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COMMUNICATIONS DE LA SSP

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From left to right: Christophe Rossel (SPS President), K. Alex Müller, Peter Grünberg, Gerardus 't Hooft, Theodor W. Hänsch (Nobel Laureates), Mauro Dell'Ambrogio (Secretary of State), Tibor Gyalog, (SPS Vice President), Johannes G. Bednorz (Nobel Laureate)

Notes from the President

Dear colleagues, dear SPS members


Christophe Rossel takes over presidency from Tibor Gyalog with the symbolic key to the "SPS house". David Jans watches the correct handing over.

After a wonderful and successful 100th anniversary celebration in Bern on June 27th, I would like to thank all those who spent so much time and effort in its preparation: namely the members of the Executive Committee, in particular our past president, Tibor Gyalog, as well as Sandra Hüni and Stefan Albietz of the Secretariat in Basel. It shows that after one century of existence our Society is still doing well and going strong. Its history has been summarized and 'officialized' in the very interesting book "Die Gründung der Schweizerischen Physikalischen Gesellschaft" by Alessandra Hool and Gerd Graßhoff of the University of Bern (see page 19).

Let me share a few ideas with you.

A learned Society like ours lives and moves forward only through the efforts of its active members and through the acquisition of new individual and collective members. Increasing the number of SPS members, in particular among young people will be one of my first priorities. This effort goes along with the promotion and encouragement of new generations of physicists by enhancing our outreach among students up to the bachelor and master levels. I would like to appeal to all physics professors at the Swiss Universities to support our Society and encourage them, as well as their students, to become active members. My call also goes to the physicists from research institutions and industry. Being myself a physicist working in an industrial research laboratory, I shall act towards strengthening the links between universities and industry.

The physics community in Switzerland is not so large but its scientific impact worldwide is outstanding. Our Society has to reflect this excellence and aim to provide top services to the community not only through the annual meetings but also by an active participation in the debate about the future of physics in our society. This can be done by increasing our interactions with the political authorities and other competent instances from academia and industry. The SPS should use the expertise of its members to create working groups and develop knowledge networks to address current issues such as energy, environment, or education and to help identify promising key areas of relevance for the future. The fact that physics plays an important role in many other disciplines and has always been on the cusp of revolutionary discoveries that drove technology, should encourage us to share our visions in research with scientists and engineers from other fields. Nevertheless I believe that the SPS alone - that is, without a stronger collaboration with the various platforms of the Swiss Academy of Sciences (SCNAT) and with the Swiss Academy of Engineering Sciences (SATW) - cannot reach such goals.

Let me also acknowledge the good synergies that were developed in the past few years with the three National Centers of Competence in Research, namely, MaNEP, Nano, and Quantum Photonics. By participating every other year in our annual meetings, they have greatly contributed to help us reach a critical mass. We look forward to continuing this collaboration. Next year we shall repeat an earlier experiment by organizing our annual meeting jointly with the Austrian Physical Society. This will take place in early September 2009 at the University of Innsbruck.

With the help of our committee members, I thus hope to continue in the footsteps of my predecessors to make the SPS stronger, more successful and more visible.

Last but not least, the writing of these few lines in English should not be perceived as giving up our national languages French and German. Indeed we shall continue to write in these two languages in the SPS Bulletin and on our webpage, even if the general trend, for practical reasons, is to favor English.

Christophe Rossel, SPS President

Reviews of the SPS Centennial Celebration

The following articles and pictures summarize the various successful activities organized during the celebration of the 100th anniversary.

The Hundredth Birthday of the SPS: A Century of Physics

During the late afternoon of 27 June 2008 the SPS celebrated its 100th anniversary with a ceremonial act and a physics fair in the Kultur-Casino Bern. About 300 persons attended the festivities. Among them were the secretary of state for education and research as well as six Nobel laureates in physics. Furthermore, all living past presidents of the SPS as well as the presidents of our partner societies in Switzerland and in Europe attended the event.

The "Hildegard Bilger Trio" plays the ouverture and an intermezzo.

The ceremony was moderated by David Jans, known from the former Science Format “MTW” on Swiss TV SF1. He led the audience through a program reflecting 100 years of physics in Switzerland, addressing the actual problems of science and taking a look into the future. Besides the official speeches of the president and of the secretary of state, Jans interviewed his guests during a round table discussion, asking them questions of interest to physicists and non-physicists.

Part of the discussion with the protagonists focused on issues relevant for the next generations. Solutions cannot be found simply by counting the number of students enrolled in a physics curriculum but also by increasing the acceptance for physics in our society. According to recent surveys and taking into account the conclusions of the World Year of Physics 2005, there is a real need for action concerning the public perception of physics.


The round table discussion: David Jans, Ruth Durrer, Jean-Pierre Blaser, Alessandra Hool, Norbert Straumann

Prior to the ceremonial act, three groups of pupils from various Swiss high schools took the opportunity to talk to the present Nobel laureates about the near future of physics and about their successful career. After the ceremony, the same pupils showed their own works about physics and nature. A variety of interesting booths transformed the foyer of the Kultur-Casino into a pleasant physics fair. Nationally well-known associations like “Schweizer Jugend forscht” presented their outstanding projects, other organizations like Swiss Physics Olympiads and the International Young Physicists’ Tournament gave an insight into their methods for exploring physics. In addition to our sponsors’ stands, some student groups presented themselves with nice and astonishing experiments, giving the right groove to the whole celebration fair. To the friendly atmosphere contributed too the “Captain Frank” music band with recent songs and some older ones from the last century. Altogether we all enjoyed a great afternoon in Bern celebrating the hundredth birthday of the Swiss Physical Society.

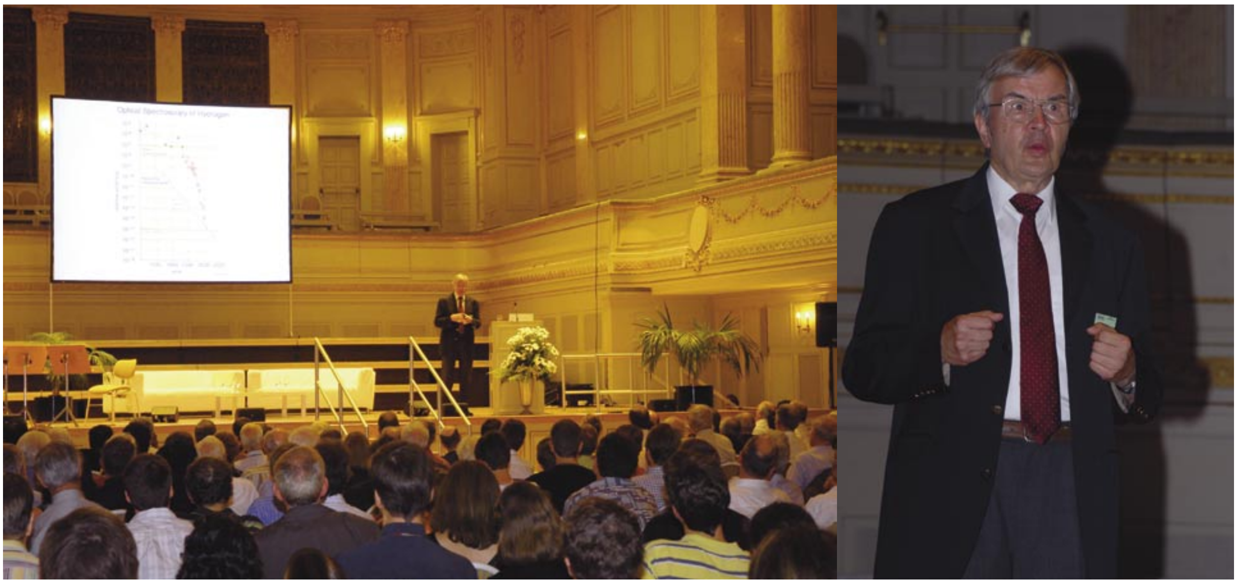
Tibor Gyalog, SPS Vice-President


Mauro Dell'Ambrogio, Secretary of State, brings the Federal Council's greetings.


Prof. Gerardus 't Hooft and Dr. Heinrich Rohrer in discussion with a group of students.

Keynote Speech "Vision for Physics"

With the keynote presentation the SPS has chosen to address the challenges of the Physics of Tomorrow, mainly to motivate young people for Physics. Since this is obviously a difficult task, we selected a well proven method: Ask one of the leading physicists to report about his current activities, and observe carefully his outlook for the future. We were happy that Theodor W. Hänsch from the Max Planck Institute in Garching agreed on giving such a keynote presentation. In his talk, he showed the enormous progress made with time and frequency measurement tools. With their increasing precision it will become possible, for instance, to test the fundamental laws of Physics, to ask if the natural constants are really constant, or if the special relativity theory really holds. On the other hand, questions like “What new technology fields might be expected from today’s fundamental research activities?” will have a strong impact on students who will later join industry. Here T. Hänsch gave a concrete outlook to optical clocks with monolithic microresonators, based on well established lithography techniques, but also ultraprecise spectroscopy in the Extreme UV using attosecond laser pulses. Looking in the future, it may be possible that atomic clocks, gyros, and interferometers become the physical instruments of the world after ‘nano’.



Prof. Theodor Hänsch talks enthusiastically about his "Visions for Physics".

We invite you to download the keynote presentation and draw your own conclusions. (www.sps.ch/100_jahrfeier/dokumente/).

Bernhard Braunecker, SPS Secretary

Students meet 5 Nobel Laureats

As part of the program of the 100th anniversary, young high school and university students met with Nobel laureates. Three groups of 15-20 students took the opportunity to discuss with the laureates Heinrich Rohrer (1986) and Gerardus ‘t Hooft (1999), Johannes G. Bednorz (1987) and Peter Grünberg (2007), and Theodor W. Hänsch (2005), respectively. While the students were certainly interested in understanding the research achievements for which the Nobel prizes were attributed, they were at least as eager to hear about the persons themselves. Who are these people and do they have a special way of thinking or working? Are they workaholics, geniuses or just “normal” persons? What made them discover their fascination for physics? When did they get their best ideas? In the night during their sleep, in their laboratory or while cycling between work and home? The bicycle was, by the way, used by Peter Grünberg to contemplate his experiments. Johannes G. Bednorz would speak of phases of very intense work but also of the need to relax and get distracted. Both would certainly agree on the great satisfaction for a physicist to be well known among his colleagues for high quality scientific contributions. Receiving the Nobel Prize is not a goal in itself but more the result of a combination of several parameters. In addition to intuition and hard work comes also a certain portion of good luck.

Klaus Kirch, SPS TASK

One of the student groups together with Professors P. Grünberg and J. G. Bednorz

The Gala Dinner

After the ceremonial act at the Kultur Casino Bern some hundred prominent guests were invited for a gala dinner at the Hotel Bellevue Palace. Among these guests were Mauro Dell'Ambrogio, Secretary of State for education and research, five Nobel laureates, many heads or representatives of the Swiss universities, of physics departments, of research organizations or companies, and naturally of the academies SCNAT and SATW. Particularly noteworthy was the presence of twelve of the past SPS presidents: Jean-Pierre Blaser (ZH, 1963-65), Ernst Heer (GE, 1971-73), Philippe Choquard (VD, 1977-79), Iris Zschokke (BS, 1979-81), Peter Minkowski (BE, 1985-85), Samuel Steinemann (VD, 1987-89), Jean Müller (GE, 1991-93), Hans-Jörg Schötzau (AG, 1993-95), Peter C. Oelhafen (BS, 1997-99), Thomas Jung (ZH, 1999-2002), Jean-Philippe Ansermet (VD, 2002-06) and Tibor Gyalog (BS, 2006-08). We were also honored by the presence of Fritz Wagner, president of the European Physical Society, as well as the presidents or representatives of the Physical Societies of Austria, Germany, Great-Britain, Italy, Lichtenstein, and Sweden.

In addition to an excellent dinner, the audience enjoyed also to hear the expert views and memories of two invited speakers. The first one was Hansruedi Ott, Professor Emeritus at the ETHZ, in his function as president of the platform mathematic-astronomy-physics (MAP) of the SCNAT and the second speaker was Jean Müller, Professor Emeritus of the University of Geneva and earlier president of the SPS.

Christophe Rossel, SPS President

Some impressions of the celebration and exhibits

Special SPS satellite meeting "Industrial Physics"

During our last annual meeting in Genève a plenary talk about "Time, Frequency and Atomic Clocks" was presented by G. Mileti, Laboratoire Temps – Fréquence, Université de Neuchâtel *), where he, among other, addressed the extreme precision of optical atomic clocks. Since Prof. T. Hänsch, who was awarded with the Nobel Prize in 2005 for this invention, joined our 'SPS-Centennial' as Keynote speaker, we took the opportunity to ask him about the state of the art of the technical realization. Since strong efforts are undertaken to miniaturize the optical clock technology down to chip-scale size, its widespread industrial use can be expected within the next few years, affecting also products of leading Swiss industries and institutions. Many existing and newly arising applications will benefit from such a module, since it is well suited, for instance, for space missions, high end metrology, and Earth surveying tasks, but also perhaps for new fields around consumer clocks.

The SPS therefore organized an application driven meeting with Prof. Hänsch on the day before the 'Festakt' with P. Vinard (RUAG Space AG), M. Darwish (The Swatch Group Ltd), ESA expert R. Czichy, P. Thomann (Laboratoire Temps–Fréquence, Université de Neuchâtel), P. E. Zinsli (State Secretariat for Education & Research), M. C. E. Huber, the former president of the European Physical Society, and Mr. A. Bodmer from 'Rahn & Bodmer Banquiers'. The SPS participants were T. Gyalog as president and B. Braunecker, who organized the meeting together with M. C. E. Huber.

Topics were discussed from the fields

- Time and frequency metrology
- Higher performance satellite navigation (Galileo)
- Precise tracking of remote space probes
- Geodesy with sub-millimeter accuracy

All participants agreed that the optical comb technique fits extremely well to Switzerland's competence in precision timing and frequency devices, navigation and remote sensing instruments.

Bernhard Braunecker, SPS Secretary

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*) see also our SPS Series "Progress in Physics" No. 7 on the next page

Progress in Physics (7)

Time, frequency and atomic clocks

G. Mileti, Laboratoire Temps – Fréquence, Université de Neuchâtel, gaetano.mileti@unine.ch

This article summarises the invited lecture given at the SPS annual meeting held in Geneva on March 27, 2008 (a pdf file of the presentation can be found on www.sps.ch). The talk first presented a few fundamentals on frequency standards and on the means to produce and characterise high performance oscillators displaying fractional frequency instabilities ranging from 10^{-10} to 10^{-17}. Then, the various types of existing atomic clocks were explained as well as their applications on ground and in space. Finally, after the description of several contributions of Switzerland (such as the atomic clocks for the European satellite navigation system GALILEO), the main trends of the domain and the current on-going research to improve them were highlighted. In summary, the general effort consists in exploiting: (1) the latest development in photonics (laser diodes and optical combs); (2) the atom-photon manipulation (optical pumping, laser cooling, etc.); (3) the extreme miniaturisation of key components.

Introduction on frequency standards

Two essential components of a clock are the “oscillator” and the “counter”. The “oscillator” provides a signal of period T (or frequency f = 1/T), which is supposedly known (or accurate) and stable. Examples of “oscillators” are a pendulum, a spring, a quartz crystal, etc. The “counter” has the function to provide a direct link between those oscillations and an output needed by the user of the clock: the exact time display, a stable 5 or 10 MHz signal, etc. Examples of “counter” components are an escapement, a gear, a dial, hands, an electronic frequency counter, etc. A third important element is the “reference”, which may be used to reduce instabilities of the oscillator frequency by adjusting it so as it matches the reference frequency.

For millennia, our time “reference” has been the earth rotation. As knowledge and science have progressed in a variety of fields (astronomy, mathematics, optics, mechanics, materials, etc.), mankind has on one hand developed tools to observe, understand and measure accurately the earth rotation period and on the other hand realised ingenious and sometime beautiful oscillators, counters and clocks. The progress in this truly interdisciplinary domain may be seen as a unique combination of “fundamental” and “applied” research symbolised for example by the quest for a reliable method to determine the longitude on sea and which led – after decades of unsuccessful attempts – to the realisation of the first marine chronometer, capable to keep the exact time within a few seconds per day during months of operation in an harsh environment. Thanks to marine chronometers, navigation on sea became safer and maps more accurate. Marine chronometers became also crucial for military purposes and for explorers such as J. Cook or J.-F. de Lapérouse.

Since the middle of last century, a new category of electronic oscillators exploiting the piezoelectric effect in quartz crystals appeared and replaced the other ones in most of the precise timing applications. In parallel, magnetic resonance on atomic samples have become our basic time (or frequency) reference. In 1967, the SI second was defined by the energy difference of a microwave transition between two hyperfine states of energy E_1 and E_2 in caesium (Cs) atoms, using the following basic formula with $\hbar = 1$:

$$\hbar\omega_0 = |E1 - E2| = 9'192'631'770 \text{ Hz} \qquad (1)$$

An atomic frequency standard is made of all the above-described basic components of a clock, with the difference that the reference is intrinsically more stable and more accurate than any other and is actually part of the device. Depending on the type of atomic clock (see below for specific examples), this reference – usually referred to as “atomic resonator” - may be a beam or a vapour of either near-room-temperature or laser-cooled atoms; it also may consist of laser-cooled atoms or ions in a trap.

The instability of atomic clocks is usually expressed as fractional frequency fluctuations. It is typically non stationary and described with its Allan deviation. The Allan deviation of a clock characterises its behaviour on various time scales and is an image of the noise processes limiting the clock stability. It may range between 10^{-10} to 10^{-17} depending on the standard and on the averaging time. These performances are determined on a short-term scale (1 to 1000 s) by various intrinsic properties of each specific atomic clock and on the medium and long-term by their aging and sensitivity towards external perturbations. The “Quality factor” $Q=\omega_0/\Delta\omega$ (where ω_0 and $\Delta\omega$ are respectively the frequency centre and the width of the magnetic resonance signal) and the “signal-to-noise ratio” (*SNR = amplitude of the reference sig-*

nal / detection noise) of the magnetic resonance have a direct impact on the clock short and medium term instability. In first approximation, the best fractional instability one may reach with a given *SNR* and a given Q is (at an averaging time of typically 1 second):

$$\delta f/f \propto (Q \cdot SNR)^{-1} \qquad (2)$$

Remembering that the magnetic resonance width $\Delta\omega$ is inversely proportional to its duration τ (Heisenberg uncertainty principle), this formula becomes:

$$\delta f/f \propto (\omega_0 \cdot \tau \cdot SNR)^{-1} \qquad (3)$$

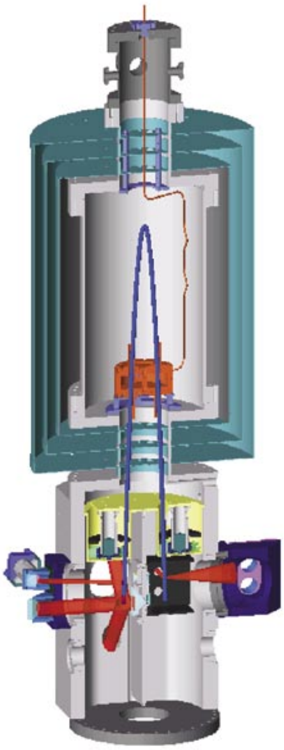
One may (very roughly) summarise the research in the domain of atomic clocks by a constant effort to improve the three basic parameters given in equations (2) or (3). As shown in the two examples below:

- the SNR has been and is still being increased in several atomic clocks, for instance by replacing discharge lamps or magnetic selectors by tunable laser sources such as semiconductor laser diodes;
- τ has been and is still being increased by slowing down atoms through laser cooling;
- Q has been and is still being decreased by increasing ω_0 using optical transitions.

Another trend of the research concerns the improvement of properties of the clocks other than frequency instability. Those are in particular: price, volume, consumption, weight, reliability, etc.

Example 1: Laser cooling and the Swiss primary frequency standard

Primary standards employ a Cs beam in vacuum which goes through a microwave Ramsey Cavity in which takes place the magnetic resonance. The obtained discriminator signal is used to measure and correct any frequency fluctuation of a quartz oscillator, providing thus a stable and accurate reference. From approximately 1960 to 1990, primary standards were based on thermal beams (average velocity of 200 m/s) providing a reference signal linewidth of typically 100 Hz, depending on the length of the cavity. With laser cooling, the atoms velocity could be significantly reduced and nowadays primary Cs standards (fountains) supply a 1 Hz wide reference signal, limited only by the earth gravitation. Such standards have now reached an accuracy below 10^{-15} and a short-term frequency stability (@ 1s) of 10^{-13} or below. Figure 1 shows the METAS Swiss Primary Frequency Standard developed by P. Thomann and his team at UNINE-LTF, formerly Observatoire Cantonal de Neuchâtel (ON). This device is unique since it uses a continuous – instead of a pulsed - Cs beam of cold atoms which reduces the effect of atomic collisions and of the phase noise of the microwave signal probing the atoms in the cavity. Note that cold atomic beams find many other applications than clocks including precision instruments such as atom interferometer gyroscopes and accelerometers.



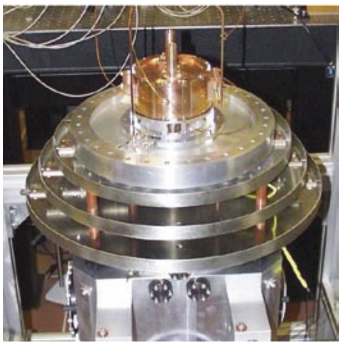


Fig. 1 Swiss primary continuous atomic fountain (LTF-METAS): CAD drawing (left) and view of the microwave cavity, magnetic shields and lower vacuum vessel

Example 2: GALILEO and the new vapour cell and miniature atomic clocks

In a large number of applications, extreme accuracy and long-term stability are not required while consumption, volume, weight or price play a crucial role. Vapour-cell atomic clocks (often referred to as “Rubidium clocks”) offer excellent short medium term performances (10^{-12} to 10^{-11} at 1 s, 10^{-11} to 10^{-14} at 20’000 s) even though their volume can be as small as a tennis ball. In this type of standards, the atoms are confined in a 1-2 cm^3 glass bulb placed inside a microwave cavity and irradiated by a light beam which creates a microwave-optical double resonance. This category of standards is needed in telecommunication systems as well as in mobile applications such as satellite navigation and positioning. The current research in this area consists in exploiting the properties of lasers to replace the presently used plasma discharge lamps as optical sources. For instance, laser diodes allow the creation of so-called “dark-states” with the Rb atoms, through the Coherent Population Trapping (CPT) effect. Figure 2 shows some atomic resonators developed by G. Mileti and his team at UNINE-LTF (also formerly ON). In particular are shown a laser-pumped Rb clock in view of the "second generation" clocks for the European GALILEO satellite navigation system and a micro-fabricated vapour cell, developed in collaboration with the Institute of Microtechnology (IMT-UNINE). This miniature cell constitutes a first step towards the realisation of chip-scale atomic clocks but may as well serve in future miniature atomic magnetometers, gyroscopes, quantum sensors in general or even quantum computing and quantum communication systems (atom chips).

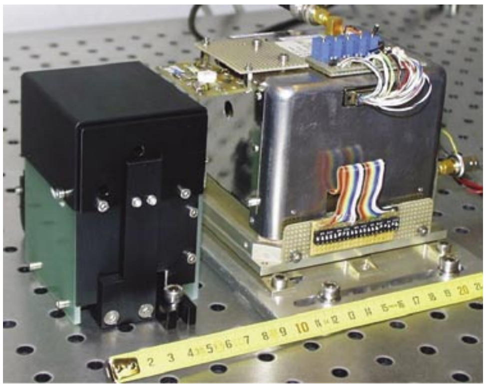
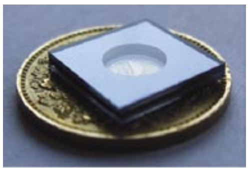


Fig. 2 Laser-pumped Rb clocks: ESA prototype for GALILEO (up) and micro-fabricated vapour cell (10x10x1.5 mm)



Other examples and conclusion

Several other types of atomic frequency standards exist and/or are currently being studied. Hydrogen (H) Masers make use of the stimulated emission of H atoms in a Teflon-coated bulb, thus providing an extraordinary stable reference in the medium a short-term range (10^{-13} at 1 s, 10^{-15} or below from 100 to 10'000 s). The main applications of H-Masers are timekeeping and VLBI (Very Long Baseline Interferometry) for radioastronomy. Optical frequency standards constitute also a very active and very successful field of research as optical references allow in principle to gain several orders of magnitude in accuracy and in stability since $\omega_0 / 2\pi$ increases from 10^9-10^{10} Hz to 10^{14}-10^{15} Hz (see equations 1-2-3). In practice, it proved very difficult to realise the "counter" providing a direct link from the quartz frequency to this reference. However, optical combs are now enabling us to establish this link in a very convenient manner (Nobel prize of Physics in 2005 by T. W. Hänsch and J. L. Hall). Combining this technique with trapped ions or cold atoms in an optical lattice makes realistic to aim at instabilities and inaccuracies as low as 10^{-18}. Space environment is also stimulating researchers to push the performances of atomic clocks to their limits and to use them for performing fundamental tests of the laws of physics. The ACES (Atomic Clock Ensemble) experiment on the International Space Station (ISS) includes a French laser-cooled Cs clock and a Swiss active H-Maser. Thanks to the micro-gravity environment, the Cs clock displays Ramsey fringes which are only 0.1 Hz wide. ACES will provide a mean for: (1) studying cold atoms in microgravity; (2) a worldwide comparison of ultra-stable clocks (30 ps accuracy and clock synchronisation at the 10^{-16} level); (3) improvements of fundamental tests of general relativity (red shift, drift of the fundamental constant α, anisotropy of speed of light, etc.). Space Hydrogen Masers will also serve to increase the baseline and therefore the angular resolution of VLBI for radioastronomy (RADIOASTRON mission).

In conclusion, research on atomic clocks is currently very active for both the everyday applications (telecoms, positioning, timescales, etc.) and the fundamental research (study of light-atoms interaction, tests of fundamental laws, etc.). Experiments are on-going both on ground and in space and their progress also depends on key technological developments, in particular in the field of photonics and micro technology. Two general trends may be observed: going optical and going miniature.

Acknowledgements

Many activities described in this article and the current research of LTF are funded by the Canton of and the University of Neuchâtel, the Swiss National Science Foundation, the Swiss Federal Office of Metrology (METAS), the Swiss Space office (SER-SSO), the European Space Agency (ESA), the European Union (INTAS, EC-FP7), the Association Suisse pour la Recherche Horlogère (ASRH), the Fondation en faveur d'un Laboratoire de Recherche Horlogère (FLRH). In addition to the members of LTF listed below, the author acknowledges the contributions of many other persons who performed the scientific, technical and administrative work at ON and at UNINE. We also thank the numerous research laboratories and companies who contributed to this research through essential scientific collaborations.

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Brief presentation of Laboratoire Temps – Fréquence (LTF-UNINE)

LTF-UNINE was created on February 1st 2008, following the transfer of two groups from Observatoire Cantonal led by P. Thomann (laser cooling and primary standards) and G. Mileti (vapour cell clocks and stabilised lasers). The main research lines concern: (1) the study the interaction of atoms and electromagnetic radiation; (2) the development of primary and frequency standards; (3) the development of optical sources and frequency standards. LTF performs also technological developments in particular related to space clocks and to the new standards for the European satellite navigation system GALILEO. The following persons presently form LTF: Prof. P. Thomann, G. Mileti, C. Affolderbach, E. Breschi, G. Di Domenico, A. Joyet, C. Schori, V. Dolgovskiy, G. K. Gulati, R. Roy, D. Miletic, T. Bandi, F. Gruet, P. Scherler.

Progress in Physics (8)

The physics of turbulent structures and blobs in magnetically confined plasmas

Ivo Furno and the CRPP Basic Plasma Physics Group
Centre de Recherche en Physique des Plasmas, Ecole Polytechnique Fédérale de Lausanne (EPFL),
Association EURATOM – Confédération Suisse, CH-1015 Lausanne

Introduction

At the edge of tokamaks, the most promising magnetic confinement concept to obtain controlled nuclear fusion on Earth, a large fraction of the particle and heat transport is attributed to the presence of plasma *blobs*. These are isolated filamentary non-linear structures with increased density and temperature with respect to the surrounding plasma. Blobs are intermittently ejected and transported away from the main plasma into the outermost region of the device, dubbed Scrape-Off Layer (SOL), where particles are rapidly lost flowing along the magnetic field lines to the wall, thus "eroding" the last plasma layer, as the name suggests it. Blob transport may affect divertor heat loads and wall recy-

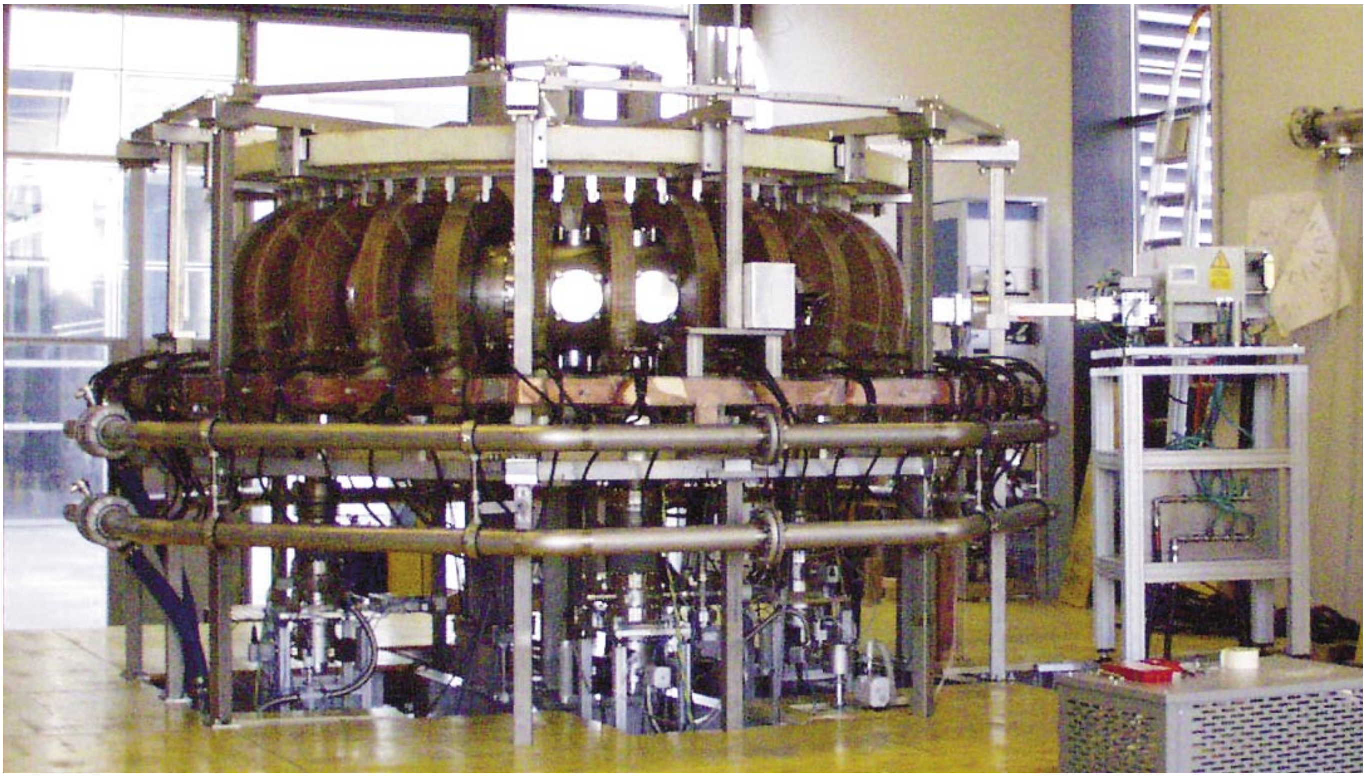

Fig. 1. The TORPEX device at the CRPP-EPFL

cling and possibly the overall performance of future burning plasmas such as ITER. Thus, in recent years, there has been an increasing experimental, theoretical, and numerical simulation effort to understand the physics of blobs. From the experimental point of view, the investigation in fusion devices is hampered by the intrinsic difficulty of having diagnostic access in the region of interest with adequate temporal and spatial resolution. To overcome these limitations, an extensive investigation of blob physics has been undertaken in the basic plasma physics device TORPEX [1] at the Centre de Recherche en Physique des Plasmas at the EPFL. TORPEX is a device much simpler than tokamaks, but in which full diagnostics access with high spatial and temporal resolution is obtained.

The TORPEX device and the experimental setup

A picture of TORPEX is shown in Fig. 1. TORPEX is a toroidal device with major and minor radius R = 1 m and a = 0.2 m respectively. For the present experiments, hydrogen plasmas are generated and sustained by microwaves at 2.45 GHz in a magnetic configuration with a dominant toroidal ($B_T = 73$ mT) and a small vertical field component (B_z=2.3 mT). This simple magnetic configuration, with open helical field lines, features ∇B and magnetic curvature similarly to the SOL of fusion devices. It is characterized by the presence of plasma blobs [2] exhibiting universal statistical properties with strong similarities with observations in tokamaks [3]. The plasma has typical electron temperatures T~ 5-15 eV and densities in the range $n \sim 2 - 15\times10^{15}$ m^{-3}. These low temperatures and densities permit high spatial and temporal resolution in-situ measurements using electrostatic probes over the entire plasma cross-section. These measurements are not achievable in typical fusion experiments. This experimental setup represents, therefore, a unique starting point to investigate the physics of blobs and associated transport with unprecedented diagnostics capabilities.

Plasma waves and blobs

The main features of this configuration are shown in Fig. 2. We identify two distinct poloidal regions with different plasma dynamics: (1) a main plasma region for r < 5 cm, where the plasma source is localized, dominated by a coherent interchange wave for -5 <r <5 cm; (2) a region for r > 5 cm with negligible plasma production and broadband fluctuation spectra, dubbed *source-free* region, characterized by the propagation of blobs. In Fig. 2 (a), we illustrate the nature of the fluctuations in the two regions using 2D profiles of the skewness S (normalized third order moment of the probability density function) of signals from electrostatic probes [4]. In the main plasma region, fluctuations are characterized by coherent oscillations at a frequency of ~3.9 kHz as shown by a probe signal in Fig. 2(b). These oscillations are associated with an interchange mode [5], which is localized around the position of maximum plasma pressure gradient. Interchange modes involve the exchange of fluid elements with different densities and tend to be unstable in the "unfavorable" curvature region where $\nabla B\cdot\nabla P>0$, P being the plasma pressure. In the source-free region, the fluctuation spectrum is broad and exempt from coherent modes, Fig. 2 (e). The skewness is positive (S ~ 1) indicating the occurrence of positive intermittent bursts, as shown in Fig. 2 (c). These bursts are associated with the presence of blobs that originate in the main plasma region and propagate outward into the source-free region as individual coherent structures over distances of the order of the minor radius.

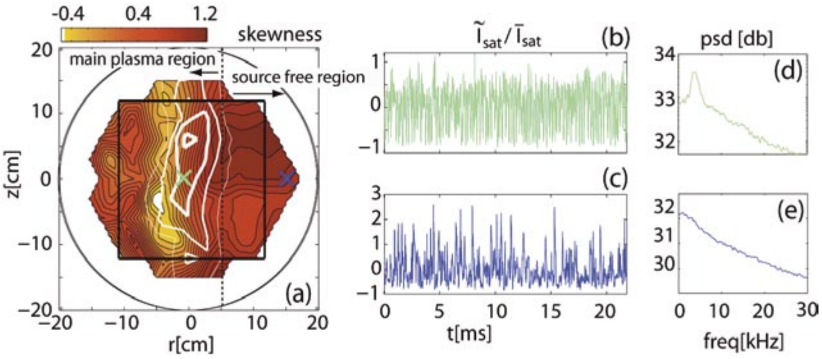

Fig. 2. (a) Poloidal profile of skewness of signals from electrostatic probes. In (a) the profile of spectral power in the frequency range 3.9 ± 1 kHz is shown in white and localizes the interchange mode. (b,c) Signals at the two locations indicated in Fig. 2 (a) show coherent fluctuations in the main plasma region (blue cross) and intermittent bursts associated with blobs at the edge (green cross). (d,e) Power spectral densities of the two signals in (b,c).

Mechanism for blob generation

To investigate the mechanism for blob generation, time resolved 2D profiles of electron density, pressure, plasma potential and velocity fields are required. These are obtained by performing a conditional sampling over many blob events of the I-V characteristic of an electrostatic probe in a time window centered on the blob detection [5]. The results of the conditional sampling are shown in Fig. 3. We show the time evolution of the fluctuating density, δn, in the mode (red) and in the source-free (black) regions.

Figure 3 shows 2D profiles of the fluctuating density,, in panels (b) – (d) and plasma potential, δV, in panels (e) – (g) at three different times during the ejection of the blob together with the velocity field of the plasma, which corresponds to the **E**×**B** drift velocity. The coherent structures are identified with the interchange wave, based on their spatiotemporal

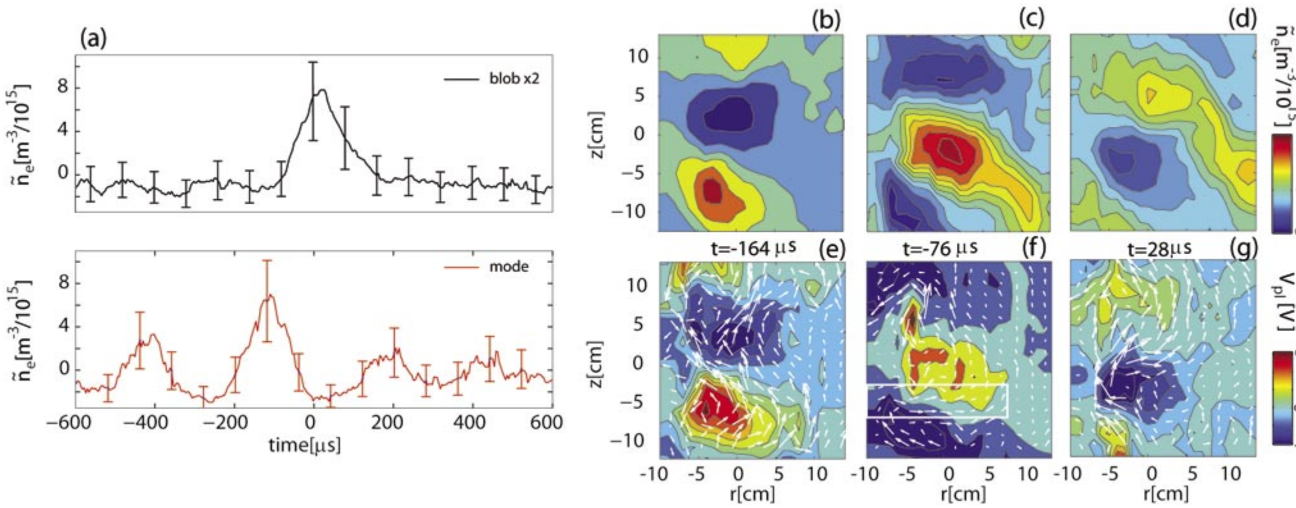

*Fig. 3. Plasma dynamics from the conditional sampling technique. Shown are (a) time history of δn in the mode region (red) and in the source free region (black). 2D profiles of (b)–(d) and (e)–(g) δV at different times during blob ejection. The arrows show the instantaneous **E**×**B** velocity.*

properties. The dynamics of blob formation and ejection from the interchange wave is captured by frames (c)–(e). A radially elongated density structure forms from the positive cell of the wave, Fig. 3 (c).

The formation of this structure follows from the convection of plasma by the **E**×**B** flow in a corridor that extends radially over a distance of the order of the minor radius, Fig. 3 (f), in which the velocity is mainly in the radial direction. In Fig. 3 (c-d), the elongated density structure is convected upward in a sheared velocity field that moves different parts of the density structure with different vertical velocities. A relative displacement between them is obtained, Fig. 3 (c). Eventually, the original density structure breaks into two parts, Fig. 3 (d). The new structure on the low field side forms a plasma blob.

In Fig. 4, we illustrate the mechanism driving the elongation of the density wave crest. The instantaneous pattern of the fluctuating $v_{E\times B}$ in Fig. 4 (a) shows a text-book example of the interchange mechanism that exchanges a zone of high plasma pressure with a zone of low plasma pressure. The time evolution of the pressure gradient, which provides the drive for the interchange mode, is shown in Fig. 4 (b) and reveals that the elongation of the density cell follows a sudden increase of the interchange drive.

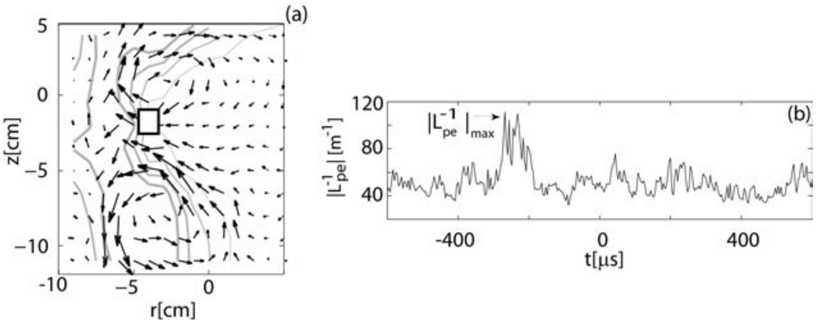

Fig.4. A zoomed view of the instantaneous fluctuating v_{ExB} velocity field at t = -184 µs shows the convective cells interchanging zones of high and low plasma pressure. (b) Time evolution of the interchange drive.

Conclusions

These results detail a fundamental phenomenon in plasmas. The accurate measurements can be used to validate theories and numerical simulations of blob dynamics. Similarly to the tokamak SOL, the magnetic configuration features open field lines, a ∇B and magnetic field curvature. Blobs in TORPEX exhibit universal statistical properties with strong similarities with observations in the tokamak SOL. Thus, the observed dynamics sheds light on the blob ejection mechanism in tokamaks and may open new venues for controlling edge turbulent transport.

This work was partly supported by the Fonds National Suisse de la Recherche Scientifique.

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Physik Anekdoten (2)

Im 2. Artikel unserer Serie geht es um Leonhard Euler, dessen 300. Geburtstag letztes Jahr gefeiert wurde. Ein mit beeindruckenden Referaten organisierter Jahreskongress der SCNAT fand im September 2007 in Basel statt, um uns den Polyhistor Euler als Mensch und Wissenschafter näher zu bringen, aber auch um Missverständnisse zu korrigieren. So erkennt man in manch populärer Literatur dem Physiker Euler nicht die Bedeutung zu, die er als Mathematiker geniesst. Das erstaunt; denn gerade moderne Arbeiten, zum Beispiel der Modellierung von Turbulenzen [1], nehmen explizit Bezug auf Eulers Fundamentaluntersuchungen. Ein möglicher Grund für diese Fehlbeurteilung wurde im Referat von Michael Eckert in Basel angesprochen und wird nun im folgenden Artikel präsentiert. Unser Autor ist Physikhistoriker am Deutschen Museum in München und ausgewiesener Fachmann für die Geschichte der Strömungslehre. Ohne seinem Beitrag vorgreifen zu wollen, sei jedoch jetzt schon als Fazit festgehalten: ‚Riskmanagement' hätte es schon vor 250 Jahren geben sollen, und Physiker, die oft am Anfang einer technischen Wertschöpfungskette stehen, sollen auch immer die nachfolgenden Prozesse beobachten, um rechtzeitig bei Fehlleistungen eingreifen zu können !

Bernhard Braunecker, SPG-Sekretär

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[1] 'Turbulenzübergänge', B. Eckhardt, B. Hof, H. Faisst, Physik in unserer Zeit; 5/2006 (37) p.212. Eindrucksvolle Belege für die Aktualität von Eulers Arbeiten wurden auch auf einer Konferenz zum Thema „Euler Equations: 250 Years On" dargeboten, vgl. http://www.oca.eu/etc7/EE250/.

Euler und das Fiasko von Sanssouci

„Ich wollte in meinem Garten einen Springbrunnen anlegen", schrieb Friedrich der Große am 25. Januar 1778 an Voltaire. Das Projekt endete jedoch in einem Fiasko. Der Preußenkönig blickte von seinem Schloss Sanssouci auf Brunnenanlagen, aus denen keine Fontänen in die Höhe schossen. Dabei sollte die Wasserkunst nach den neuesten Erkenntnissen der Hydraulik ausgeführt werden und selbst Versailles an Pracht übertreffen. „Euler berechnete die Leistung des Räderwerks, damit das Wasser in ein Bassin hinaufgelänge, über Kanäle wieder abfließe, um in Sans-Souci aufzusteigen. Meine Mühle wurde nach allen Regeln der Mathematik gebaut, und sie konnte keinen einzigen Wassertropfen weiter als fünfzig Schritt unter das Bassin hinaufpumpen. Eitelkeit der Eitelkeiten! Eitelkeit der Mathematik!" [1]

Das Fiasko von Sanssouci gilt seither als Paradebeispiel für das Auseinanderklaffen von Theorie und Praxis. Und **Leonhard Euler**, das Mathematikgenie aus Basel, wurde zur Zielscheibe von Spott und Schadenfreude. „Das physikalische Universum bot Euler eine Gelegenheit, Mathematik zu treiben, es war ihm nicht als solches von Interesse; und wenn das Universum nicht mit seiner Analysis übereinstimmte, dann lag der Fehler beim Universum," liest man in einem populären Buch mit dem Titel „Die großen Mathematiker". Und ein Physikhistoriker brachte es auf den lapidaren Schluß: „Der geniale Mathematiker Euler war zweitklassig als Physiker". Es fehlt auch nicht an Vermutungen für die Gründe seines Scheiterns. „Unglücklicherweise hat er die Wirkung der Reibung weggelassen, mit peinlichen praktischen Folgen," vermutete ein Physiker.


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Was ist damals im Schlosspark von Sanssouci geschehen? Wir wissen darüber aus einer Baugeschichte, die vom letzten Architekten des Königs verfasst wurde, sehr gut Bescheid. **Friedrich der Große** wünschte neben einer Vielzahl von im Park verstreuten Brunnen eine Fontäne von mindestens 30 Meter Höhe – in einem Park, der nur von dem in einiger Entfernung träge dahinfließenden Havelwasser zehren konnte. Der Plan sah vor, mit einem Kanal Wasser von der Havel in einen am Rand des Schlossparks gelegenen Saugbrunnen zu leiten, von wo es durch eine Pipeline in ein höher gelegenes Reservoir gepumpt werden sollte. Die Pumpe sollte von einer Windmühle angetrieben werden. Das Reservoir war etwa 1 km vom Saugbrunnen entfernt auf dem Höneberg – gut 50 Meter über dem Wasserspiegel der Havel – und hätte die im Schlosspark verteilten Springbrunnen beliefern sollen. Der Höhenunterschied sollte den nötigen Druck für die Wasserfontänen in den Springbrunnen erzeugen.

Zunächst lief alles nach Plan. Das Wasserkunstprojekt nahm 1748, kurz nach Vollendung des Schlosses von Sanssouci, seinen Anfang. Zuleitungsgraben, Reservoir, Windmühle und Pumpe wurden in weniger als einem Jahr fertig gestellt. Die Rohre für die Pipeline zum Reservoir wurden aus Holzbohlen nach Art von Fässern, mit eisernen Bändern umklammert, zusammengefügt. Als man jedoch Wasser hindurchpumpte, platzten die Rohre am unteren Ende, bevor das Wasser beim Reservoir ankam. Jetzt ersetzte man diese aus Bohlen zusammengefügten Holzrohre durch ausgebohrte Fichtenstämme. Doch auch diese Rohre platzten. Nun war klar, dass Holzrohre dem Druck nicht standhielten. Jetzt wurde eine neue Pipeline aus Metallrohren zusammengesetzt, die zwar nicht platzten, aber zu wenig Wasser in das Hochreservoir förderten, weil sie falsch dimensioniert waren. Mit dem missratenen Pipelinebau verging viel Zeit. Dann sorgte der Siebenjährige Krieg (1756-1763) für eine weitere Unterbrechung. Am Ende riss dem König der Geduldsfaden, und er ließ das Unternehmen einstellen.

Der Chronist des fehlgeschlagenen Wasserkunstprojekts von Sanssouci hatte selbst leidvolle Erfahrungen mit den Bauprojekten des Preußenkönigs gemacht. Er wußte ein Lied von dessen extravaganten Wünschen zu singen, gepaart mit Knauserigkeit, was die Aufwendungen betraf. Er nannte die Namen der mit der praktischen Durchführung beauftragten Personen und sparte nicht mit Kritik, was ihre Eignung für diese Aufgabe betraf. Hätte Euler das Scheitern verursacht, wie der König in seinem Brief an Voltaire behauptete, dann wäre dies vermutlich auch in der Baugeschichte im Detail geschildert worden, aber Euler wird darin überhaupt nicht erwähnt!

Glücklicherweise sind wir über Eulers Wirken nicht auf Spekulationen angewiesen. Sein wissenschaftliches Werk und auch sein Briefwechsel mit Friedrich dem Großen und mit dem Präsidenten der Berliner Akademie sind in einer vielbändigen Edition überliefert. Wenn man diese Quellen auswertet, gelangt man zu dem Schluss, dass Euler keine Schuld am Fiasko von Sanssouci trifft. Seine Analyse führte zur modernen hydraulischen Theorie der instationären Rohrströmung. Wenn die Pumpe das Wasser im Rohr in Bewegung setzt, kommt es zu einem Druckanstieg am Rohranfang. Dieser Druckanstieg ist um so größer, je mehr Wasser sich in der Pipeline befindet; er ist auch vorhanden, wenn gar kein Höhenunterschied zu überwinden ist. Eulers hat diesen hydrostatisch nicht faßbaren, dynamischen Druck berechnet und daraus Empfehlungen für die Pumpenleistung und die Dimensionen der Pipeline gegeben, die jedoch nicht beachtet wurden. Er hat sogar ausdrücklich davor gewarnt, dass das Projekt scheitern werde, wenn der Pfusch mit der Pipeline zwischen Pumpstation und Hochreservoir nicht beendet würde.


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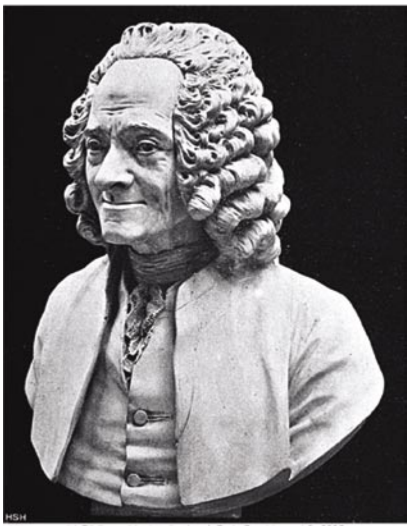
Insgesamt war Euler nur sehr kurz mit dem Sanssouci-Projekt betraut. Von dem ersten Brief Eulers vom 21. September 1749, adressiert an **Maupertuis**, den Präsidenten der Berliner Akademie der Wissenschaften, bis zur Mitteilung seiner Analyse am 17. Oktober 1749 in einem Brief an den König vergingen nur knapp vier Wochen. Das erklärt, warum sein Name in der Baugeschichte, die den Pfusch ja über Jahrzehnte hinweg beschreibt, gar nicht erwähnt wird. Aber Eulers Analyse traf den wunden Punkt der ganzen Angelegenheit. Die nötige Stärke der Bleirohre müsse aus Experimenten bestimmt werden, forderte er. Er ging davon aus, dass nach dem ersten Platzen der Holzrohre Bleirohre verwendet würden, aber die Praktiker ignorierten dies und benutzten auch noch lange danach Holzrohre für die Pipeline. Über die kritische Frage des Drucks schrieb Euler: „Ich habe Berechnungen über die ersten Versuche angestellt, bei denen die Holzrohre geplatzt sind, sobald das Wasser auf eine Höhe von 70 Fuß angehoben wurde. Ich finde, dass die Rohre tatsächlich einem Druck ausgesetzt waren, der einer 300 Fuß hohen Wassersäule entspricht. Das ist ein sicheres Anzeichen dafür, dass die Maschine noch weit von einem perfekten Zustand entfernt ist". Was die Dimensionierung der Rohre angeht, fand Euler, „dass man unbedingt größere Leitungsrohre verwenden muss". Auch dieser Rat wurde ignoriert. Als man nach weiteren Fehlschlägen endlich Bleirohre einsetzte, hatten diese einen viel zu geringem Innendurchmesser.

Eulers Theorie der Rohrströmung, die er aufgrund seiner Beschäftigung mit der „Maschine von Sanssouci" entwickelte, war das Vorspiel zu der Formulierung der allgemeinen Bewegungsgleichungen für ideale (das heißt reibungsfreie) Fluide. Diese „Eulerschen Gleichungen" wurden erst im 19. Jahrhundert durch Einbeziehung der Reibung zu den „Navier-Stokes-Gleichungen" erweitert. Sie bilden das Fundament der gesamten Strömungslehre. Dass Eulers Theorie der Rohrströmung einem Wasserbauingenieur unserer Tage nicht praxisgerecht erscheint, da der Reibungseinfluss je nach Anordnung erheblich sein kann, kann aber nicht als Ausrede für den Pfusch von Sanssouci herhalten. Das Verständnis der Rohrreibung bereitete noch im zwanzigsten Jahrhundert erhebliche Probleme. Erst in unserer Zeit sind auch solche Fragen theoretisch lösbar, wobei jedoch praktisch verwendbare Resultate solcher Theorien meist nur durch den Einsatz von Computern gewonnen werden können.



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Warum wurde Euler zum Sündenbock für das Fiasko von Sanssouci? Als Friedrich II. Euler 1740 nach Berlin berief, herrschten hochgesteckte Erwartungen am Hof des Preußenkönigs, denn die Akademie sollte endlich zu dem werden, was sie schon bei ihrer Gründung 1700 hätte sein sollen: eine den Pariser und Londoner Gelehrtenvereinigungen ebenbürtige Akademie. Aber es dauerte nicht lange bis zu den ersten Meinungsverschiedenheiten zwischen Euler und dem König. Euler hoffte auf die Präsidentschaft der Akademie, aber Friedrich fand ihn dafür nicht schöngeistig genug. Nach Maupertuis' Tod im Jahr 1759 übernahm er lieber selbst die Leitung der Akademie, als sie Euler anzuvertrauen. 1766 kehrte Euler enttäuscht nach St. Petersburg zurück, wo er schon vor 1740 gewirkt hatte. Als der König in seinem Brief an **Voltaire** Euler die Schuld für das Fiasko von Sanssouci gab, lag der Vorfall mit den geplatzten Rohren, den

Euler analysiert hatte, schon fast 30 Jahre zurück. Nur im Abstand von mehr als zweihundert Jahren erscheint die Äußerung des Königs authentisch. Aber sein Zerwürfnis mit Euler und sein mangelndes Verständnis von Mathematik und Technik machen Friedrich, den man immer noch „der Große“ nennt, zu einem ungeeigneten Gewährsmann für die Geschichte der mißratenen Wasserkunst von Sanssouci. Traurig ist nur, dass sich bis heute viele seinem Urteil und Spott anschlossen, obwohl das Eulersche Werk zur Genüge die Verleumdung Lügen straft, er sei ein praxisferner Theoretiker gewesen.

Michael Eckert, Deutsches Museum München

Referenzen:

[1] Eine ausführliche Darstellung mit den entsprechenden Literaturangaben findet sich in Michael Eckert: Euler and the Fountains of Sanssouci. Archive for History of Exact Sciences, 56, 2002, 451-468. Eine Analyse der Eulerschen Arbeit mit Blick auf seine kurz darauf erarbeitete allgemeine Theorie der idealen Fluide erscheint in Michael Eckert: Water-art problems at Sanssouci—Euler's involvement in practical hydrodynamics on the eve of ideal flow theory, Physica D (2007), doi:10.1016/j.physd.2007.09.006.

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Die Schweizerische Physikalische Gesellschaft (SPG) feiert im Sommer 2008 ihr hundertjähriges Jubiläum. Nahezu alle wichtigen mit der Schweiz verbundenen Physiker des 20. Jahrhunderts waren Mitglied der SPG - Albert Einstein, Wolfgang Pauli und Paul Scherrer sind nur einige wenige Beispiele. Die vorliegende Festschrift erzählt die Geschichte der SPG, beginnend mit ihren Anfängen 1908.

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