publishing*, 2002, 295 pages

Introduction To Dusty Plasma Physics
P.K. Shukla, A.A. Mamun, *IOP Publishing*, 2002, 270 pages

Introduction To Mesoscopic Physics (Second Edition)
Y. Imry, *Oxford University Press*, 2002, 236 pages

Matter & Interactions. Modern Mechanics (Vol. I)
R. Chabay, B. Sherwood, *Wiley*, 2002, 432 pages

Matter & Interactions. Electric and magnetic interactions (Vol. II)
R. Chabay, B. Sherwood, *Wiley*, 2002, 936 pages

If you are interested in reviewing one of the above books, or in receiving books for review in general, please send us name, and contact co-ordinates, along with the your field(s) of specialisation to:

Book Reviews, EPS Secretariat
BP 2136, 68060 Mulhouse Cedex, France

Below is a list of EPS Europhysics Conferences, and EPS Sponsored Conferences. Europhysics Conferences are organised by EPS Divisions and Groups. Sponsored Conferences have been reviewed by experts in the field following application, and based on criteria such as timeliness and topical coverage, are considered to merit EPS sponsorship.

2003 EUROPHYSICS CONFERENCES

CLEO®/Europe—EQEC 2003

22–27 June 2003 Munich ICM (Germany)
Contact Mrs. Patricia Helfenstein
European Physical Society
34 rue Marc Seguin
BP 2136
F-68060 Mulhouse Cedex
tel +33 3 89 32 94 42 **fax** +33 3 89 32 94 49
email p.elfenstein@uha.fr
web www.cleoeurope.org

30th EPS Conference on Controlled Fusion and Plasma Physics; 30 CCFPP

07–11 July 2003 St Petersburg (Russia)
Contact Dr. Andrey D. Lebedev
Ioffe Institute
26 Polytekhnicheskaya
RU-191024 St Petersburg
tel +7 812 247 42 24 **fax** +7 812 247 10 17
email eps2003@mail.ioffe.ru
web www.ioffe.ru/EPS2003/

35th Conference of the European Group for Atomic Spectroscopy 2003 - (EGAS 2003)

15-18 July 2003 Université Libre de Bruxelles, Brussels (Belgium)
Contact Professor M.R. Godefroid
35th EGAS Conference
Laboratoire de Chimie Physique Moléculaire
CP160/09 Université Libre de Bruxelles
50 Avenue F.D. Roosevelt
B-1050 Brussels, Belgium
tel +32 2 650 30 12 **fax** +32 2 650 42 32
email egas35@ulb.ac.be
web http://www.eps-egas.org

International Europhysics Conference on High Energy Physics, HEP 2003

17–23 July 2003 Aachen (Germany)
Contact Prof. Ch. Berger I.
Physikalisches Institut der RWTH
Aachen D-52056 Aachen, Germany
tel +49 241 8027162 **fax** +49 241 8022661
email berger@rwth-aachen.de
web http://eps2003.physik.rwth-aachen.de

International Symposium on Atomic Cluster Collisions: fission, fusion, electron, ion and photon impact (ISACC 2003)

18–21 July 2003, Palace of Grand-Duke Vladimir, St Petersburg (Russia)
Contact Prof. Dr. Andrey V. Solov'yov
Institut für Theorische Physik Universität
Frankfurt am Main Robert-Mayer str. 8-10
D-60054 Frankfurt am Main Germany
tel +49 69 79822534 **fax** +49 69 79828350
email solovyov@th.physik.uni-frankfurt.de
web http://www.ioffe.ru/atom/ISACC2003

XXIII Dynamics Days (Europe) Conference

24–27 September 2003, Palma de Mallorca (Spain)
Contact Dr. Oreste Piro
Insituto Mediterraneo de Estudios Avanzados (IMEDEA) CSIC - Universidad de las Islas Baleares
07071 Palma de Mallorca, Spain
tel +34 971 173230 **fax** +34 971173426
email piro@imedea.uib.es
web www.imedea.uib.es/~ddays

Applications of Physics in Financial Analysis 4 - APFA 4 -

13–15 November 2003 Warsaw, Poland
Contact Prof. Dr. Janusz Holyst
Warsaw University of Technology
Faculty of Physics
Koszykowa 75
PL-00-662 Warsaw, Poland
tel +48 22 6607133 **fax**+48 22 6282171
email jholyst@if.pw.edu.pl
web www.if.pw.edu.pl/~apfa4

Conference on Computational Physics: CCP 2004

01–04 September 2004 Conference Center Magazzini del Cotone, Genoa (Italy)
Contact Prof. Giovanni Ciccotti
Dipartimento di Fisica
Università "La Sapienza"
P.zzale A. Moro, 2
00185 Roma
tel +39 06 49 91 43 78 **fax** +39 06 49 57 697
email Giovanni.ciccotti@roma1.infn.it

2003 SPONSORED CONFERENCES

Frontier Detectors for Frontier Physics

25–31 May 2003 La Biodola, Elba Island (Italy)
Contacts Prof. Franco Cervelli
INFN, Sezione di Pisa
Via Livornese, 1291
I-56010 S.Piero a Grado, Pisa, Italy
tel +39 050 880 241 **fax** +39 050 880 318
email franco.cervelli@pi.infn.it
Dr. Lucia Lilli
tel +39 050 880 327 **fax** +39 050 880 318
email lucia.lilli@pi.infn.it
web www.pi.infn.it/pm/2000

Direct Reactions with Exotic Beams 2003 (DREB 2003)

10–12 July 2003 University of Surrey,Guildford, Surrey(United Kingdom)
Contact Dr. W.N. Catford
Dept. of Physics
UK - Guildford GU2 7XH
tel +44 1483 68 68 04 **fax** +44 1483 68 67 81
email W.Catford@surrey.ac.uk
web www.ph.surrey.ac.uk/~phs1wc/dreb2003/announce1.htm

International Congress on Mathematical Physics (ICMP 2003) & Young Researchers Symposium (YRS)

25 July–02 August 2003, Lisbon (Portugal)
Contact Prof. Jean-Claude Zambrini (President of the Local Organizing Committee of the Intern. Congress on Math. Physics 2003)
Av. Prof. Gama Pinto, 2
P-1649-003 Lisboa, Portugal
tel +351 217904727 **fax** +351 217954288
email zambrini@cii.fc.ul.pt
Patricia Paraiba (Conference Secretary)
tel +351 217904739 **fax** +351 217954288
email patricia@cii.fc.ul.pt
web http://icmp2003.net/

The International Conference on Magnetism - ICM 2003

27 July–01 August 2003, Palazzo dei Congressi, Rome (Italy)
Contact Dr. Dino Fiorani (Chairman ICM 2003)
ISM-CNR; Area della Ricerca Via Salaria Km 29.500
P.O. Box 10
I-00016 Monterotondo Scalo (RM) Italy
tel +39 06 90672553 **fax** +39 06 90672552
email dino.fiorani@mlib.cnr.it
Mrs Grazia Ianni (Secretary) ISM-CNR; Area della Ricerca
tel +39 06 90672285 **fax** +39 06 90672470
email grazia.ianni@mlib.cnr.it
web www.icm2003.mlib.cnr.it

Summer School on Particle and Nuclear Astrophysics

17–29 August 2003 Nijmegen (Netherlands)
Contact Prof. P.J. Mulders
Vrije Universiteit
Dept of Physics and Astronomy,
FEW De Boelelaan 1081
NL-1081 HV Amsterdam, the Netherlands
tel +31 20 444 7863 **fax** +31 20 444 7992
email mulders@nat.vu.nl
web http://nijmegen03.hef.kun.nl

International Conference "Physics and Control" (PhysCon 2003)

20–22 August 2003 St. Petersburg (Russia)
Contact Prof. Alexander L. Fradkov
Institute for Problems of Mechanical Engineering
61 Bolshoy ave. V.O.
RU–199178 St. Petersburg,
Russia
tel +7 812 321 4766 **fax** +7 812 321 4771
email info@physcon.ru
web http://www.physcon.ru

2nd International Girep Seminar 2003

01-06 September 2003 - Università degli Studi di Udine (Italy)
Contact Prof. Marisa Michelini (Director of Cird)
Physics Department of Udine University, Udine, Italy
tel +39 0432 558208 **fax** +39 0432 558222
email michelini@fisica.uniud.it
Donatella Ceccolin (Conference Secretary)
tel +39 0432 558211 **fax** +39 0432 558222
email Donatella.Ceccolin@amm.uniud.it
web www.uniud.it/cird/

International School of Nuclear Physics, 25th Course "Heavy Ion Reactions from Nuclear to Quark Matter"

16–24 September 2003 Erice (Italy)
Contact Prof. Amand Faessler
Universität Tuebingen Institut für Theoretische Physik Auf der Morgenstelle 14
D-72076 Tübingen, Germany
tel +49 7071 29 76 370 **fax** +49 7071 29 53 88
email amand.faessler@uni-tuebingen.de
web http://www.uni-tuebingen.de/erice/

Xth Vienna Conference on Instrumentation

February 2004 University of Technology, Vienna (Austria)
Contact Professor Meinhard Regler
Institute of High Energy Physics of the Austrian Academy of Sciences
Nikolsdorfergasse 18 A-1050 Vienna, Austria
tel +43 1 544 73 28 41 **fax** +43 1 544 73 28 54
email wcc@hephy.oeaw.ac.at or meinhard.regler@oeaw.ac.at
web http://wcc.oeaw.ac.at

Contact **Susan Mackie** • EDP Sciences • 250, rue Saint Jacques • F-75005 Paris • France
Phone +33 (0)1 55 42 80 51 • fax +33 (0)1 46 33 21 06 • e-mail mackie@edpsciences.org

TU VIENNA

Announcement of an open permanent position at the Institute of Solid State Physics, Faculty of Science and Informatics at the Vienna University of Technology

Tenured Full Professorship in Applied Physics

The applicant is required to have outstanding academic credentials in the field of Materials Science. She/he is expected to strengthen the ongoing research activities of the institute in the areas of "*materials under extreme conditions*" and "*development of novel preparative and analytical techniques*" *). Familiarity with and working experience at international large-scale research facilities is desirable. The candidate is expected to carry a teaching load of both mandatory courses of the physics core curriculum as well as elective courses.

The applicant must meet the following requirements:

- **an Austrian or equivalent foreign terminal academic degree in the field under consideration,**
- **an outstanding academic track record in research and teaching,**
- **pedagogic and didactic skills,**
- **leadership abilities,**
- **international working experience in the field of research.**

Application deadline: March 15, 2003

The Vienna University of Technology is committed to increase female employment in leading scientist positions. Qualified female applicants are expressly encouraged to apply and will be given preference when equally qualified.

Applications including a detailed curriculum vitae, list of publications, and copies of the five most outstanding publications of the applicant should be sent to the Dekanat der Fakultät für TNI, Getreidemarkt 9, 1060 Vienna, Austria.

*) For more information on the research program of the institute see http://www.ifp.tuwien.ac.at/, the development plan of the Physics division in the Faculty of Science and Informatics can be found at http://info.tuwien.ac.at/dektnf/entwicklungsplan.htm.

FACULTY POSITION IN EXPERIMENTAL CONDENSED MATTER PHYSICS UNIVERSITE LIBRE DE BRUXELLES

The Department of Physics of the Université Libre de Bruxelles (ULB) invites applications for a TENURE TRACK appointment at the Assistant Professor (« Chargé de cours ») level effective September 2003. The successful applicant should have a good command of the French language, be able to teach at all undergraduate levels and conduct a vigorous research program. The official announcement (in French), containing further details, is available at http://resu1.ulb.ac.be : 8070/greffe/files/427.pdf. Please note that the deadline for applications has been extended to 1st March 2003. Contact : Prof. D. Bertrand (Chairman) at bertrand@hep.iihe.ac.be.

WESTFÄLISCHE WILHELMS-UNIVERSITÄT MÜNSTER

-Department of Physics-

The Institute for Nuclear Physics invites applications for a

Professorship (C4) for Experimental Physics
with emphasis on Nuclear and Particle Physics

to begin on **October 1st, 2003.**

The successful candidate is expected to fully represent the field of experimental physics in research and education. The field of research for the present position is defined within the research programme "Subatomic Physics" of the Department. It covers the area of fundamental physics of nuclei and particles and their interactions at highest possible energies. The successful candidate will take a leading role in the execution of Big Science projects as defined by the Science Programme of the German Ministry of Science and Education BMBF.

Participation in all teaching activities and academic administration duties of the Department is expected.

Qualification requirements are a proven record of scientific achievements, either through a habilitation or equivalent accomplishments. The latter may also be obtained through a profession outside the university.

Qualified women are strongly encouraged to apply. Women with equal qualifications and scientific performance will be given preference, unless there are prevailing reasons within the person of a particular candidate.

Preference will be given to candidates with disabilities.

Applications together with the curriculum vitae, the scientific career, a list of publications with up to 5 recent reprints and a description of teaching experiences should be sent by **April 1st, 2003** to

Dekan des Fachbereichs Physik
der Westfälischen Wilhelms-Universität Münster
Wilhelm-Klemm-Str. 9 D - 48149 Münster Germany

Physics Spring School In Toulouse PSSIT-2003

«Modeling and Simulation in Micro and Nano Technologies and Materials Engineering»

LPST/IRSAMC - LAAS - ATOMCAD
Toulouse - FRANCE,
April 7th - 11th, 2003

The scope of the school is beyond the world of Micro and Nano Technologies and is also directed towards Materials Engineering. In this respect, the emphasis is put on the use of atomic scale properties for the design of materials showing specific macroscopic properties.

http://www.lpst.ups-tlse.fr/PSSIT

Georges.Landa@lpst.ups-tlse.fr

EURESCO Conferences

A Programme of the European Science Foundation with the support of the European Commission

2003 PROGRAMME

Physics, Engineering & Material Sciences

On line at: http://www.esf.org/euresco/

- **Solid/Fluid Interfaces*:**
EuroConference on Complex Fluid Interfaces,
San Feliu de Guixols, Spain, 29 March - 3 April
Chair: R.K. Thomas (Oxford)

- **Advanced Environments and Tools for High Performance Computing*:**
EuroConference on Problem Solving Environments and the Information Society,
Albufeira (Algarve), Portugal, 14 - 19 June
Chair: E. Houstis (Patras)

- **Biological Surfaces and Interfaces*:**
EuroConference on Understanding and Improving Specific Interactions,
Castelvecchio Pascoli, Italy, 21 - 26 June
Chairs: A.G. Thomas (Manchester) and F. Jones (London)

- **Bionanotechnology*:**
EuroConference on Biomolecular Devices,
Granada, Spain, 9 - 14 July
Chair: A.J. Turberfield (Oxford)

- **What Comes beyond the Standard Model?:**
Symmetries beyond the Standard Model,
Portoroz, Slovenia, 12 - 17 July
Chair: N.S. Mankoc-Borstnik (Ljubljana)

- **Molecular Liquids*:**
Routes from Local Order to Large-Scale Cooperativity EuroConference,
Castelvecchio Pascoli, Italy, 5 - 10 September
Chair: R. Buchner (Regensburg)

- **Fundamental Problems of Mesoscopic Physics:**
Interactions and Decoherence,
Granada, Spain, 6 - 11 September
Chair: I.V. Lerner (Birmingham)

- **Bose-Einstein Condensation*:**
EuroConference on the New Trends in Physics of Quantum Gases,
San Feliu de Guixols, Spain, 13 - 18 September
Chair: Y.G. Castin (Paris)

- **Surface Plasmon Photonics*:**
EuroConference on Nano-Optics,
Granada, Spain, 20 - 25 September
Chairs: L. Martin-Moreno (Zaragoza) and F.J. Garcia-Vidal (Madrid)

- **Quantum Optics*:**
EuroConference on Cavity QED and Quantum Fluctuations: From Fundamental Concepts to Nano-Technology,
Granada, Spain, 27 September - 2 October
Chair: A. Lambrecht (Paris)

- **Fundamental Aspects of Surface Science:**
Manufacture and Properties of Structures with Reduced Dimensionality,
Kerkrade, The Netherlands, 4 - 9 October
Chair: B. Poelsema (Enschede)

- **Electromagnetic Interactions with Nucleons and Nuclei*:**
EuroConference on Hadron Structure viewed with Electromagnetic Probes,
Santorini, Greece, 7 - 12 October
Chair: E. DeSanctis (Frascati)

Conferences are open to researchers world-wide, whether from industry or academia.
Participation will be limited to 100.
Deadline for applications: 3-4 months before a conference.
*The registration fee covers full board and lodging. Grants are available (*EC support from the High Level Scientific Conferences Activity), in particular for nationals under 35 from EU or Associated States.*

For information & application forms contact:

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