europhysicsnews

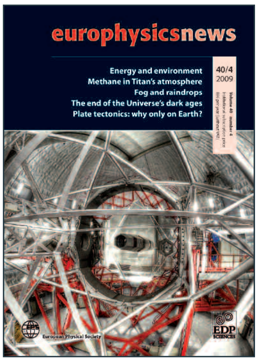
40/4
2009

Energy and environment
Methane in Titan's atmosphere
Fog and raindrops
The end of the Universe's dark ages
Plate tectonics: why only on Earth?

Volume 40 • number 4
Institutional subscription price:
88€ per year (without VAT)

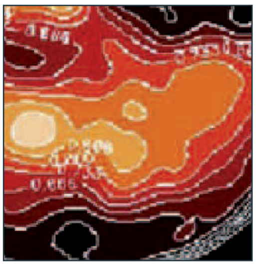
European Physical Society

EDP SCIENCES



europhysicsnews

Cover picture: The world's biggest time machine was recently inaugurated. The Gran Telescopio CANARIAS (GTC) has celebrated its official opening on July 24th at the Observatorio del Roque de los Muchachos, and was attended by Their Majesties the King and Queen of Spain.

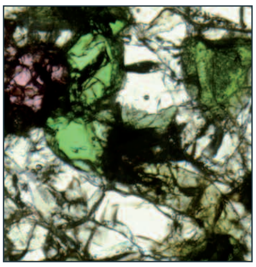


▲ PAGE 16

Methane in Titan's atmosphere

▲ PAGE 22

The end of the Universe's dark ages



▲ PAGE 27

Plate tectonics: Why only on Earth

EDITORIAL

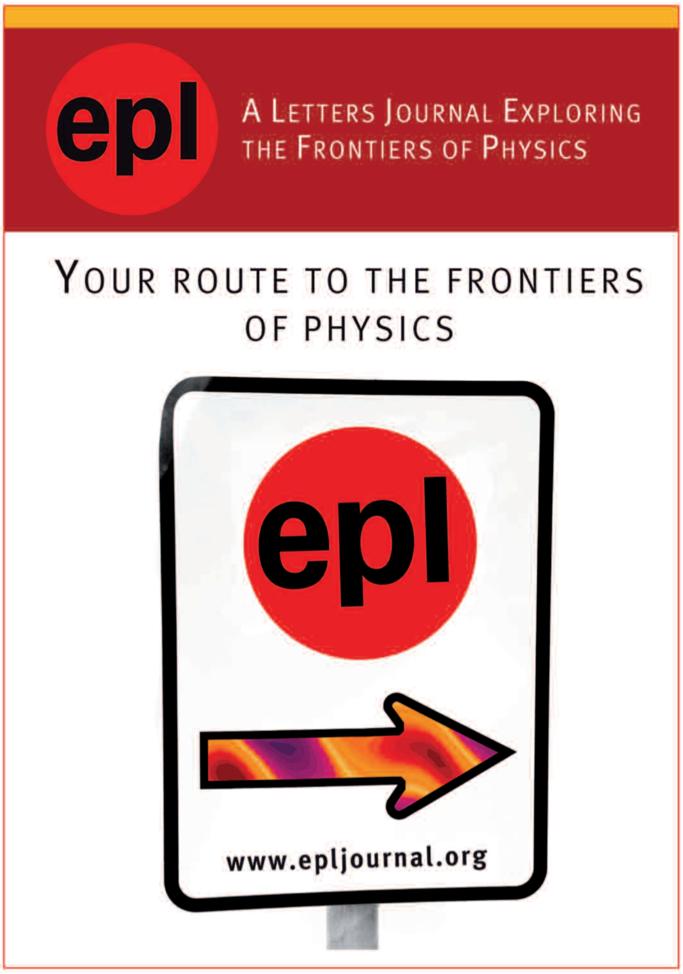
NEWS

HIGHLIGHTS

FEATURES

BOOK REVIEW


EXCIMER LASERS PSX-100 & PSX-501
157 nm - 193 nm - 222 nm - 248 nm - 308 nm - 337 nm - 351 nm
100 & 300 Hz
0.5 - 2.5 W
SMALL PACKAGE
POWERFUL PERFORMANCE
Neweks AS
19 Akadeemia tee, Tallinn, Estonia
Phone 372 6703703
FAX 372 6703504
www.excimer.ee
neweks@excimer.ee


epl
A Letters Journal Exploring the Frontiers of Physics
Your route to the frontiers of physics
epl
www.epljournal.org


Web of Conferences
For All Events in All Scientific Fields
AN INTERNATIONAL EVENTS CALENDAR
to search for a conference or a congress
to announce or promote an event
A COMPLETE & FLEXIBLE CONFERENCE PROCEEDINGS PUBLISHING SERVICE
Online publication on a specialized website
All articles fully citable (DOI names) and indexed
Maintenance and archiving, creation of series
Printing and CD/DVD publishing options
Now you can announce your conference free of charge at www.webofconferences.org
EDP SCIENCES
Web of Conferences is an EDP Sciences service

europhysicsnews
2009 • Volume 40 • number 4

Europhysics news is the magazine of the European physics community. It is owned by the European Physical Society and produced in cooperation with EDP Sciences. The staff of EDP Sciences are involved in the production of the magazine and are not responsible for editorial content. Most contributors to Europhysics news are volunteers and their work is greatly appreciated by the Editor and the Editorial Advisory Board. Europhysics news is also available online at: **www.europhysicsnews.org**.
General instructions to authors can be found at: **www.eps.org/publications**

Editor
Claude Sébenne
Email: claude.sebenne@impmc.jussieu.fr

Science Editor
L.J.F. (Jo) Hermans
Email: Hermans@Physics.LeidenUniv.nl

Executive Editor
David Lee
Email: d.lee@eps.org

Graphic designer
Xavier de Araujo
Email: x.dearaujo@eps.org

Director of Publication
Jean-Marc Quilbé

EPS Secretariat
address: EPS • 6 rue des Frères Lumière
BP 2136 • F-68060 Mulhouse Cedex • France
tel: +33 389 32 94 40
fax: +33 389 32 94 49
web: www.eps.org

Secretariat is open 09.00–12.00 / 13.30–17.30 CET except weekends and French public holidays.

EDP Sciences
Managing Director: Jean-Marc Quilbé

Production: Agnès Henri
Email: henri@edpsciences.org

Advertising: Aurelie Lefebvre
Email: lefebvre@edpsciences.org

address: EDP Sciences
17 avenue du Hoggar • BP 112 • PA de Courtabœuf • F-91944 Les Ulis Cedex A • France
tel: +33 169 18 75 75
fax: +33 169 28 84 91
web: www.edpsciences.org

Subscriptions
Individual Members of the European Physical Society receive Europhysics news free of charge. **Members of EPS National Member Societies** receive Europhysics news through their society, except members of the Institute of Physics in the United Kingdom and the German Physical Society who have access to an e-version at **www.europhysicsnews.org**. The following are subscription prices available through EDP Sciences.
Institutions: 88 euros (without VAT, European Union countries); 105 euros (without VAT, the rest of the world).
Individuals: 58 euros (VAT included, European Union countries); 58 euros (the rest of the world).

Contact: subscribers@edpsciences.org or visit **www.edpsciences.org**

ISSN 0531-7479 • ISSN 1432-1092 (electronic edition)

Printer Rotofrance • Lognes, France
Dépôt légal: Août 2009

OPEN ACCESS – EVERYTHING FOR FREE?

Scientific publishing isn't what it used to be. Or is it? Some things have changed, but how fundamental have these changes been, or how fundamental should they be?
A common opinion among physicists is that "reading scientific articles should be for free". However, just as there are no free lunches, scientific publishing will never be for free. Trustworthy systems for peer review and for archiving are adamant. Publication costs are to a great extent generated by the editorial process, independent of the publication form. A change of a business model does not necessarily lead to lower costs for production or distribution.
The advent of Internet and electronic media has certainly had an impact. When we need a scientific article, we rarely go to the library these days; we get it off the Internet. What has not changed so much is that a vast majority of journals are still based on peer review. Non-peer-review electronic archives, or self-archiving, are mainly seen as complements, facilitating access. Another thing that has not changed so much is that most of scientific publishing is still financed by business models based on paid subscriptions.
Open access as a social movement has very early roots, but it mainly gained momentum with the development of the Internet. Physics as a subject has been at the forefront, with self-archiving at arXiv.org starting already in 1991, and now being well established in the physics community. But open access *can* reach further than voluntary self-archiving. A wide spectrum of suggestions have emerged, including making the electronic archiving compulsory, and also totally new business models, where the publications are not financed by traditional subscriptions. For example, a few journals offer the possibility of free reading to everybody if the author pays for the publication of his/her results ("author pays").
The opinions about Open Access are many and widely differing, among scholars, publishers and librarians, and stated opinions are sometimes one-sided and not always well informed. The Executive Committee of EPS has decided to take its position in a paper on Open Access, where minimum criteria for scientific publishing are indicated, in order to safeguard the scientific quality of the publications.
The so-called Berlin declaration states that, *e.g.*, scientific results should be made as accessible as possible to as wide an audience as possible, regardless of the financial strength of the reader. EPS is in favour of this general objective and supports the Berlin declaration. Going a step further, EPS insists on maintaining and nurturing mechanisms for the upkeep of scientific quality, which in practice means peer review systems.
EPS does endorse posting of published scientific papers on freely accessible electronic archives.
EPS is not in favour of a shift of the entire scientific publication industry towards a business model where the publication of results has to be paid for. In such an environment, journals would have conflicting incentives in terms of maintenance of scientific quality. Accepting fewer papers would give higher prestige and higher quality, but accepting more would give a better cash flow. No convincing solution to this problem has yet been presented.
Novel solutions have to be found in order to create a just and sustainable business model for overall Open Access. The EPS Executive Committee has proposed a set of boundary conditions for this.
The full text of the EPS position paper is published on the EPS webpage (free of charge!). ■

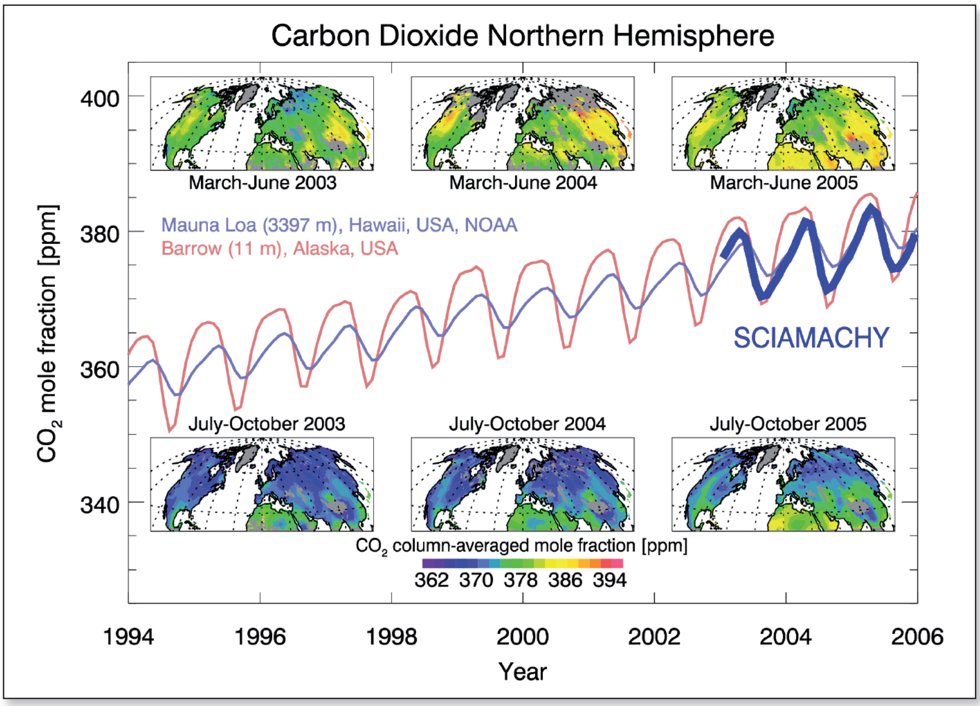
Anders Kastberg and **Martina Knoop**,
Members of the Executive Committee of the EPS

ENERGY AND ENVIRONMENT "THE INTIMATE LINK"

Public opinion recognizes the intimate link that exists between energy production and environmental change. Over the past few years, politicians have been converted and business people compete to demonstrate their green credentials. Environmentalism has also become a moral issue with church leaders taking position. The question is how to convert this new enthusiasm for reducing anthropogenic modification of System Earth into action.

The EPS, some time ago, launched its Energy Working Group, which has produced a number of position papers to provide answers from the physics point of view. The Environmental Physics Division (EPD) recently issued a position paper [1] considering the environmental effects of energy production, and arguing the need for sustained monitoring of greenhouse gases and air pollutants, in particular the monitoring from space to provide the global picture. Furthermore, the paper discusses topical issues such as geo-engineering, which it meets with scepticism and nuclear power, which is greeted with pragmatism. Bio-fuels are not seen as a panacea to global warming, rather the opposite, since the fertiliser required for efficient growth releases the much more potent greenhouse gas nitrous oxide.

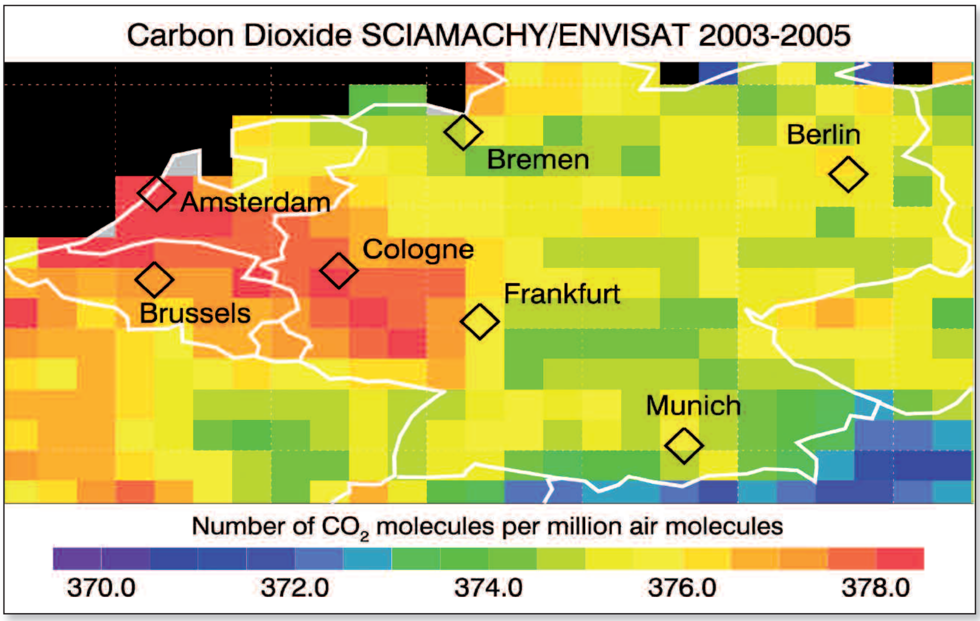
The IPCC 4th Assessment Report (AR4) is quite clear in attributing identified climate change to the use of fossil fuels. The response of the Earth System to the current and future changes, however, is poorly understood and this is reflected in the wide range of the estimates in the rise of Earth surface temperature. Recent modelling work is showing that the lack of understanding of the response of the land surfaces to the changing climate makes our knowledge of the response of the system even poorer than at the time of AR4. Key scientific questions with respect to the long lived greenhouse gases concern our understanding of the release and uptake of CO_2 in the terrestrial biosphere, the release of CH_4 from wetlands, permafrost (clathrates) etc., and the fluxes of N_2O associated with the use of fertiliser and natural processes. The response of the uptake of CO_2 in the ocean is also of great significance.



▲ **FIG. 1: Seasonal variation of carbon dioxide (total dry column amount) over the Northern hemisphere measured by SCIAMACHY. Comparison with ground-based measurements at Mauna Loa and Barrow shows good agreement. The reflectivity over the oceans is not high enough to produce sufficient signal to noise for the solar photon absorption measurements. Source: Michael Buchwitz, University Bremen, Germany.**

Challenge in measuring greenhouse gases from space lies in the difficulty to separate the troposphere from the stratosphere and the mesosphere and to obtain sufficient accuracy in boundary layer to retrieve emissions. A vertical profile of the mixing ratio of CO_2 and CH_4 in the lower troposphere would be very valuable but as yet no simple method from space has been shown to be feasible. Small changes in the dry column-mixing ratio of these gases, however, are amenable to measurement. Their temporal and regional variations test our understanding of the carbon cycle by constraining the size of the sources and sinks of CO_2 and CH_4.

Pioneering experiments carried out on SCIAMACHY [2], a German-Dutch-Belgian grating spectrometer on board the European Space Agency satellite ENVISAT, initiated this type of measurement in 2002 and have continued since, see Figures 1 and 2. These successful first attempts have their limitations. In part, these relate to the availability of space qualified infrared detectors at the time of instrument development now 20 years ago. New 2D detector array technology will enable significant advances to be made in measurement precision and spatial resolution. Immersed grating technology yields a compact instrument modest in satellite resources. Normalising the solar photons absorbed by CO_2 in the atmosphere around 1.6 µm by the well-mixed oxygen A-band absorption around 0.8 µm yields the dry column. The O_2 triplet sigma transition at 1.3 µm needs investigation to provide a better proxy for atmospheric scattering. Improving the spectral resolution of the measurements compared with SCIAMACHY enables the small differences in the path of light through the atmosphere induced by the scattering by aerosol and clouds to be removed, thus improving measurement precision.



▲ **FIG. 2:** CO_2 over Europe showing industrial emissions. Source: Schneising *et al.*, Atmos Chem Phys, 2008.

The European GMES programme (Global Monitoring for Environment and Security) supports a network of satellites, Sentinels, and ground based systems to provide sustained global monitoring of a wide range of geo-physical parameters. GMES Sentinels for atmospheric composition include a geo-stationary satellite at 36.000 km distance from Earth producing a picture over Europe once every half hour and a polar-orbiting sun synchronous satellite at 800 km distance covering the entire globe approximately once per day. These Sentinels will not become operational before 2020 and it is not clear whether the optimal measurements for CO_2 and CH_4 will be within the scope of the overall satellite payload, the latter being driven by the requirements for numerical weather prediction. ENVISAT, with a 5-year operational lifetime has already passed its best-before date.

The recently launched Japanese GOSAT also has a limited life and sadly, the NASA Orbiting Carbon Observatory launch failed. Thus, a data gap is looming for most greenhouse gases, whilst CO_2 is not covered at all.

Improved global measurements of CO_2 and CH_4 are therefore needed for the period 2012 and beyond for good scientific and societal reasons. There is also a strong strategic case for Europe to produce their own CO_2 and CH_4 data products from their own instruments. In order to be effective in the post-Kyoto era, European leadership can only be assured by an independent treaty monitoring and verifying capability. It is not wise to rely on the excellent efforts of partners in America or Japan. Europe is one of the major sources of anthropogenic pollution. Europe has also been a major source of chlorofluorocarbons and other compounds, which ▮▮▮

destroy stratospheric ozone. The provision of an independent capability was one important reason for proposing and developing an independent ozone monitoring instrument GOME, a SCIAMACHY derivative, flying on the ESA ERS-2 satellite, now succeeded by operational instruments on the EUMETSAT meteorological satellites. These have proved prudent investments without which Europe (and the world) would have been without global ozone monitoring capability addressing key aspects of the Montreal Protocol on substances that deplete stratospheric ozone. The same logic holds true for CO_2. The technology is available, with improved instrumentation compared with SCIAMACHY, which has demonstrated feasibility. Knowledge is advanced by the experiment-theory cycle. The second recommendation of the EPD position paper is to explore new avenues in climate modelling. Current models rely on the hydrodynamic approximation assuming a Maxwellian velocity distribution of the atmospheric molecules. However, the atmosphere is never in equilibrium being continuously stirred by the solar beam and the Earth rotation and therefore a Maxwellian velocity distribution does not exist. Deviations need to be accounted for in the calculation of spectral line shapes and chemical reaction rates, and the interaction between particle streams and atmospheric waves will change behaviour.

Hence, the EPS-Environmental Physics Division recommendation is:

- Europe needs a CO_2 and CH_4 measurement satellite with precision modellers require (polar orbit, passive near infrared nadir sounder of CO_2, CH_4 and O_2 dry column amounts at 20×20 km^2 ground resolution)
- Theoretical climate modelling needs to include non-thermal effects in the calculation of rate coefficients and line shapes and in the interaction between particle streams and atmospheric waves. ■

Adelbert P.H. Goede[1] and **John P. Burrows**[2],
[1] FOM Institute for Plasma Physics Rijnhuizen, 3430BE Nieuwegein, the Netherlands
[2] Centre for Ecology and Hydrology, Wallingford, Oxon OX10 8BB, United Kingdom

References

[1] *Energy and Environment, "The Intimate Link"*, a position paper of the EPS Environmental Physics Division, EPS, February 2009. See: www.eps.org/about-us/position-papers/about-us/position-papers/eps_energy_environment_pp.pdf

[2] A.P.H. Goede J.P. Burrows and M. Buchwitz, *Global mapping of greenhouse gases and air pollutants, EPN* **38/6** pp. 26 (2007).

CONFERENCES, EVENTS & PRIZES

ECOSS 26
The 26th European Conference on Surface Science will be held in Parma, Italy, 30 August-4 September 2009.

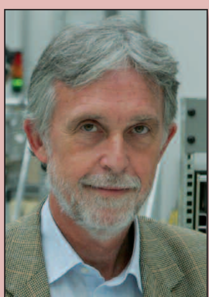
▶ Website:
www.ecoss26.eu

CCP 2009
The International Conference on Computational Physics 2009 will be held from 15 - 19 December 2009 at Grand Hi-Lai Hotel, Kaohsiung No. 266, Cheng-Kung 1st Rd., Kaohsiung, Taiwan 801.

▶ E-mail:
ccp2009@elitepco.com.tw

Honoris causa Doctorate
Europhysics News compliments Professor Franck Steglich, Founding Director of the Max Planck Institute for Chemistry and Physics of Solids in Dresden (Germany), who has been awarded the title of Doctor Honoris Causa of the Jagiellonian University in Krakow (Poland) on 18 November 2008.

2009 IBA-Europhysics Prize for Applied Nuclear Science and Nuclear Methods in Medicine
The European Physical Society (EPS), through its Nuclear Physics Board (NPB) awards a Prize, sponsored by Ion Beam Applications (Belgium), every second year to researchers who have made outstanding contributions to Applied Nuclear Science and Nuclear Methods and Nuclear Researches in Medicine. Such contributions represent the breadth and strength of this field in Europe.
The 2009 IBA-Europhysics Prize is awarded to Prof. **Pier Andrea Mandò** (Department of Physics, University of Florence and INFN) for outstanding and seminal contributions to the application of the Ion Beam Analysis techniques in the field of Cultural Heritage studies, favouring the birth of a new interdisciplinary research area that brings together scientific and humanistic skills.



TCXIV on SCS
The 15th Training Course in the Physics of Strongly Correlated Systems will be held at the International Institute for Advance Scientific Studies (IIASS), Vietri sul Mare (Salerno), Italy, October 5-16 2009.

▶ E-mail:
srusso@sa.infn.it

Future Perspectives in Superconductivity and Josephson Effect
To celebrate the 70th birthday of Prof. Antonio Barone, an international meeting on Future Perspectives in Superconductivity and Josephson Effect will take place in Naples (Italy) on September 29, 2009.

▶ Website:
http://baronebirthday.fisica.unina.it

HOW TO GET AN ERC ADVANCED GRANT ?

The European Research Council has released results of the first competition for Advanced Grants in November 2008. Out of 2167 applications covering all branches of science the ERC selected for financing 275 grants, which gives a 12.7% success rate.
Proposals in the group Physical Science and Engineering (PE) were evaluated by one of 9 panels of experts, two of which where devoted to physics: PE2 - Fundamental constituents of matter and PE3 - Condensed Matter Physics.

In spring 2008 I took part in evaluation of the proposals in physics as a member of the PE-2 panel. A preliminary verification of all applications with respect to formal issues was performed by the ERC experts. The vast majority of applications passed this test and were distributed among all members of the panel. In the first phase every application was evaluated by at least four experts.
Every member of our panel had to evaluate 30-40 applications and was asked to evaluate on a scale from 0 to 4 points a) scientific achievements of the principal investigator and b) quality of the research project. The sum of both scores was used to create the first ranking list of all projects.
In general both scores were independent, but in practice their occurrence appeared to be correlated: the final position at the ranking list depended strongly on the scientific CV of the principal investigator. During the first three-day meeting of the panel in Brussels each proposal was presented by a lead reviewer and discussed in detail. About one third of the best applications were retained for further evaluation.
In the second phase these applications were also evaluated by external referees nominated by the panel. During the second meeting of the panel the financial part of each application was considered. These issues could influence the total budget of the project endorsed by the panel, but they did not have much impact on the position of the application on the final ranking list of applications, according to which the ERC was awarding the grants..
The list of successful applicants in both physics panels, published by the ERC website, is presented in Table 1 of the web version of this article (link to be provided by the author: karol@tatry.if.uj.edu.pl). Any reader knowing the main actors of the European physicists' scene can verify if he agrees with the statement that the *Advanced Grants* were awarded to the leaders in our field.

Every applicant had to choose his 10 best publications published in the recent decade and add how many times each of these papers were cited in the literature. The total number L of these citations describes well how the scientific community perceives their recent achievements. These numbers were provided by the ERC in the dossier of every applicant.
However, during the evaluation process the panel did not put much emphasis on any bibliometric data. It was the opinions of

▼TABLE:
Mean number of publications, citations, counting articles without citations and the h-index computed for the laureates of the 2008 ERC AdG for Physical Science and Engineering panels.

Panel	Name	papers	citations	no auto	index h
	Physical Sciences & Engineering				
PE1	Mathematical foundations	29	281	141	9
PE2	Fundamental constituents of matter	106	4192	2148	30
PE3	Condensed matter physics	109	2357	1253	23
PE4	Physical & Analytical Chemical sciences	137	4051	2248	33
PE5	Materials & Synthesis	254	5782	3735	38
PE6	Computer science & informatics	55	564	262	10
PE7	Systems & communication engineering	51	949	384	15
PE8	Products & process engineering	55	503	242	12
PE9	Universe sciences	125	4039	2162	33
PE10	Earth system science	92	1514	910	21

the experts which did matter, not the bare numbers. Only after completing the evaluation process, I realised a correlation between these data and the final outcome. For instance, the median number L among all 117 applications evaluated by the PE-2 panel was equal to 384, the median for the group of 33 proposals in the second phase was equal to 853, while it amounts to 1326 for the group of 14 winning proposals.

To make a reasonable use of the parametric data, one needs to rescale them according to some average values in a given field, since the mean values of publications and citations depend on the branch of science and even its sub-field. As a rule of thumb, one can only say that the chances for the final success of a physicist are not large unless he can select ten of his papers written during the last decade which were cited in total a *few hundred times* and his scientific achievements are well known outside his narrow sub-field of physics.

Such a preliminary condition will be different in other fields, but for any scientist it could be useful to compare his record with the data characterising the group of 2008 Advanced Grant laureates. For every successful applicant, we found in the *ISI Web of Knowledge*[1] their number of publications, number of citations and their Hirsch *index*[2] and computed the median for each panel. These data, presented in Table, reflect large differences between various branches of science.

In conclusion, the quality of the best applications for the ERC Advanced Grants was very high, at least in the PE-2 panel. To have a fair chance to obtain such a grant the potential applicant has to:

1. prepare his application precisely according to the formal criteria provided by the ERC,
2. produce a very good research proposal written in a clear way. On the one hand, it should satisfy the experts in the field, but on the other hand it has to be understandable for other members of the panel,
3. demonstrate an outstanding scientific CV which allows the experts to consider him as one of the leaders in the field. Not only his bibliometric parameters should be far above the average in his specialisation, but his achievements should be widely known and appreciated. ■

Karol Zyczkowski,
Jagiellonian University,
Cracow, Poland

note

[1] These data were taken for the 1996-2008 time range comparable with the 10 years time window used in ERC applications.

[2] Hirsch index of a scientist is equal to *h* if he has at most *h* papers each of which was quoted at least *h* times.

2009 QEOD* PRIZES

* QUANTUM ELECTRONICS AND OPTICS DIVISION OF THE EPS

EPS-QEOD prize ceremony was awarded at CLEO®/Europe–EQEC 2009 in Munich, Germany

EPS Quantum Electronics Prize for Fundamental Aspects

The EPS QEOD Prize 2009 for fundamental aspects is awarded to **Alain Aspect** (CNRS, Institut d'Optique Graduate School, Palaiseau, France and École Polytechnique, Palaiseau, France). It recognizes his numerous pioneering contributions to the fields of quantum and atom optics, including his seminal experiments in 1982 that confirmed the counterintuitive nature of quantum entanglement and that paved the way to the modern research in quantum information.

EPS Quantum Electronics Prize for Applied Aspects

The EPS QEOD Prize 2009 for applied aspects is awarded to **Thomas Ebbesen** (University of Strasbourg, Strasbourg, France). It recognizes his pioneering contributions to surface plasmon photonics including the discovery of the phenomenon of extraordinary optical transmission.

Fresnel Prize for Fundamental Aspects

The Fresnel Prize 2009 for fundamental aspects is awarded to **Tobias Kippenberg** (Max-Planck-Institut für Quantenoptik, Garching, Germany, and Swiss Federal Technical Institute Lausanne (EPFL), Switzerland). It recognizes his original and fundamental contributions to the field of cavity optomechanics with the aim to observe fundamental predictions of quantum measurement theory.

Fresnel Prize for Applied Aspects

The Fresnel Prize 2009 for applied aspects is awarded to **Romain Quidant** (ICFO-Institut de Ciències Fotòniques, Castelldefels, Barcelona, Spain). It recognizes his contributions to the field of plasmon optics and particularly for his groundbreaking and pioneering research into the concept of plasmon-based optical manipulation.

QEOD Thesis Prizes for Fundamental Aspects

- **Fernando G.S.L. Brandao** (Imperial College, London, United Kingdom), for research in quantum information theory (thesis at Imperial College).
- **Alexei Ourjoumtsev** (Max-Planck-Institut für Quantenoptik, Garching, Germany), for research on novel quantum states of light (Thesis at the Institut d'Optique Graduate School/ University Paris XI, France).

QEOD Thesis Prize for Applied Aspects

- **Deran Maas** (ETH, Institute of Quantum Electronics, Zurich, Switzerland), for research into novel pulsed semiconductor lasers (thesis at ETH Zurich Switzerland).
- **John C. Travers** (Imperial College London, UK), for research on optical fibre super-continuum generation (thesis at Imperial College London, United Kingdom). ■

pictures

1 A. Aspect
2 T. Ebbesen
3 T. Kippenberg
4 R. Quidant

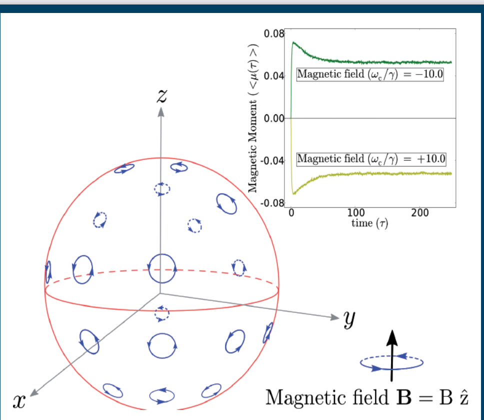
Is Diamagnetism possible classically?

In a diamagnetic material the induced magnetisation is directed opposite to the external magnetic field. Physically, consistent with the Lenz's law, such a response is expected for the classical motion of a charged particle under the Lorentz force of the magnetic field that acts perpendicular to the velocity, and does no work. This appealing picture was argued to be invalid by Bohr: the effect of the completed orbits (bulk effect) is exactly cancelled by that of the incomplete orbits at the boundary, in the opposite sense (surface effect). This absence of classical diamagnetism was supported through statistical mechanics by van Leeuwen – Bohr-van Leeuwen theorem – implying that the observed diamagnetism is quantum mechanical.

This subtle role of the boundary is revisited by considering the motion of a charged particle *in a finite but unbounded system*, the surface of a sphere, through the classical Langevin dynamics. Inasmuch as the closed surface of the sphere has no boundary, a non-zero classical orbital diamagnetic moment is expected. This *avoided cancellation* is supported by our numerical simulation of the random particle motion as governed by the Langevin equation: the computed average magnetic moment is indeed non-zero in the long-time limit (Fig.). The limitting velocity distribution, however, remains Maxwellian as in equilibium. A finite but unbounded essentially classical system with avoided cancellation can be realised as an ultra-thin conducting shell around an insulating core in the limit of low carrier concentration. The temperature has to be low enough so that the thermal de Broglie wavelength is much larger than the shell thickness.

Assuming that the Langevin dynamics does describe equilibrium, classical diamagnetism appears to be possible and realisable. ■

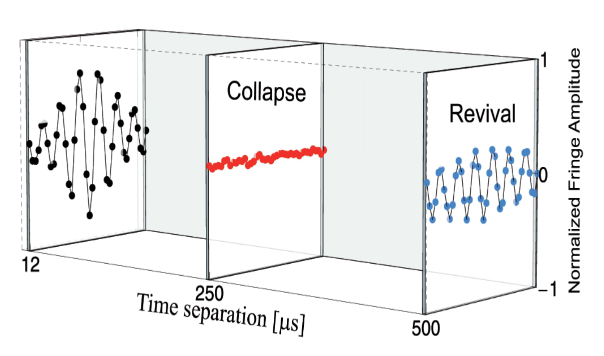
N. Kumar and **K. Vijay Kumar**,
'Classical Langevin Dynamics of a charged particle moving on the surface of a sphere and diamagnetism: A surprise', *EPL* **86**, 17001 (2009).



▶ Schematic of orbits on a sphere where cancellation is avoided. Graph shows magnetic moment vs. time

Collapse and revival of **Ramsey fringes**

Quantum non-demolition measurements on trapped ensembles of atoms can engineer non-classical collective states. An understanding of decoherence mechanisms for such schemes is obviously of crucial importance.



▲ Echo spectroscopy Ramsey fringes as a function of the time separation between two light pulses around the echo pulse.

Using off-resonant laser light with a Gaussian intensity profile, the decoherence and dephasing inflicted on trapped Cs atoms in a coherent superposition of the two clock states have been investigated at the Niels Bohr Institute, Copenhagen. A clear manifestation of atomic motional dynamics was observed in echo spectroscopy on the clock transition. The oscillatory movement of particles implies that the spatially varying ac Stark shifts from two identical light pulses create atomic phase imprints, which generally do not cancel completely when applying an in-between Hahn echo pulse. Rather, the echo fringe amplitude - a measure of the remaining coherence - decreases with increasing light pulse separation.

However, a striking fringe revival at a separation of half a trap oscillation period highlights the intimate connection between the dynamics of internal and external degrees of freedom: An atom samples the same light intensity during the first and second pulse and thus the Hahn echo can rephase the ensemble.

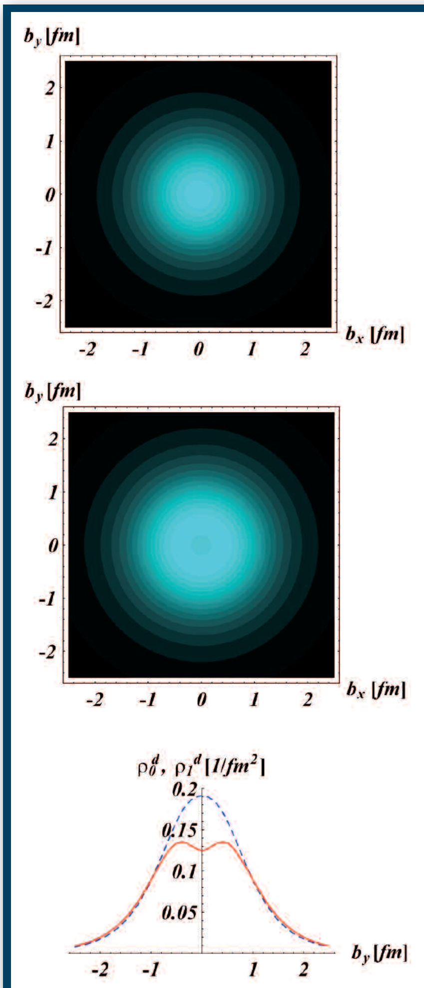
Recognizing these dynamical effects is important for a correct determination of irreversible decoherence. Moreover, they lead to a time dependence for the correlation between consecutive non-demolition measurements on an ensemble. ■

D. Oblak, J. Appel, P.J. Windpassinger, U.B. Hoff, N. Kjærgaard and **E.S. Polzik**,
'Echo spectroscopy of atomic dynamics in a Gaussian trap via phase imprints', *Eur. Phys. J. D* **50**, 67 (2008).

Charge densities in polarized deuterons

The study of the space distribution of quarks inside hadrons is a fundamental issue in hadron physics. This paper tackles the problem of extracting information on the spatial distribution of the quark charges inside longitudinally and transversely polarized deuterons, in a model independent way, exploiting available experimental information on the electromagnetic form factors. The authors develop a general formalism for spin-1 particles and apply it to the deuteron; a formalism for the nucleons had been presented previously.
The results are very interesting; in the figure it is shown the quark transverse charge density for longitudinally polarized deuterons, with helicity 1 (upper panel) and 0 (middle panel). The lowest panel compares the two cases (for the density along the y-axis), showing how the charge density for zero helicity states exhibits a dip at the center of the deuteron. ■

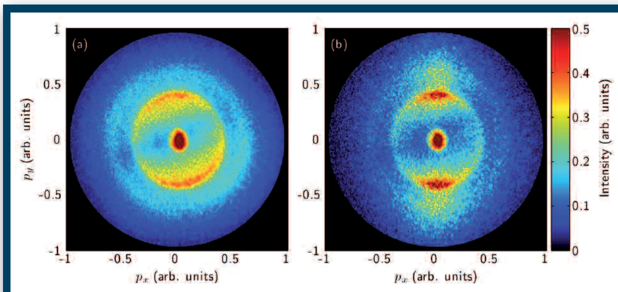
C.E. Carlson and **M. Vanderhaeghen**, 'Empirical transverse charge densities in the deuteron', *Eur. Phys. J A* **41**, 1 (2009).



◄ Quark transverse charge density for longitudinally polarized deuterons, with helicity 1 (upper panel) and 0 (middle panel). The lowest panel compares the two cases, for the density along the y-axis.

Field-free molecular alignment robed by FLASH

One of the main driving forces behind the development of high-flux extreme ultraviolet (XUV) and x-ray free-electron lasers (FELs) is the possibility to perform diffractive imaging of small objects. One of the prospects of x-ray FELs is to image isolated bio-molecules by reconstruction starting from single-shot photon diffraction patterns. Alternatively, one may employ diffraction of electrons emitted as a result of photo-ionization by the FEL as a probe of molecular structure. Due to the shorter electron wavelength, this will allow for Ångström resolution already at the XUV FEL sources available today, like the FEL in Hamburg (FLASH).
In molecular imaging experiments, it is required that the measurements are done in the molecular frame, meaning in a coordinate system that is fixed with respect to the molecular axis. This can be done by aligning the molecules in the laboratory frame prior to doing the experiment. In a first proof-of-principle experiment we have demonstrated laser-induced molecular alignment at FLASH. A femtosecond infrared laser pulse that was precisely synchronized to FLASH was used to create an aligned sample of CO_2 molecules, and 46 eV photons from FLASH were used to doubly photo-ionize the molecules, leading to a rapid fragmentation by means of a Coulomb explosion. A velocity map imaging spectrometer was used to record the momentum distributions of the O^+ fragments, allowing to deduce the degree of alignment from their angular confinement. Importantly, the alignment was achieved both while the infrared alignment laser was present and subsequently, at regular intervals, under field-free conditions, the latter opening up possibilities for future experiments on time-resolved molecular imaging in the molecular frame. ■



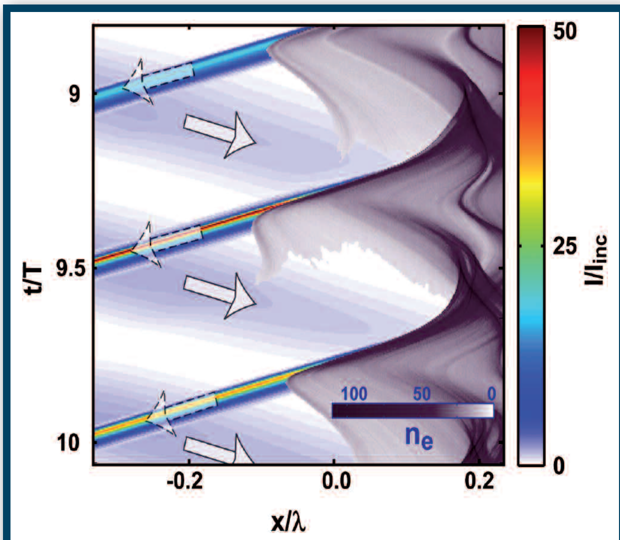
▲ O^+ fragment distributions from a randomly aligned (a) and an aligned (b) sample of CO_2. The outer ring corresponds to the Coulomb explosion channel.

P. Johnsson, **A. Rouzée**, **W. Siu**, **Y. Huismans**, **F. Lépine**, **T. Marchenko**, **S. Düsterer**, **F. Tavella**, **N. Stojanovic**, **A. Azima**, **R. Treusch**, **M.F. Kling** and **V.L.M.J.J. Vrakking**, 'Localized states and interaction induced delocalization in Bose gases with disorder', *EPL* **85**, 30002 (2009).

Towards intense **attosecond pulses**

We show that "zero-cycle" (with zero carrier frequency) attosecond pulses can be efficiently generated in reflection from a solid target surface without any additional spectral filtering. The key-point is to use two-beam (driver and probe) surface high order harmonic generation. The high intensity driver beam excites a periodic motion of the target surface with relativistic velocity. The attosecond pulses are produced upon reflection of the probe from the oscillating surface (Fig.). The new quality brought about by the two-beam scheme is based on: (i) more gentle harmonic spectrum roll-off with larger effective bandwidth; (ii) constant (or equivalent to constant) harmonic spectral phases. Moreover, the probe waveform is not only efficiently compressed to attosecond spikes, but also experiences a significant relativistic amplification. In a single-beam case on the contrary such amplification is not possible and the attosecond pulses have to be synthesized from the reflected radiation with enormous energy losses. We present the results of first experiments using two beams for high order harmonic generation. ■

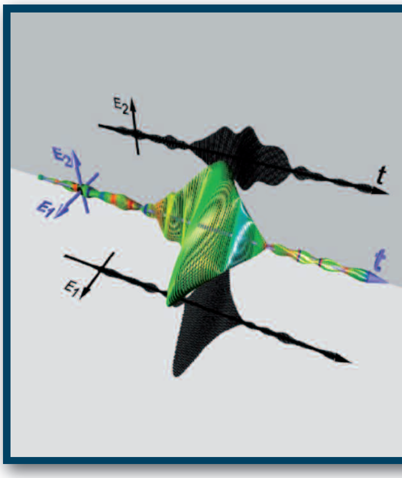
A.P. Tarasevitch, **R. Kohn** and **D. von der Linde**, 'Towards intense attosecond pulses: Using two beams for high order harmonic generation from solid targets', *J. Phys. B: At. Mol. Opt. Phys.* **42**, 134006 (2009).



▲ Particle-in-cell simulation of the probe pulse reflection. The plasma electron density oscillations $n_e(x,t)$ (gray-scaled) are induced by the driver wave (not shown). The normalized intensity of the probe wave $I(x,t)$ is color-coded. The wave propagates from the left to the right and is reflected from the oscillating surface. Upon reflection the waveform is compressed to sharp spikes of much higher intensity.

Twisting ultraviolet femtosecond pulses

Femtosecond (fs) laser pulses are versatile tools in physics, chemistry, and biology, due to their shortness and spectral bandwidth. The different colors contributing to a fs pulse can be governed with the help of conventional pulse shapers, which allow a change of the intensity and/or phase of each frequency component, thereby also changing the temporal shape of the laser pulse. This tailoring is exploited in fs quantum control, where the outcome of a photochemical reaction is selectively modified via the pulse shape.



◀ Measured polarization-shaped UV pulse at a central wavelength of 400 nm in a quasi-3D electric-field representation in the time domain: the pulse starts out linearly polarized, changes to elliptical, and ends again linearly polarized. The shadows show the amplitudes in two orthogonal polarization directions. Colors indicate different frequencies.

The temporal response of molecular systems in light-matter interactions is generally not a scalar function. It is therefore desirable to also vary the direction of the electric field vector on an ultra-fast time scale. While optical components like wave plates change the polarization state of the laser pulse statically, a fs polarization pulse shaper can change the polarization within the pulse in a programmable way, enabling enhanced control of *e.g.* chemical reactions or nanostructure near-field distributions.
Despite many advances in this active research field, polarization-shaped laser pulses have never been demonstrated in the UV regime. We have now developed an experimental concept for the indirect generation of polarization-shaped fs laser pulses in the UV. By frequency-doubling polarization-shaped laser pulses in an interferometrically stable setup comprising two perpendicularly-oriented nonlinear crystals, UV pulses with twisted polarization can be created in a well-defined way. The method has many prospective applications aimed at achieving optical control of photoreactions. ■

P. Nuernberger, **R. Selle**, **F. Langhojer**, **F. Dimler**, **S. Fechner**, **G. Gerber** and **T. Brixner**, 'Polarization-shaped femtosecond laser pulses in the ultraviolet', *J. Opt. A: Pure Appl. Opt.* **11**, 085202 (2009).

Dynamical stability with **long-range interactions**

Systems with long-range interactions have the remarkable property to organize spontaneously into large-scale coherent structures. These quasi-stationary states (QSS) correspond to galaxies in the universe and vortices in two-dimensional turbulence. In many physical situations, the collisional relaxation time is huge so these QSS are not Boltzmannian equilibria. In fact, they result from a violent collisionless relaxation and they are steady states of the Vlasov equation on some coarse-grained scale.

On general grounds, it is important to study the dynamical stability of steady states of the Vlasov equation. This problem was first considered in plasma physics where the interaction between charges is repulsive. A powerful method to determine the linear stability of a spatially homogeneous distribution function *f(v)* has been devised by Nyquist (1932). To apply the Nyquist method, we just have to plot the hodograph of the dielectric function. If this curve encircles the origin then the system is unstable, otherwise it is stable. The number of tours gives the number of unstable modes. From this graphical method, one can prove very simply that the Maxwellian distribution is always stable in a plasma.

For attractive interactions, the sign changes and the Nyquist curve is reversed. To illustrate the Nyquist method for attractive interactions, we have considered the Hamiltonian Mean Field (HMF) model. This is a one dimensional model in which the particles interact via a cosine potential. This model shares many analogies with self-gravitating systems but is simpler to study (self-gravitating systems are generally spatially inhomogeneous precluding the application of the Nyquist method). In that case, the Nyquist method shows that a Maxwellian distribution becomes unstable below a critical temperature T_c. We have performed an exhaustive study of more complex distributions leading to rich stability diagrams. ■

P.H. Chavanis and **L. Delfini**, 'Dynamical stability of systems with long-range interactions: application of the Nyquist method to the HMF model', *Eur. Phys. J. B* **69**, 389 (2009).

Correlation Matrices for Optical Beams

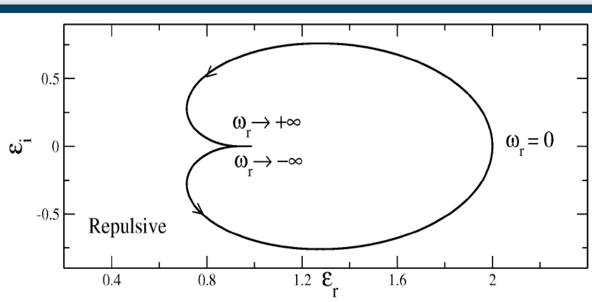
After the 1850s, Stokes initiated the polarization optics and Verdet first estimated the coherence area of sunlight. Since then, the descriptions of polarization and coherence properties of light beams were developed independently. Strange as it may sound to many, it became clear only recently that these two phenomena are strictly intertwined and have to be studied within a single theory, namely, correlation theory of the optical electromagnetic field.

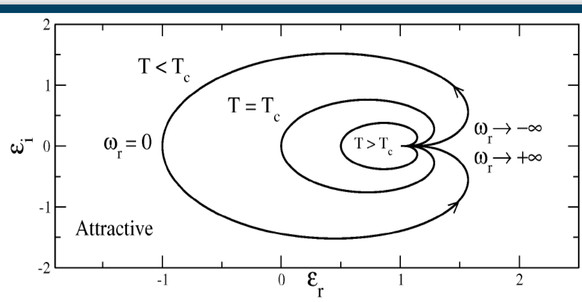
From the mathematical standpoint, the basic tool to investigate coherence and polarization is a 2×2 correlation matrix, whose elements are functions of two space points. Unfortunately, such functions cannot be chosen at will because the correlation matrix has to be endowed with the mathematical property of non-negative definiteness. In most cases, assessing whether an assigned correlation matrix is non-negative definite or not is a formidable task. As a consequence, the models adopted up to now for describing coherence and polarization of optical beams belong to a rather restricted class.

Resorting to the theory of reproducing kernel Hilbert spaces, we presented a rule for devising genuine correlation matrices, *i.e.*, matrices for which non-negative definiteness is guaranteed from the start. This newly established condition affords a safe guide for investigating new structures of the correlation matrix and permits us to find a number of electromagnetic sources/beams with very peculiar correlation properties. For example, it may happen that the *x* and *y* components of the field at two points P_1 and P_2 are well correlated if P_2 lies on the right of P_1 but completely uncorrelated if P_2 is on the left. As another example, cases exist for which the *x-x* and *y-y* correlations are those pertaining to a diverging beam, but *x-y* correlation behaves as in a converging beam. Our rule also suggests how new sources could be synthesized in the laboratory. ■

F. Gori, **V. Ramirez-Sanchez**, **M. Santarsiero** and **T. Shirai**, 'On genuine cross-spectral density matrices', *J. Opt. A: Pure Appl. Opt.* **11** (2009).

► Nyquist curve for repulsive and attractive interactions in the framework of the HMF model.

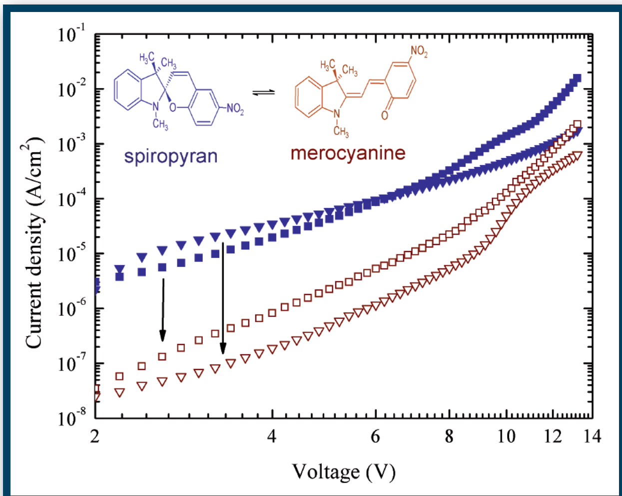




Carrier mobility switching in polymers

This paper reports on a switching device based on reversible modulation of charge carrier mobility by photochromic additive distributed in a polymer matrix. The light induced photochromic conversion of the additive is accompanied by significant increase of its dipole moment. The presence of the dipole moment induces a change of electrostatic potential in its vicinity and shifts the site energies of individual polymer repeating units. Since the position and orientation of the photochromic additive with respect to the polymer chain are essentially random the effect results in broadening of the distribution of the transport states and consequently in the lowering of the charge carriers mobility. These notions suggested by quantum chemistry modeling are proved by experimental characterization of the optical and electrical switching properties of the suggested switch. The observed current-voltage characteristics showed reversible decrease of the currents after the photochromic switching of the additive to its metastable state with high dipole moment. This behaviour was explained on the basis of charge carrier mobility decrease due to the presence of charge traps. Impedance spectroscopy revealed a drop of the bulk conductivity when the polar state of the photochromic molecules was present. The induced conductivity decrease is proportional to the drop observed by current-voltage characterization. ■

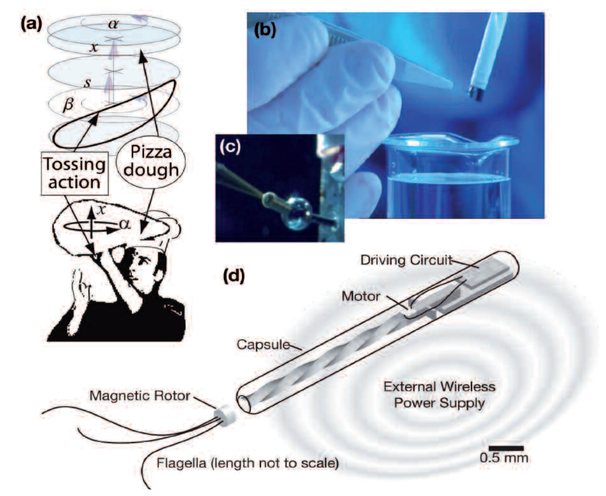
▮▮▮ **M. Weiter**, **J. Navrátil**, **M. Vala** and **P. Toman**,
'Photoinduced Reversible Switching of Charge Carrier Mobility in Conjugated Polymers', *Eur. Phys. J. Appl. Phys.* **48**, 10401 (2009).



▲ Light-induced decrease of the current of the MDMO-PPV doped by spiropyran for different concentration of the dopant: 5% (square) and 10% (triangle). The full symbols represents the j-V behaviour of the beginning state of the system (ON state), whereas the open symbols describe the state after the photochromic conversion (OFF state).

Physics of pizza tossing **for micro-motors**

Originally a simple pedagogical tool in explaining how our new micro-motors work, pizza tossing grew to become an integral part of our analysis once we realized that the analogy between the two systems was far more than coincidental. By using pizza dough in place of the rotor, and deriving and solving the strongly nonlinear equations describing the way the dough travels through the air, we were able to determine how much and how quickly the dough rotates, and the energy efficiency of the toss itself.



► The (a) physical representation of a pizza toss helps in the design of (b,c) micro-motors for (d) swimming micro-robots.

Briefly, if one tosses the dough one toss at a time–that is, if one tosses then catches–the hands should move in a helical fashion. If one tosses the dough continuously, not stopping its spin every time, then the hands should move continuously in circles. The model was developed to understand the contact dynamics within our 250-micron-diameter standing wave ultrasonic micro-motors (SWUMs), intended for propelling flagella in micro-robots to swim through the bloodstream, potentially revolutionizing future surgical procedures.
The hands tossing the dough represent the vibrating stator of the SWUM while the dough represents the rotor. The difference is only in the details: a chef tosses dough, about once a second, a few tens of centimeters into the air, while a SWUM tosses the rotor around a few million times a second a few hundred nanometers away from the stator. Until now, trial and error has been used to design such motors without an adequate understanding of the forces involved. ■

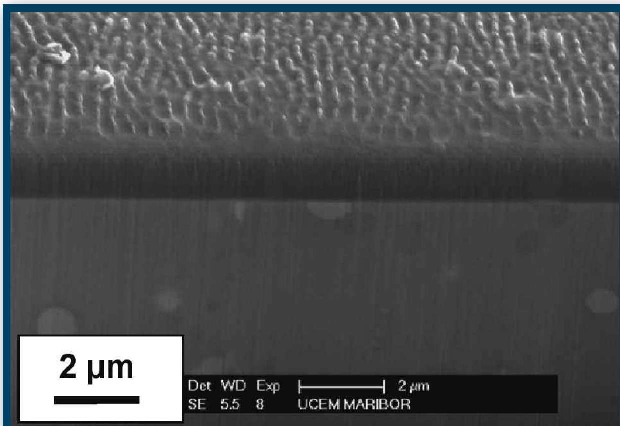
▮▮▮ **K-C. Liu**, **J. Friend** and **L. Yeo**,
'The behaviour of bouncing disks and pizza tossing.'
EPL **85** 60002 (2009).

TiAlN/TiN coatings **changed by laser pulses**

Tool steel pieces are often TiN coated to add hardness to the surface. Adding aluminium and forming (TiAl)N makes the coating even more attractive, due to enhanced oxidation resistance and mechanical properties. Multilayered (combined) coatings show even more advantages. However, due to the increased hardness and brittleness, mechanical micro-structuring becomes difficult, and using laser beams is one of the solutions. Lasers can also be used for surface nano-patterning in these cases.

We have investigated effects of two different pulsed lasers, a TEA CO_2 laser at 10.6 μm (100 ns pulse) and Nd:YAG laser at 532 nm (40 ps), irradiating a 2.17 μm thick multilayered TiAlN/TiN coating (40 layers) on H11 tool steel, at fluences around 12 J cm^{-2}. The effects were qualitatively similar, but quantitatively different. Coating ablation was produced by only 30 pulses of the Nd:YAG laser, but at least 660 pulses of the TEA CO_2 laser. At all pulse counts periodic surface structures were created on the coating, with periodicities very close to the laser wavelengths. They were observed even with one pulse of the Nd:YAG laser, and it was the only important feature produced at its lower fluence of 0.5 J cm^{-2}. At lower pulse counts these structures were observable in the centre of the irradiated zone, and at higher counts, when the centre undergoes damage, they were observed at the periphery, on the remaining coating. They were assumed to originate from the surface electromagnetic waves (SEW) created, because their periods strongly depended on the laser wavelength. ■

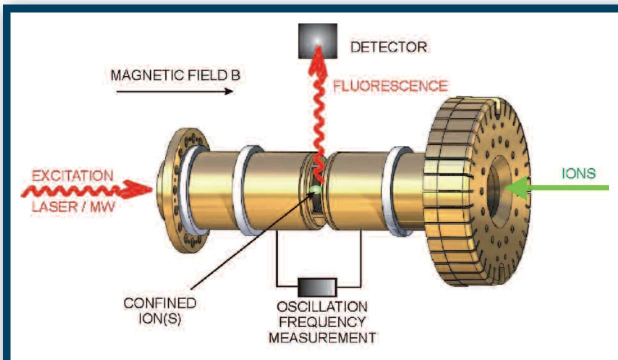
B. Gakovic, **M. Trtica**, **B. Radak**, **S. Petrovic**, **P. Panjan**, **M. Cekada**, **T. Desai** and **D. Batani**,
'Modification of multilayered TiAlN/TiN coating by nanosecond and picosecond laser pulses', *J. Opt. A: Pure Appl. Opt.* **11**, 015601 (2009).



▲ FIB cross-section of the damage with SEW induced periodic structures: they were only one period deep.

Spectroscopy of highly charged ions

We present novel methods for precision laser spectroscopy of highly charged ions by use of Penning traps. Confinement of ions in traps is most often motivated by the extended times available for investigations and the possibility to cool the trapped ions' motions nearly to rest, thus avoiding Doppler broadening of spectral lines. However, specific properties of the confinement itself may also be used for studies of intrinsic ion properties. We discuss a set of possibilities for high-precision spectroscopy of forbidden transitions in highly charged ions. Such measurements make stringent tests of bound-state quantum electrodynamics (QED) calculations possible and provide access to fundamental quantities such as the fine structure constant and nuclear properties of the ions.

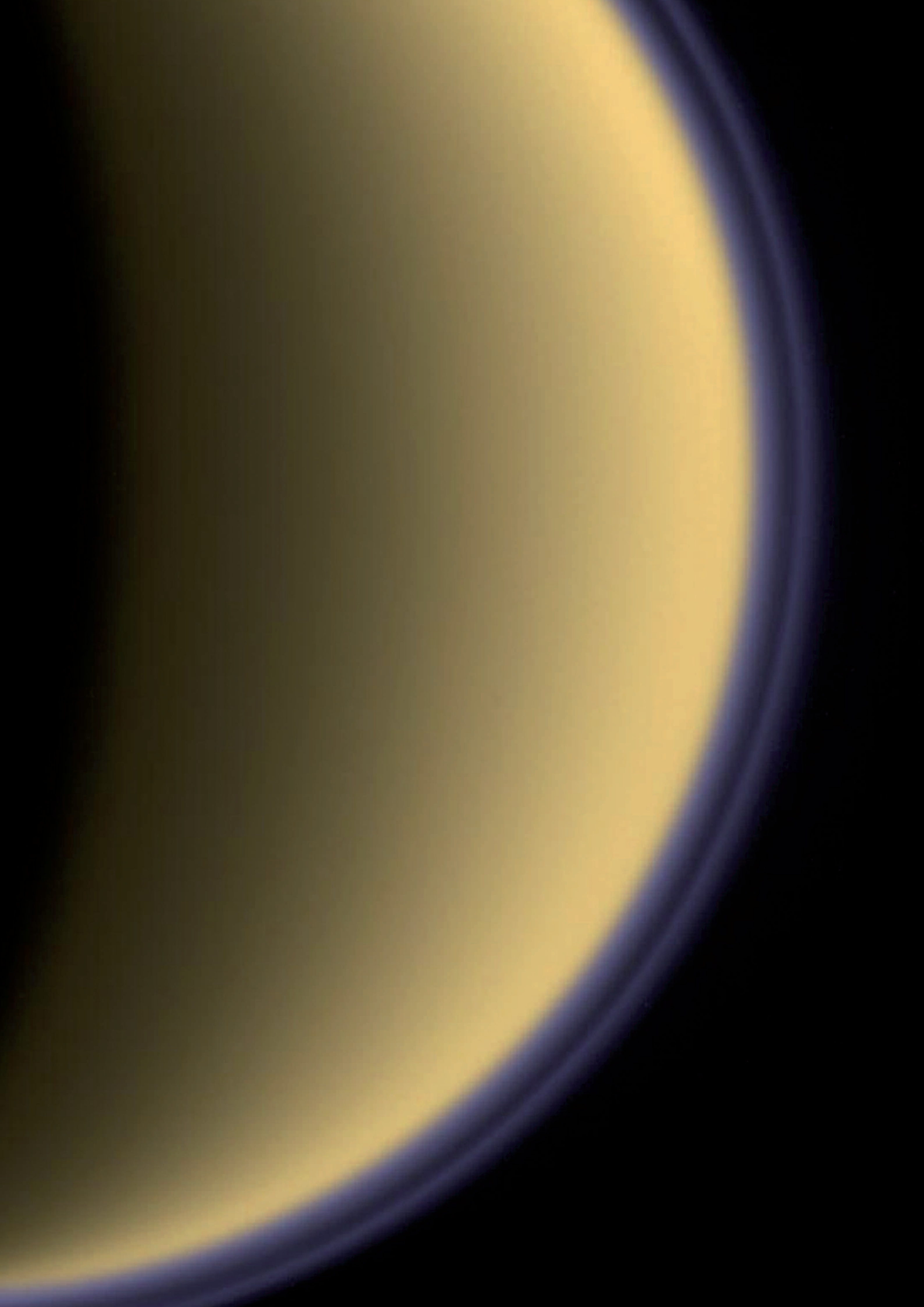


▲ Schematic view of a Penning trap for confinement and spectroscopy of externally produced ions.

The presented laser-microwave double-resonance technique uses the trapping-field-induced Zeeman splitting of hyperfine levels for a combination of laser spectroscopy with microwave spectroscopy. It opens up the possibility for a simultaneous and independent precision measurement of the bound electrons' and nuclear magnetic moments (g-factors) in the absence of any shielding effects and using only spectroscopic data.

The 'blind' spectroscopy makes use of a special combination of the confinement with an additional magnetic field superimposed to the trapping field. It allows a radiofrequency probing of the optical transition of interest. Consequently, it circumvents the need for optical detection (hence the name 'blind') and allows application to cases where detectors are unavailable. The obtainable relative accuracy lies beyond 10^{-10} which even allows to 'weigh' optical excitation due to the relativistic frequency shift. Since only a single ion is needed, it can furthermore be applied to rare ion species which are not readily available. ■

M. Vogel and **W. Quint**,
Trap-assisted precision spectroscopy of highly charged ions', *J. Phys. B: At. Mol. Opt. Phys.* **42**, 154016 (2009).



METHANE IN TITAN'S ATMOSPHERE:

FROM FUNDAMENTAL SPECTROSCOPY TO PLANETOLOGY[1]

Vincent Boudon[1], **Jean-Paul Champion**[1], **Tony Gabard**[1], **Michel Loëte**[1], **Athéna Coustenis**[2], **Catherine De Bergh**[2], **Bruno Bézard**[2], **Emmanuel Lellouch**[2], **Pierre Drossart**[2], **Mathieu Hirtzig**[2], **Alberto Negrão**[3] and **Caitlin A. Griffith**[4],

[1] Institut Carnot de Bourgogne – UMR 5209 CNRS-Université de Bourgogne, Dijon, France

[2] Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique, Observatoire de Paris-Meudon, Meudon, France

[3] Istituto di Fisica dello Spazio Interplanetario, Via del Fosso del Cavaliere, I-00133 Roma, Italie et Faculdade de Engenharia da Universidade do Porto, Porto, Portugal

[2] Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA

DOI: 10.1051/epn/2009601

The methane molecule (CH_4) is relatively abundant in the Universe and in particular in our Solar System. On Earth, it is the main compound of natural gas and is also the second greenhouse gas of anthropic origin. On Saturn's satellite Titan it plays a role similar to water on Earth and leads to a complex chemistry.

Methane is present in significant quantities in the atmosphere of various extraterrestrial objects: the giant planets of the Solar System (Jupiter, Saturn, Uranus and Neptune), but also Titan (satellite of Saturn), Triton (satellite of Neptune), Mars, Pluto and, further away, brown dwarves, some « cold» stars and giant exoplanets.

The principal method for the determination of the chemical composition and physical conditions of these planetary atmospheres is spectroscopy. This optical diagnostic technique allows chemical species to be identified from the light they absorb or emit at different wavelengths.

The understanding of a planetary atmospheric spectrum requires the ability to correctly model that of its different compounds. In many cases, strong methane absorption bands dominate the spectrum of such bodies. Thus, the detection of minor compounds (complex organic molecules, trace gases, etc…) or the determination of other parameters such as the surface properties, involves the subtraction of the CH_4 spectrum. This, in turn, requires an extremely reliable model valid over a wide spectral range (from microwaves to near infrared). Moreover, even at low or moderate resolution, the spectral absorption profile depends on the underlying fine structure. Its modeling thus requires the analysis of high-resolution laboratory spectra, which involves the study of a huge number of quantum states and the identification of a huge number of spectral lines.

◀ **This image of Titan was taken by the Cassini spacecraft during its first flyby of the largest moon of Saturn on July 2, 2004. It shows a thin, detached haze layer floating above the orange atmosphere. © NASA/JPL/Space Science Institute**

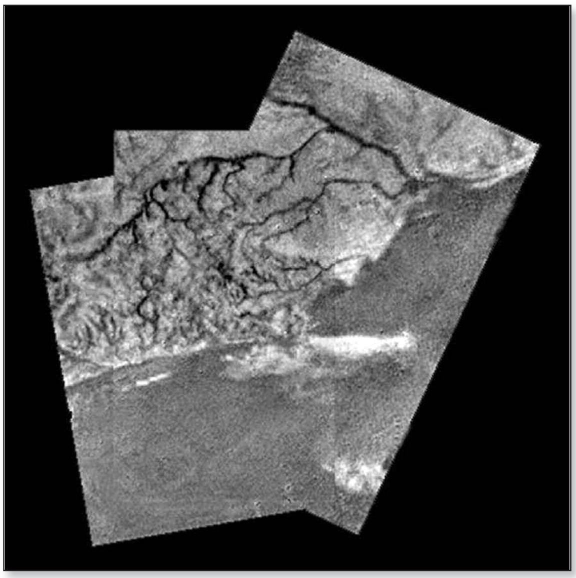
Methane on Titan

Titan, Saturn's main moon, has a 5150 km diameter and possesses a thick atmosphere mainly composed of nitrogen, N_2 (98 % in average), that does not absorb light, but also of an important quantity of methane (about 1.5% in the neutral atmosphere), a little oxygen, as well as various other organic molecules, the sign of a complex chemical activity.

Titan's surface temperature is a low –179 °C and water can only exist there as ice. On Titan, CH_4 plays a role similar to water on Earth. It is present in the gaseous form in the atmosphere, forms clouds and there is evidence for methane rains leading to mixed methane and ethane rivers and lakes on the surface.

note

[1] An extended version of this paper was first published in French in May 2008 in *uB Sciences*, volume 3, the research journal of the *Université de Bourgogne*. A French shortened version similar to the present one was then published in *Reflets de la Physique*, volume 11, pp. 13–16 (2008), the journal of the *Société Française de Physique*.



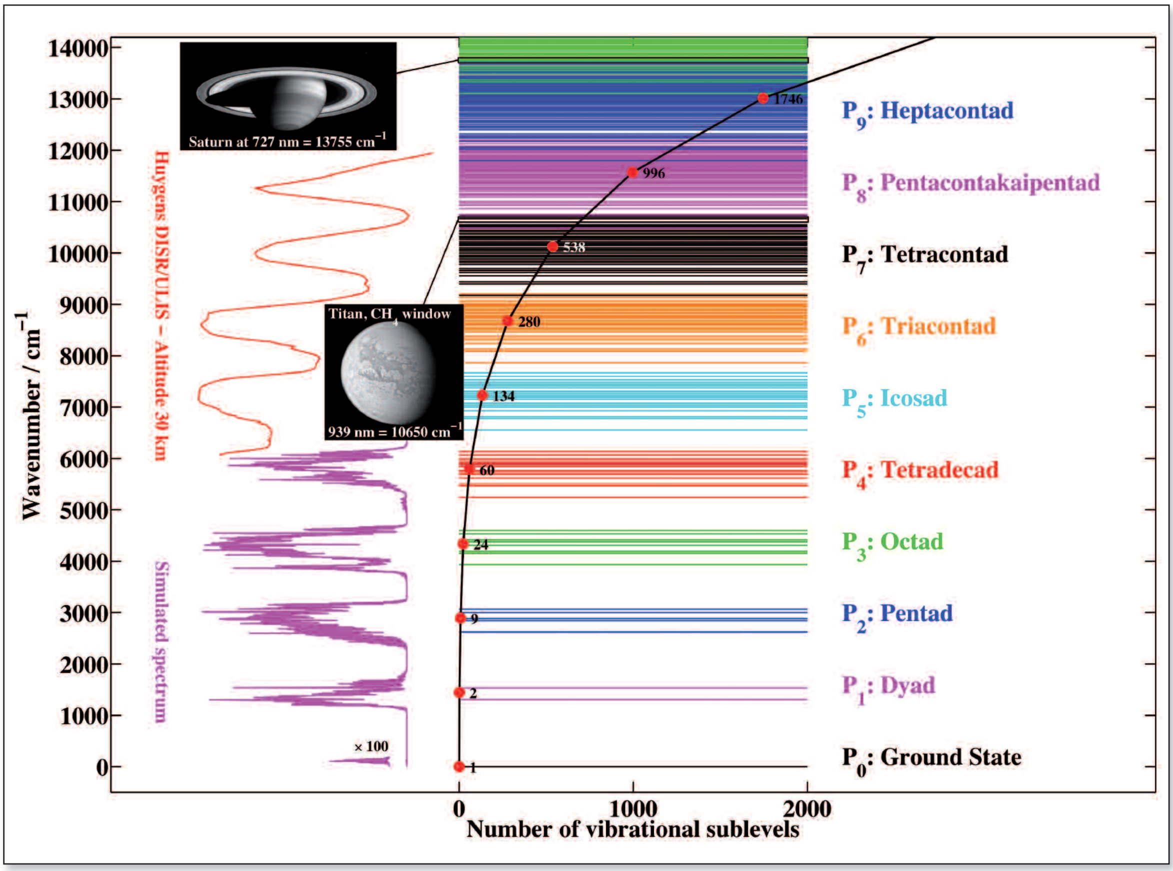
► **FIG. 1:** "Dried" methane rivers imaged by the Huygens probe during its descent on Titan. © NASA/JPL/ Space Science Institute.

This conception of Titan mainly comes form the observations and measurements made by spacecraft like Voyager 1 in 1980 and, essentially by the Cassini-Huygens mission (NASA/ESA/ASI) which, since July 2004, has revolutionized our knowledge of Saturn's system including Titan. One of its main features was the European Huygens probe descent in Titan's atmosphere and its landing on the surface on January 14, 2005 after a two and a half hour descent. The Cassini orbiter continues to regularly flyby Titan and the other kronian satellites with a host of different instruments (cameras, spectrometers, radar, …), supplementing observations made from Earth orbit (Hubble Space Telescope, ISO satellite) or from the ground, often at higher spectral resolution.

A series of large and regularly spaced absorption bands due to methane dominate the Titan spectra recorded by the DISR (Descent Imager/Spectral Radiometer) of the Huygens probe during its descent, and by VIMS (Visual and Infrared Mapping Spectrometer) on the orbiter.

Images taken during the Huygens descent combined with radar images from the Cassini orbiter provide valuable information. Fluvial networks cover around 1 % of the surface (see Figure 1). Large smooth areas, interpreted as methane and ethane lakes or seas, cover important parts of the polar regions.

Furthermore, methane decomposition in the upper atmosphere leads to a series of chemical reactions producing various organic compounds such as ethane (C_2H_6) and other more complex hydrocarbons. Nitrogen (N_2) dissociation and its recombination with methane leads to the formation of nitriles like hydrogen cyanide (HCN). Polymerization of some compounds produces a complex material, which constitutes the solid particles of the orange haze that fills the atmosphere. These particles become condensation cores for ethane and other gases and continuously fall on Titan's



► **FIG. 2:** Methane's spectrum complexity. Horizontal lines represent vibration energy levels. The black curve gives the number of vibrational sublevels for each polyad. The names correspond to the different absorption bands. Different spectral regions are illustrated by images and spectra: in pink, a simulated spectrum for lower polyads and, in red, an example of the spectra recorded on Titan by the Huygens probe. © NASA/JPL/ Space Science Institute).

surface. All this allows one to build up the scheme of a true "methane cycle" on Titan that mimics the water cycle on Earth.

The main question that arises about methane is that of its origin because this molecule is efficiently destroyed in the upper atmosphere by solar radiation and the processes we described in the previous paragraph. So it should have completely disappeared long ago. There must then exist methane sources capable of re-fueling the atmosphere. According to recent models, lakes alone (unless very deep), are not sufficient to explain the observed quantities (around 5 % of methane near the surface and 1.5 % in the stratosphere). Another possibility would be the presence of methane trapped in ice crystals or formed by other processes (such as serpentinization) in the interior of the satellite. It could then slowly find its way up to the surface where it would be released through cryovolcanic eruptions.

Methane spectrum

CH_4 has several remarkable spectroscopic properties. First, this molecule is highly symmetrical, the four hydrogen atoms placed at the vertices of a regular tetrahedron. A second essential characteristic of the methane spectrum is related to the ordering of its energy levels. The four characteristic vibrational frequencies of the atoms in the molecule display simple ratios between each other. The consequence is that the vibrational energy levels are grouped into sets called *polyads* that are regularly spaced. The more the energy increases, the bigger is the number of levels in each polyad (see Figure 2). This grouping is responsible for methane's large absorption bands.

In environments like a planetary atmosphere containing a few percent of methane and in which sunlight crosses several hundred kilometers, even highly excited polyads, although extremely weak when observed in the laboratory, can absorb almost all light at the corresponding wavelengths. Figure 2 shows a Saturn image taken by the Cassini spacecraft on which the dark zones correspond to the absorption of light in the region of a highly excited polyad. This absorption of light by methane is also responsible for the opacity of Titan's atmosphere. However, transparency windows between polyads exist. They allow observing other compounds in this atmosphere and, moreover, constitute the only means to glimpse at Titan's surface remotely. Again in Figure 2, another Titan image taken by the Cassini spacecraft through one of these spectral windows reveals the topography of the Saturnian moon.

Thus, the modeling of the absorption of light in such atmospheres necessitates considering a huge number of excited states. But the complexity goes further! The rotational structure of the spectrum superimposes onto the vibrational one. Because of the even higher number of rotational states (see Figure 3), it is mandatory to undertake high-resolution studies in order to finely reproduce the profile of the observed bands, since this depends on the underlying structure. Moreover, intensity calculations should be as precise as possible, in view of concentration measurements. Intensities also depend on the temperature. Reciprocally, the precision of the intensity model conditions that of the temperature measurement. Finally, a reliable model provides a much bigger flexibility than an interpolation from laboratory measurements, which is necessarily limited.

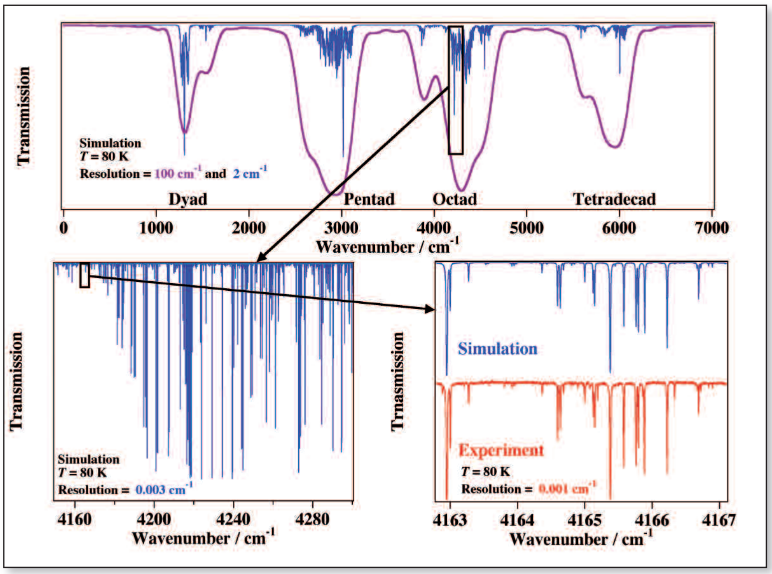
On **Titan, CH_4** plays a role **similar to water** on **Earth**

Recent results

Calculated methane spectral line lists have recently allowed significant contributions to the analysis of some measurements concerning Titan.

For instance, using these lists, it was possible to interpret ISO satellite data from 1997 in the 2.4 – 4.9 μm spectral range [1]. The advantage of using a wide spectral range instead of a window-by-window study (as in previous works) is to allow for a better determination of the spectral behavior of Titan and hence a better constraint over the aerosol model for Titan, as well as a determination of the methane abundance in the lower atmosphere (below 3 %). Furthermore, albedo measurements of Titan's surface, obtained simultaneously through several infrared windows after the atmospheric subtraction, allowed scientists to constrain Titan's surface composition, shown to be compatible with the presence of water ice and organics.

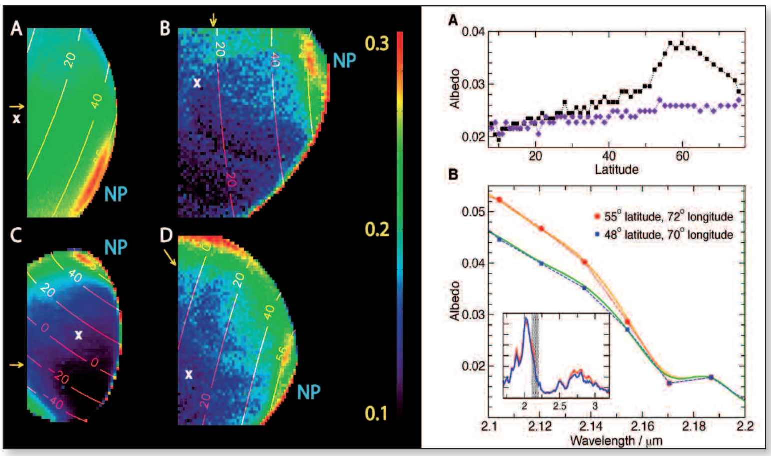
▼ FIG. 3: Simulated methane spectrum at increasing spectral resolutions, showing the rotational structure **(in blue)**. In the upper panel, the magenta curve represents a low-resolution calculated spectrum. The lower right panel compares a very small part of the calculated spectrum with a laboratory measurement **(in red)**.



Another recent major contribution was the evidence of a vast polar ethane cloud at Titan's North pole [2]. This was made possible thanks to the simulation of the methane spectrum in the so-called octad region (see Figure 2) around 2.1 to 2.2 µm. As illustrated in Figure 4, it was shown that the difference between spectra inside and outside the cloud is due to diffusion by small particles in the 30 to 50 km altitude range, with characteristics indicating that this cloud is likely to be composed of ethane. Ethane (C_2H_6), the main product of methane photodissociation by solar radiation, should precipitate on the ground. The apparent absence of liquid ethane on the ground at mid latitudes of Titan was up to recently a mystery. These new observations suggest that in fact ethane seems to condensate in this type of polar clouds and is then likely to accumulate in the lakes that are present in these regions.

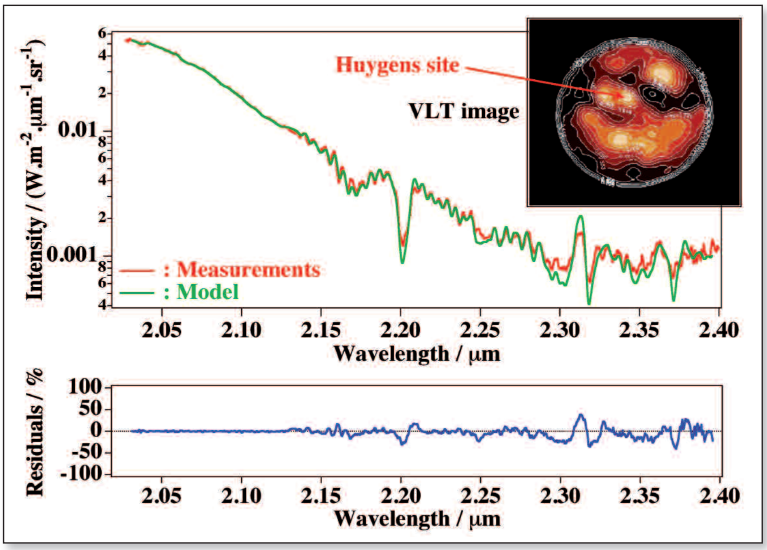
Calculated methane absorption coefficients in the mid infrared allow for a correct modeling of Titan's atmospheric absorption as measured by the CFHT [3], from which surface albedo variations can be deduced.

Finally, spectra were recorded between 2.03 and 2.40 µm thanks to the VLT for different regions of Titan, including the Huygens probe landing site, as can be seen in Figure 5 [4]. Calculated absorption coefficients, using the methane abundance profile, as measured by the Huygens probe, allow again for a correct modeling of Titan's atmospheric absorption, from which the surface albedo can be deduced in a spectral domain that was not covered by Huygens' DISR instrument.



▲ **FIG. 4: Left:** Albedo (proportion of reflected solar light) maps of Titan at 2.8 µm obtained by the VIMS instrument of the Cassini spacecraft. Red areas have highest albedo. The red spot near the North Pole (NP) is an ethane cloud. **Upper right:** Albedo as a function of latitude at 2.11 µm (in black) and 2.17 µm (in magenta), revealing the diffusion by the cloud that is visible at 2.11 µm beyond 51°N. **Lower right:** measured (dots) and simulated (curves) spectra at two different latitudes. The difference between spectra at these two latitudes reflects the diffusion by the ethane cloud that is situated around 30 to 50 km altitude. Figure from Reference [2].

▼ **FIG. 5: Upper right:** VLT (Very Large Telescope) image. Bright zones correspond to high albedo regions. **Top:** Measured spectrum around the Huygens landing site with a resolving power of 700 **(in red)** and simulated spectrum **(in green)**. **Bottom:** relative difference between measurements and the best model **(in blue)**. Above 2.12 µm, the measurement error is ± 27 %. The vertical haze profile and the surface albedo at 2 µm were determined from these measurements.



Perspectives

Advances in the theoretical model presented here (mainly with respect to higher polyads and spectral line shapes), associated with experimental work at Titan's atmospheric conditions, would allow us in the future to better constrain the methane opacity. This would lead to the resolution of remaining issues with the interpretation of Cassini-Huygens and Earth-based near-IR Titan data, concerning essentially the vertical haze profile and the composition of Titan's surface. ■

Acknowledgments

The authors recognize financial support from the *Agence Nationale de la Recherche*, within the ANR-08-BLAN-0254 project.

References

[1] Titan's 3-Micron Spectral Region from ISO High-Resolution Spectroscopy, A. Coustenis, A. Negrão, A. Salama, B. Schulz, E. Lellouch, P. Rannou, P. Drossart, T. Encrenaz, B. Schmitt, V. Boudon and A. Nikitin, *Icarus* **180**, 176 (2006).

[2] Evidence for a Polar Ethane Cloud on Titan, C.A. Griffith, P. Penteado, P. Rannou, R. Brown, V. Boudon, K.H. Baines, R. Clark, P. Drossart, B. Buratti, P. Nicholson, C.P. Mckay, A. Coustenis, A. Negrão and R. Jaumann, *Science* **313**, 1620 (2006).

[3] Titan's Surface Albedo from Near-Infrared CFHT/FTS Spectra : Modeling Dependance on the Methane Absorption, A. Negrão, A. Coustenis, E. Lellouch, J.-P. Maillard, P. Rannou, B. Schmitt, C.P. Mckay and V. Boudon, *Planetary and Space Science* **54**, 1225 (2006).

[4] 2-µm Spectroscopy of Huygens Probe Landing Site on Titan with VLT/NACO, A. Negrão, M. Hirtzig, A. Coustenis, E. Gendron, P. Drossart, P. Rannou, M. Combes and V. Boudon, *Journal of Geophysical Research* **112**, E02S92 (2007).


© iStockPhoto

PHYSICS IN DAILY LIFE: FOG AND RAINDROPS

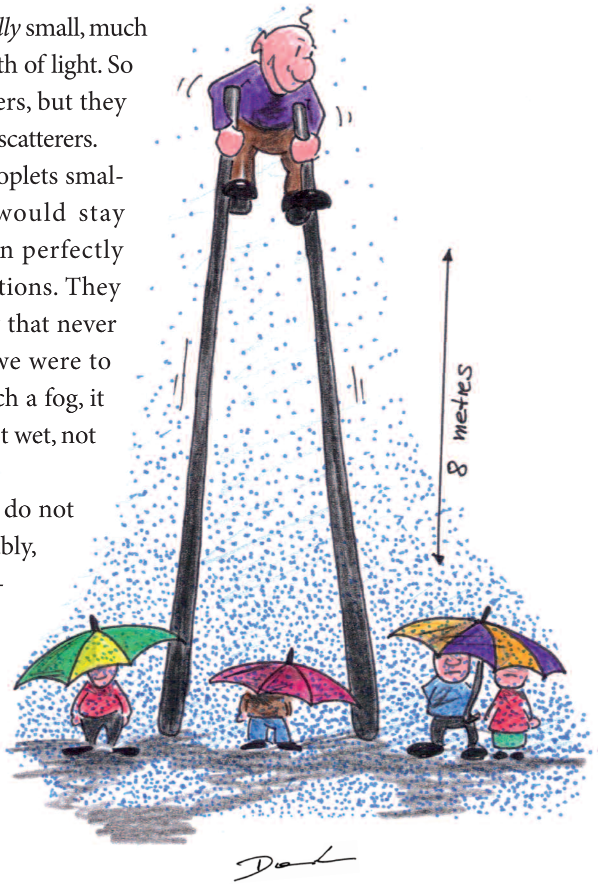
* L.J.F. (Jo) Hermans * Leiden University, The Netherlands * Hermans@Physics.LeidenUniv.nl * DOI: 10.1051/epn/2009602

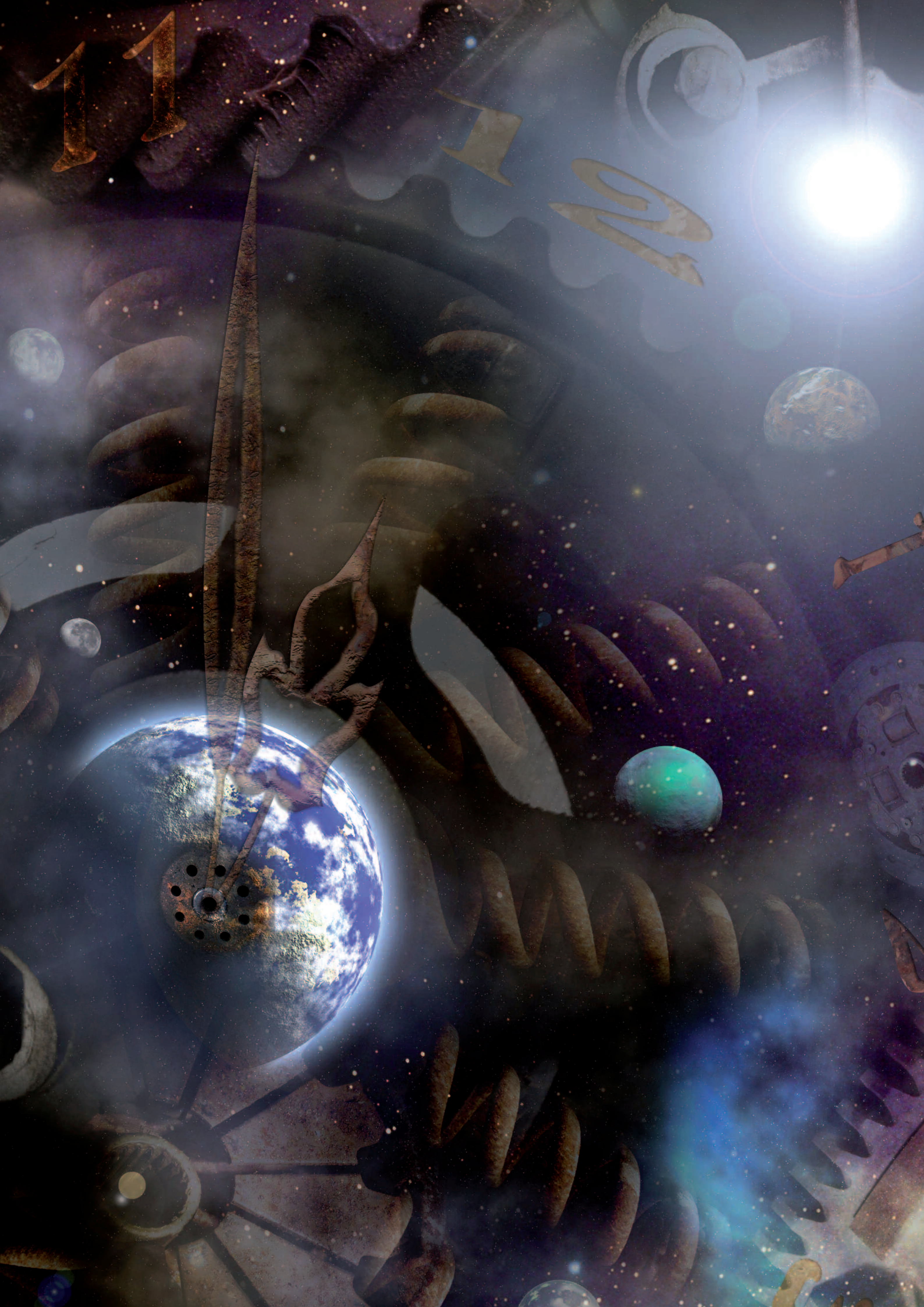
As every physicist knows, fog – or mist – is just a collection of tiny drops of water, at least if it is caused by nature. What distinguishes them from rain is, of course, their size. They are so small that their vertical speed is almost negligible. The dramatic effect of size on speed is obvious if we realize that for droplets smaller than, say, 0.1 mm, the flow profile around the droplet is purely laminar, so the friction F is determined by Stokes' law: $F = 6\pi\eta Rv$, with η the viscosity, R the radius and v the speed. And since the friction is balanced by weight, which is proportional to R^3, we see that the speed is proportional to R^2. This means that small droplets fall very slowly indeed. Take, for example, water droplets of 2 μm diameter, much larger than the wavelength of light and therefore still visible. We find that they fall through air at a speed of about 0.1 mm per second. That's not particularly fast: even the slightest wind or air turbulence will offset such low speed.

But wait: do we really need turbulence to keep such tiny droplets airborne? Isn't thermal motion sufficient to keep them from falling? Don't they behave like ordinary molecules in the atmosphere, having a height distribution obeying Boltzmann's law? We can easily check if this is the case. We remember that the Boltzmann distribution for this case implies a distribution over height h decaying as $\exp(-mgh/kT)$. In normal atmospheric conditions, the 1/e value is reached at a height of around 8000 m. Obviously, for particles much heavier than nitrogen or oxygen molecules we must settle for a distribution that stays closer to earth. Let us scale down the atmosphere for water droplet by a factor of one thousand, choosing a 1/e-value of 8 m. For this to be the case, the mass of a water droplet must be 1000 times that of a nitrogen or oxygen molecule, *i.e.*, it must consist of about 1500 water molecules. This is more like a large cluster than a droplet. Its diameter can be readily estimated by using the typical 'size' of 0.3 nm for small molecules or atoms in a liquid. In the case of water, we can even do a simple calculation if we consider a litre of water and use Avogadro's number. Sure enough, we find pretty exactly 0.3 nm for the distance between the centres of two neighbouring water molecules. From this it follows that the diameter of the cluster is only 5 nm. This is *really* small, much smaller than the wavelength of light. So we cannot see such clusters, but they surely make efficient light scatterers.

The conclusion? Mini-droplets smaller than about 5 nm would stay airborne forever, even in perfectly calm atmospheric conditions. They would form a perfect fog that never reached the ground. If we were to walk or cycle through such a fog, it would be our *front* that got wet, not so much our head.

Alas, these mini-droplets do not survive very long. Inevitably, they collide and form larger drops. Slowly but surely they will start to fall. And by the time we can distinguish individual drops, we can be sure that we are walking in the rain. ■





PROBING THE END OF THE UNIVERSE'S DARK AGES WITH LOFAR

* **Saleem Zaroubi** * Kapteyn Astronomical Institute, University of Groningen, The Netherlands * **DOI: 10.1051/epn/2009603**

About four hundred million years after the Big Bang, the first radiation-emitting objects in the Universe formed, and the all-pervasive gas transformed from neutral to ionized. This pivotal era, the Epoch of Reionization, holds the key to structure formation and evolution in the early Universe.

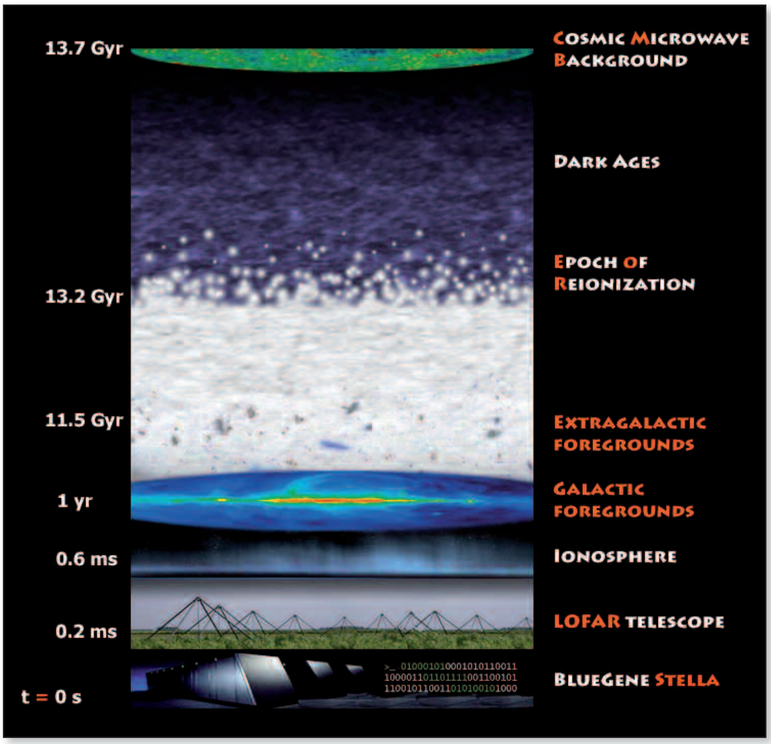
In the last decades an overarching paradigm for the formation and evolution of structure in the Universe has emerged: the cold dark matter (CDM) model. CDM is a refinement of the Big Bang theory, proposing that matter in the Universe consists mostly of slow, non-baryonic particles that interact through gravity. A recent modification of CDM is the addition of a dark energy component that currently dominates the Universe's energy density and accelerates its expansion. According to the CDM paradigm, very early, tiny density fluctuations in an otherwise homogeneous and isotropic Universe took 13.7 billion years to grow into the highly complex cosmos that we observe today.

About 400,000 years after the Big Bang, the Universe's temperature and density decreased to below 3000 K, allowing ions and electrons to (re)combine into neutral hydrogen and helium – heavier elements were negligible. Immediately afterwards, photons decoupled from baryons and the Universe became transparent, leaving a relic radiation known as the cosmic microwave background (CMB) radiation. This event ushered the Universe into a period of darkness, known as the Universe's Dark Ages. These Dark Ages ended about 400 million years later, when the first stars, black holes, etc. formed and started emitting ionizing radiation. When a sufficient number of UV-emitting objects had formed, the temperature and the ionized fraction of the gas in the Universe increased rapidly and most of the neutral hydrogen eventually ionized. This period, in which the cosmic gas went from being almost completely neutral to almost completely ionized, is known as the Epoch of Reionization (hereafter EoR). A cartoon of the various phases featuring in this transition phase is shown in Figure 1.

The EoR was a watershed epoch in the history of the Universe. Prior to it, dark matter dominated the formation and evolution of structure while baryonic matter played a marginal role. After the EoR, the role of cosmic gas in the formation and evolution of structure became prominent and, on small scales, even dominant. Studies of this crucial epoch touch upon fundamental questions in cosmology, galaxy assembly, and formation of quasars and very metal poor stars. Much theoretical effort is currently dedicated to understand the physical processes that triggered and governed the evolution of this epoch, and their ramifications for subsequent structure formation [1-3].

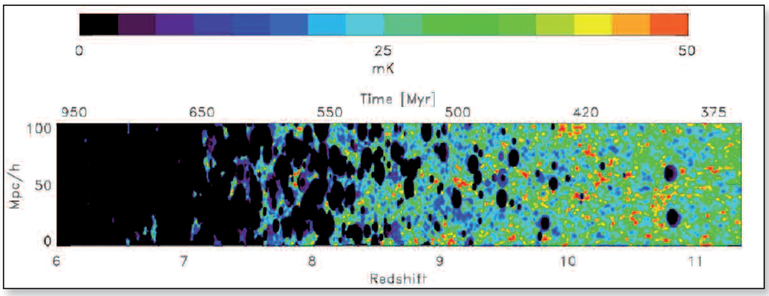
What do we know about the Epoch of Reionization?

Currently, there are only two strong observational constraints on the EoR. The CMB temperature and polarization data obtained by the WMAP satellite allow measurement of the total Thomson scattering of the primordial CMB photons off intervening free electrons produced by the EoR along the line of sight. They show that the CMB intensity has only been damped by ~9%, indicating that the Universe was mostly neutral for 400 million years and then ionized. However, the Thomson scattering measurement is an integral constraint telling us little about the sources of reionization, its duration or how it propagated to fill the whole Universe.



▲ **FIG. 1:** This sketch illustrates the likely development of the Epoch of Reionization (EoR). About 0.4 million years after the Big Bang (z~1100) hydrogen recombined and remained neutral for about 400 million years until the first radiation emitting sources emerged, an era known as the "Universe's dark ages". At z~10, the first stars, galaxies and quasars began to heat and ionize the intergalactic medium. The neutral IGM can be observed with LOFAR through its redshifted 21cm spin-flip transition to redshift 11.5 (when the Universe was 400 million years old). However, instrumental, ionospheric, Galactic and extra-galactic contaminants corrupt the 21 cm signal. (Courtesy of V. Jelić)

▼ **FIG.2:** A slice through time of the evolution of the reionization process in the intergalactic medium. The x-axis gives the redshift or time and the y-axis gives the spatial coordinate. At high redshifts the early Universe is neutral except for small volumes around the first ionizing sources. As time progresses the number of ionizing sources increases and the bubbles (black areas) become larger until they fill the whole Universe. The color scheme represents brightness temperatures given in the bar above the figure (Courtesy of Rajat M. Thomas) .



Another constraint comes from specific features in the spectra of distant quasars, known as the Lyman-alpha forest. These features, which are due to neutral hydrogen, indicate two important facts about reionization. First, hydrogen in the recent Universe is highly ionized, only 1 part in 10000 being neutral. Second, the neutral fraction of hydrogen in the distant Universe suddenly increases at redshift 6.5, *i.e.*, about 900 million years after the Big Bang, demarcating the end of the reionization process. Despite these data providing strong constraints on the ionization state of the Universe at redshifts below 6.5, they say very little about the reionization process itself.

A whole slew of possible constraints currently discussed in the literature are either very controversial, very weak or, as is often the case, both. Most are very interesting and exciting; but can be investigated reliably only with a new generation of instruments such as the James Webb Space Telescope, replacing the Hubble Space Telescope in the next decade.

The Reionization process

To ionize hydrogen one needs photons with energies of 13.6 eV or higher: the reionization of the Universe requires ultraviolet photons. A crucial question is which sources in nature provided the UV photons needed to ionize the Universe and maintain it in that state. Obvious candidates are the first stars (so called Population III stars) and (mini)quasars – these are objects powered by massive black holes. Various papers have considered other sources of reionization, like decaying or self-annihilating dark matter particles or decaying cosmic strings. However, the constraints on such objects make it unlikely that they could reionize the Universe by themselves.

Massive black holes powering quasars convert mass to radiation extremely efficiently. They produce a large amount of UV and X-ray radiation above the ionization threshold. In fact, one of the main discoveries of the last decade is that huge quasars, powered by black holes with masses above 10^9 solar masses, already existed at redshift ~6.5 (about 900 million years after the Big Bang). How these black holes managed to accumulate so much mass in such a short time is a puzzle in its own right. However, the mass distribution of the massive black holes in the early Universe is unknown, rendering the role played by quasars during reionization very uncertain.

Population III stars formed from the primordial mix of elements and thus only contain hydrogen and helium. This composition makes them very different from present-day stars. In order for a star to form, the initial proto-star has to radiate some of the energy gained by gravitational contraction, or the collapse will rapidly halt as the cloud reaches hydrostatic equilibrium. Population III stars are poor radiators until the cloud from which they form reaches high temperatures. This causes them to be very massive and hence are very efficient and abundant sources of UV photons yet are very short lived. Theoretically, these objects could have reionized the Universe but our knowledge of them, including the question whether they have existed at all in sufficient numbers, is very uncertain.

The basic scenario for the EoR is simple. The first radiation-emitting objects ionize their immediate surroundings, forming ionized bubbles which expand until the ionization consumes all ionizing photons. As the number of objects increases, so do the number and size of the bubbles which eventually fill the total volume. However, many details must be clarified. What controls the formation of the first objects and how much ionizing radiation do they produce? How do the bubbles expand into the intergalactic medium and what do they ionize first, high-density or low-density regions? In order to answer such questions, cosmologists try to simulate the EoR by combining models that track the formation of dark matter halos with radiation transport mechanisms that track the evolution of the ionization bubbles.

Figure 2 shows a slice through such a simulation where the scale of the vertical axis is 100 comoving Mpc/h (Megaparsecs per h, where h~0.7 is the Hubble constant measured in units of 100 km/s/Mpc) and the horizontal axis is the redshift (bottom) or the corresponding time after the Big Bang (top) [4]. We began with a cosmological structure formation simulation in which we identify possible ionization sources and then used a spherically symmetric radiative transport code to calculate the amount of ionization around each source as a function of redshift (time). Here we assumed that the ionization is driven by black holes with masses ranging from 100 to 107 solar masses in mini-quasars. Obviously, results of the simulation depend on the assumptions. For example, with the same number of ionizing photons stars will produce smaller bubbles but at many more locations.

Studies of this **crucial epoch** touch upon **fundamental questions** in **cosmology**

The 21 cm emission as a probe of the EoR

The study of the 21cm emission line from neutral hydrogen may be our best hope to study the formation of structure in the Dark Ages and the EoR [5-7]. The strength of the 21 cm emission or absorption depends on the relative occupation number of the ground state and the excited state. The 21 cm line can be excited through either collisions or Lyman-alpha excitation – called the Wouthuysen-Field effect [8-10].

◀ **FIG. 3:** An artist's impression of the layout of the LOFAR telescope over Western Europe. For the EoR, only the central part of the telescope is relevant. (courtesy of Peter Prijs)

The 21 cm line emission from the EoR is redshifted by the cosmic expansion to meter wavelengths. For example, at a redshift of 9 (550 million years after the Big Bang) the 21 cm line is at 2.1 m (or a frequency of ~140 MHz). This feature allows us to study and map the reionization process time-slice by time-slice. Measuring the 21 cm radiation from the diffuse intergalactic medium prior to and during the EoR holds great promise for studying the matter distribution at these very early stages. It will also tell us the nature of the first ionization sources, their abundance and distribution, as well as how the EoR progressed.

Observational Status and Prospects

Observation of 21 cm radiation from the EoR and earlier requires radio telescopes, which currently lack enough sensitivity. Fortunately, in the coming years, this will change with the introduction of novel radio telescopes with the specific goal to observe redshifted 21-cm line emission from the EoR. These include LOFAR (the LOw Frequency Array)[1] now under construction in a number of European countries led by the Netherlands (see Figure 3); the Murchison Widefield Array (MWA)[2] currently built in western Australia by Australian and US institutes; and the international Square Kilometer Array (SKA)[3], by far the most ambitious project to be built within a decade.

LOFAR and MWA will start to collect data within a year and are set to map the spatial distribution of neutral hydrogen in the Universe over several hundred square degrees of the sky. Each point in these maps will be observed at many frequency- or time-slices between the redshifts of 11.5 and 6.5 in which significant evolution in the neutral hydrogen fraction is expected. These telescopes are interferometric arrays with large collecting areas and will have the sensitivity to detect the very weak signals emitted by the early Universe.

These observations will not be easy due to a number of complicating factors. For example, the redshifted 21 cm emission passes through overwhelming galactic and extra-galactic foregrounds that severely contaminate the data. The radio signal is further badly affected by the Earth's ionosphere, and by the instrument's response. All these effects must be carefully neutralized by an exquisite calibration of the telescope (see Figures 1 & 4 for more detail).

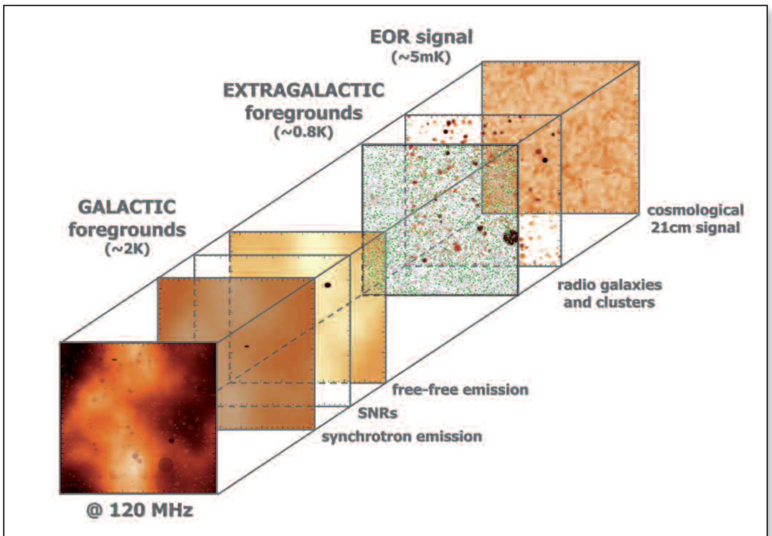
Despite these difficulties, the near future will be very exciting for this field as observational success will open a completely new area in cosmology, shedding light on the Universe's Dark Ages and the Epoch of Reionization, and bridging the huge observational gap in our knowledge of the Universe between 400,000 years after the Big Bang – when recombination occurred – and one billion years later when the Universe was fully ionized. ■

notes

[1] www.lofar.nl
[2] www.haystack.mit.edu/ast/arrays/mwa/
[3] www.skatelescope.org

About the Author

Saleem Zaroubi is an associate professor of Astronomy at the University of Groningen. He obtained his PhD from the Hebrew University of Jerusalem and held positions at UC-Berkeley and the Max Planck Institute for Astrophysics. He is a co-PI of the LOFAR Epoch-of-Reionization project.



▲ **FIG. 4: The figure illustrates the various galactic and extra-galactic contaminants of the redshifted 21 cm radiation from the EoR. These foregrounds have amplitudes of about 3 orders of magnitude larger than the expected cosmological signal. (Courtesy of V. Jelić)**

References

[1] Barkana, R. and Loeb, A., *Physics Reports* **349** 2, 125 (2001).

[2] Ciardi, B and Ferrara, A., *Space Science Reviews* **116**, 625 (2005).

[3] S.R. Furlanetto, S.P. Oh, and F.H. Briggs, *Physics Reports* **433** 4, 181(2006).

[4] R.M. Thomas *et al.*, *Monthly Notices of the Royal Astronomical Society* **393**, 32 (2008).

[5] C.J. Hogan and M.J. Rees, *Monthly Notices of the Royal Astronomical Society* **188**, 791 (1979).

[6] D. Scott and M.J. Rees, *Monthly Notices of the Royal Astronomical Society* **247**, 510 (1990).

[7] P. Madau, A. Meiksin and M.J. Rees Martin, *Astrophysical Journal* **475**, 429 (1997).

[8] S.A. Wouthuysen, *Astronomical Journal* **57**, 31 (1952).

[9] G.B. Field, *Astrophysical Journal* **129**, 536 (1959).

[10] G.B. Field, *Proceedings of the Institute of Radio Engineers* **46**, 240 (1958).

[11] V. Jelić *et al.*, *Monthly Notices of the Royal Astronomical Society* **389**, 1319 (2008).

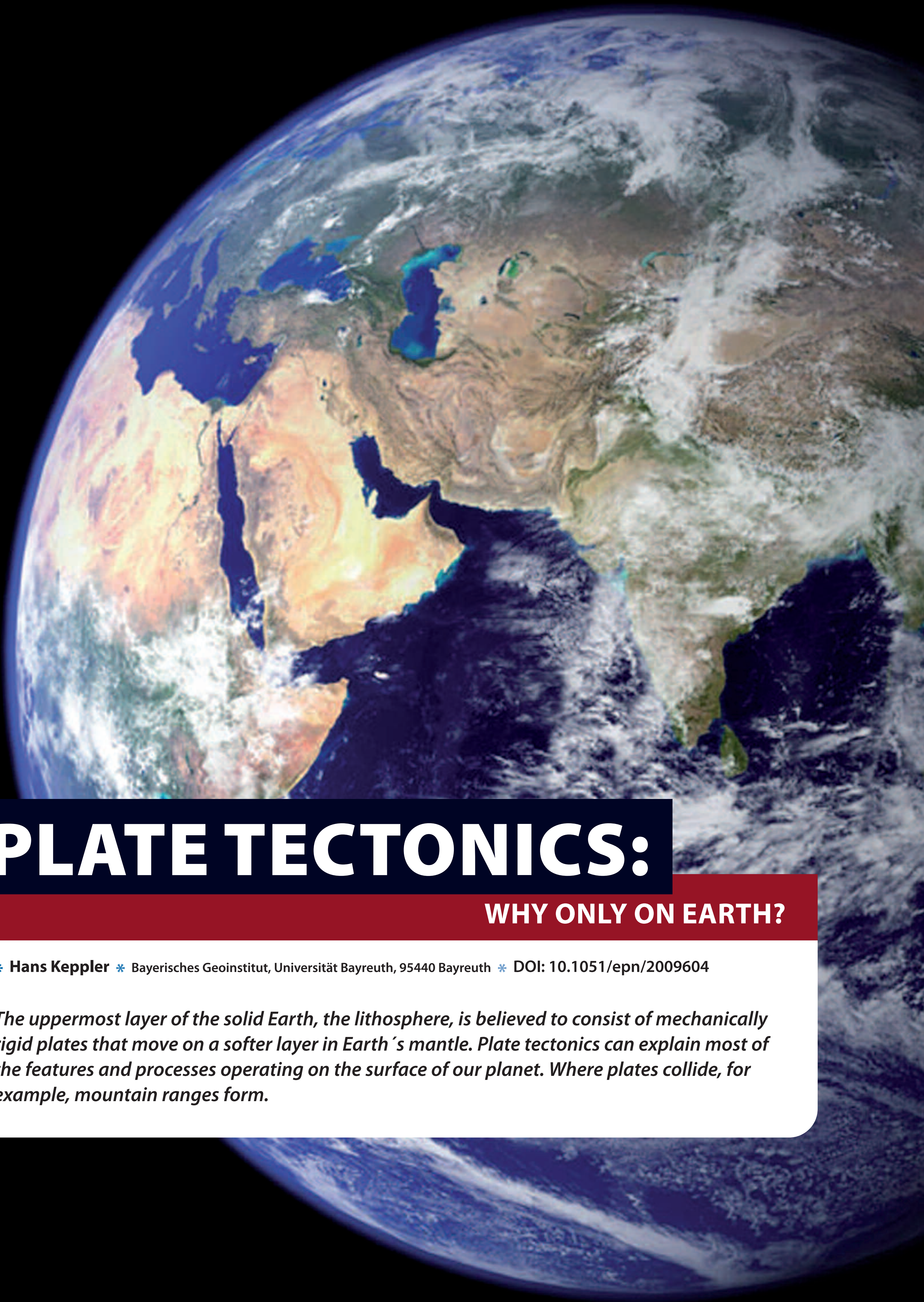


PLATE TECTONICS:

WHY ONLY ON EARTH?

* **Hans Keppler** * Bayerisches Geoinstitut, Universität Bayreuth, 95440 Bayreuth * DOI: 10.1051/epn/2009604

The uppermost layer of the solid Earth, the lithosphere, is believed to consist of mechanically rigid plates that move on a softer layer in Earth´s mantle. Plate tectonics can explain most of the features and processes operating on the surface of our planet. Where plates collide, for example, mountain ranges form.

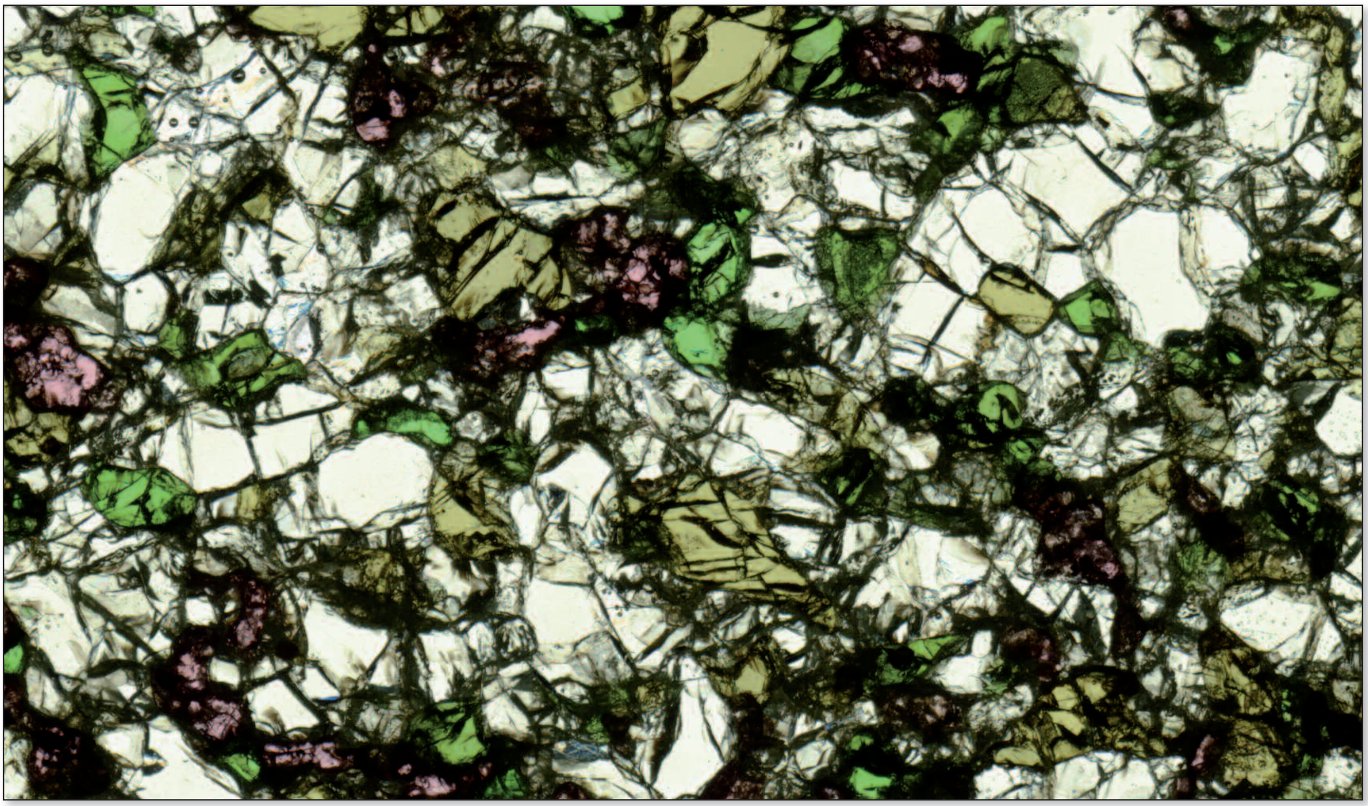
◀ P.27: Earth as seen from space. Image: NASA/GSFC"

At some other places, the oceanic lithosphere dives back into the Earth´s mantle. These subduction zones are also causing volcanic activity; the "ring of fire" surrounding the Pacific Ocean is a prominent example. In turn, new lithosphere is produced at the middle oceanic ridges by volcanic processes.

There is little doubt that the concept of plate tectonics describes how the Earth operates now and how it operated in the last few hundred million years. A more difficult question is, how far plate tectonics reaches back in Earth´s 4.6 billion years of history. There is increasing geochemical evidence, however, that plate tectonics was established very early in Earth´s history, perhaps already within the first billion years. Therefore, it is rather surprising that none of the other terrestrial planets – Mercury, Mars and Venus – show any sign of plate tectonics today or in their geologic history. Plate tectonics causes surface features on a planet that can be easily recognized by remote sensing, even without detailed geological sampling. The elevation of Earth´s surface has a pronounced bimodal distribution, with most of the continents being approximately 1 km above sea level and most of the ocean bottoms being approximately 4 km below sea level. Elevations between those extremes or exceeding them are rare. This bimodal distribution is a direct consequence of plate tectonics, corresponding to the difference in composition of the continental and oceanic crust, which again can be traced back to the difference in the melting processes occurring below middle oceanic ridges and in subduction zones. There is nothing like this on any other known planet and other indicators of plate tectonics are also missing. So, why does plate tectonics only exist on Earth?

The importance of the asthenosphere

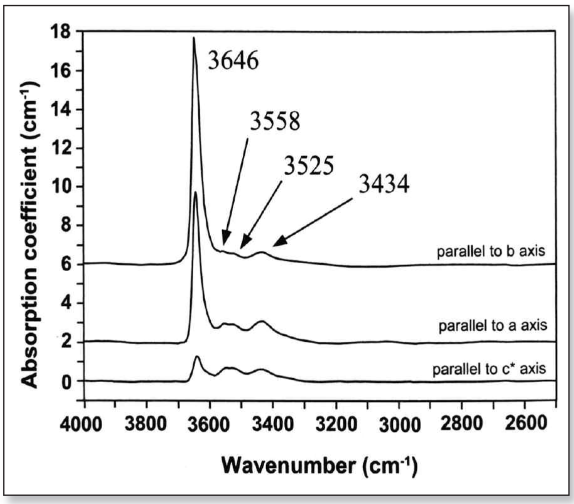
Earth´s mantle is solid, because observations of earthquakes show that it transmits elastic shear waves. However, the rocks and minerals of the mantle apparently can be plastically deformed over geologic time, so that over very long time scales, the mantle behaves like an extremely viscous liquid. This was actually known already more than a century ago, long before the advent of plate tectonics. The continuous uplift of Scandinavia by several mm per year that can be observed today is a response to the disappearance of the load of the glaciers at the end of the ice age, and suggests a liquid-like behavior of the material below the lithosphere. Convection in Earth´s mantle



▲ **FIG. 1:** Thin section of a mantle xenolith, a piece of the Earth´s mantle brought to the surface by a volcanic eruption. The almost colorless grains are olivine $(Mg,Fe)_2SiO_4$, brown is enstatite $(Mg,Fe)SiO_3$, intense green is diopside, Cr-bearing $CaMgSi_2O_6$, and red is garnet $(Mg,Fe)_3Al_2(SiO_4)_3$. All mineral formulae are simplified; in particular, enstatite and diopside contain some Al as well. Grain size is about 1 mm. Sample from Pali-Aike, Patagonia; photograph courtesy of Sylvie Demouchy, CNRS Montpellier.

by solid-state deformation of rocks is what ultimately drives plate motions on Earth´s surface. The energy source for this convection is partially radioactive decay, partially heat retained from the origin of the Earth. Geodynamic models of mantle convection can correctly reproduce many features of plate motions in the last several hundred million years. Interestingly, these models show that it is quite difficult to get a style of geologic activity similar to plate tectonics. Over a wide range of parameters, most models either yield planets with a rigid lithosphere or planets without any stable lithosphere. In order to get something that looks like plate tectonics, apparently a channel of low viscosity below the lithosphere is required. There is independent evidence for the existence of such a channel on Earth. Seismic measurements show that between a depth of about 60 km and 220 km below the oceans, the velocities of elastic shear and compression waves are reduced, indicating a reduced bulk and shear modulus, *i.e.*, the presence of softer material. Under continents, the upper boundary of this "seismic low-velocity zone" is depressed to 150 km depth. The seismic low-velocity zone is therefore often identified with the asthenosphere, the mechanically weak layer in the mantle that allows the movement of plates. But why is the asthenosphere so weak?

It was often believed that the transition from the rigid lithosphere to the asthenosphere is a purely thermal boundary. As temperature increases with depth, the mechanical strength of rocks should decrease. However, recent seismic data indicate an extremely sharp boundary between the lithosphere and the asthenosphere, with major changes in seismic velocities occurring over just a few kilometers [1]. This cannot be explained by a gradual change in temperature; rather, this observation implies a phase change, some modification in the mineralogy of the mantle. Moreover, a gradual increase in temperature cannot explain why the asthenosphere apparently also has a lower boundary – temperature keeps increasing towards the center of the Earth. Understanding the origin of Earth´s asthenosphere is therefore probably the key to understanding why plate tectonics exists on Earth, but not on other planets, such as Venus. Venus is in size, mass and composition almost a twin of Earth. But why is the geology of Venus so different? One obvious observation is that there is hardly any water on Venus – the surface is hot, with a dense CO_2-rich atmosphere; water has been lost to space by a runaway greenhouse effect. Could the particular tectonic style on Earth be somehow related to the presence of water?



◄ FIG. 2: **Polarized infrared absorption spectra of a diopside (Cr-bearing $CaMgSi_2O_6$) crystal. All bands correspond to OH point defects in different structural environments in the crystal. From the dependence of infrared absorbance on the direction of the electric field vector, the orientation of the OH group in the crystal can be determined. From [5].**

Water in Earth´s mantle

Earth´s upper mantle consists of silicates such as olivine $(Mg,Fe)_2SiO_4$, enstatite $(Mg,Fe)SiO_3$, and diopside $CaMgSi_2O_6$ that do not contain any water in their chemical formula. For this reason, it was believed for a long time that nearly all of the water in our planet is in the oceans and that the mantle is essentially dry. Violent volcanic eruptions sometimes bring pieces of mantle rocks up to the surface (Fig. 1). Accurate chemical analyses of minerals from such samples often appeared to show traces of water. However, this was usually dismissed as a surface contamination or inclusions of foreign material. This view slowly changed in the 1960´s, when a few mineralogists started to look at such samples by infrared spectroscopy. This method is very sensitive to traces of molecular water or OH groups. Moreover, it can also provide data on the chemical environment of the protons (H^+) in a material. If polarized infrared radiation is used, infrared absorption will be strongest when the OH dipole is parallel to the electrical field vector, while no absorption occurs if the OH dipole and the electrical field vector are perpendicular to each other. Studies of gem-quality, optically clear oriented single crystals of mantle minerals by infrared spectroscopy showed that these minerals always contain traces of water in the form of OH groups with a defined orientation relative to the crystallographic axes (Fig. 2). This cannot be random impurities. Apparently, some water is chemically dissolved in these mantle minerals as OH point defects [2]. The concentrations do not appear to be spectacular – a few hundred to a few thousand of ppm, or 0.01 to 0.1 wt. %. However, integrated over the enormous mass of the mantle, these minerals constitute a water reservoir comparable in size to the mass of all oceans. Moreover, the traces of water drastically change the physical properties of minerals. Already 1000 ppm or 0.1 wt. % of water dissolved as OH defects in the crystal lattice reduce the creep strength of olivine by three orders of magnitude [3]. This is probably because the incorporation of protons produces cation vacancies, which enhance the mobility of dislocations. Numerical models suggest that this reduction of mantle viscosity by traces of water dissolved in the crystal lattice is one prerequisite for the development of plate tectonics. But can water also explain the channel of low viscosity in Earth´s asthenosphere?

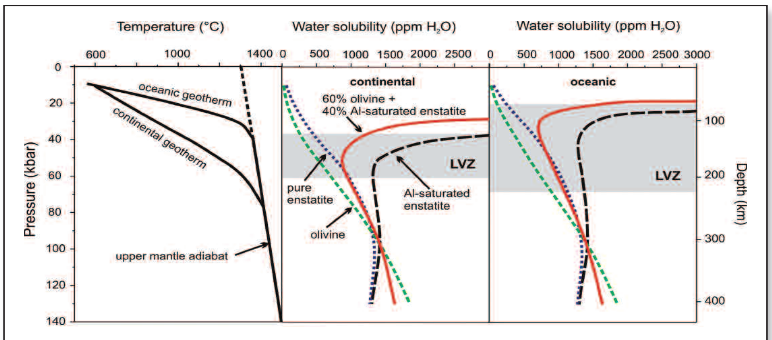
Earth, the water planet

Water drastically reduces the melting point of silicates. At 1 bar, dry basalt would melt around 1200°C. However, in the presence of 10 % water, and if the confining pressure is high enough to prevent the water from escaping from the system, the melting point drops to 800°C or less. This is because water is highly soluble in silicate melts. Also, even a very small fraction of melt in a rock can reduce its creep strength and viscosity drastically. At the same time, the velocities of elastic shear waves and compression waves would be reduced, consistent with the seismic observations for the asthenosphere. The temperatures in the asthenosphere are too low to allow melting in the absence of water. However, with some water present, melting may be possible. But if the presence of melt is restricted to the asthenosphere, what could be the reason? Is perhaps the water content in the asthenosphere higher than in the rest of the mantle? Considering the efficient convective mixing of the entire mantle, this appears to be unlikely.

Traces of water in minerals **drastically reduce** their **mechanical strength**

Recently, a new model has been proposed [4] that elegantly explains the formation of partial melt in Earth´s asthenosphere (Fig. 3). Among the minerals of the upper mantle, olivine and Al-bearing enstatite are the main hosts of water. Experimental studies show that the solubility of water as OH defects in olivine continuously increases with pressure and temperature, and therefore with depth in the mantle. However, the water solubility in enstatite sharply decreases with depth. This different behaviour is due to differences in the substitution mechanism responsible for water incorporation. In olivine, two protons substitute for Mg^{2+}; the resulting cation vacancy makes the crystal more compressible. Accordingly, water dissolution is favored at high pressure. In enstatite, however, $H^{+} + Al^{3+}$ substitute for Si^{4+}. This causes an expansion of the crystal lattice and therefore, water solubility drops at high pressure. The different behaviour of olivine and enstatite produces a pronounced minimum of water solubility in a depth interval in the mantle corresponding exactly to the seismic low velocity zone. At this depth, not all water can be dissolved in the solid minerals anymore. The excess water forms a partial melt. By the presence of a small fraction (about 1 %) of partial melt, the strength of the rock is greatly reduced. The model correctly predicts the different depth of the seismic low-velocity zone below continents and oceans; it also correctly predicts that the upper boundary of this zone should be very sharp, while the lower boundary is more gradual (compare the red curve in Fig.3).

It therefore appears that the formation of an asthenosphere and therefore the existence of plate tectonics are only possible in a planet with a water-bearing mantle, consistent with the absence of plate tectonics on Venus. Earth is the water planet – not only because of its oceans, but also because of its tectonic style. ■



▲ **FIG. 3: Water solubility in minerals of the Earth´s mantle. The bulk water solubility (red curve) is a weighed average of the water solubility in olivine (green) and Al-bearing enstatite (black). The bulk water solubility has a pronounced minimum at the depths interval of the asthenosphere, corresponding to the seismic low velocity zone (LVZ, gray shaded). In this region, not all water can be stored in the solid minerals anymore; the excess water causes partial melting. By the presence of a small amount of melt, the mechanical strength of the rock is greatly reduced. The model correctly predicts the different depths of the asthenosphere below continents and oceans due to the differences in the temperature profiles (left). From [4].**

About the Author

Hans Keppler studied mineralogy and chemistry at the University of Karlsruhe (Germany), where he also obtained his Ph. D. He was a research fellow at the California Institute of Technology. After some time at the Bayerisches Geoinstitut in Bayreuth and the University of Tübingen, he returned to Bayerisches Geoinstitut in 2004 as a Professor of Experimental Geophysics. Since 2007, he is also the director of this institute.

References

[1] C.A. Rychert *et al.*, *Nature* **436**, 542 (2005).

[2] H. Keppler and J.R. Smyth, *Water in nominally anhydrous minerals* (Mineralogical Society of America, Chantilly, 2006).

[3] S.J. Mackwell *et al.*, *J. Geophys. Res.* **90**, 11319 (1985).

[4] K. Mierdel *et al.*, *Science* **315**, 364 (2007).

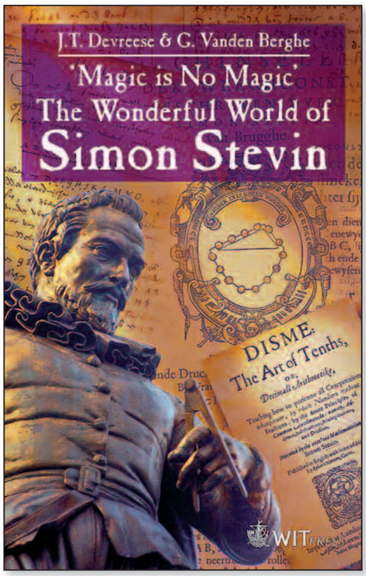
[5] G. Bromiley *et al.*, *Am. Mineral.* **89**: 941 (2004).

BOOK REVIEW:

'MAGIC IS NO MAGIC', THE WONDERFUL WORLD OF SIMON STEVIN

by J.T. Devreese and G. Vanden Berghe (WIT press 2008; ISBN 978-1-84564-391-1)

Simon Stevin (1548-1620) is one of the Low Countries' greatest applied mathematicians and physicists. He was born in the city of Bruges, where he enjoyed a superb upbringing. As a Protestant he fled from the repressive climate and settled in Leiden in 1581.

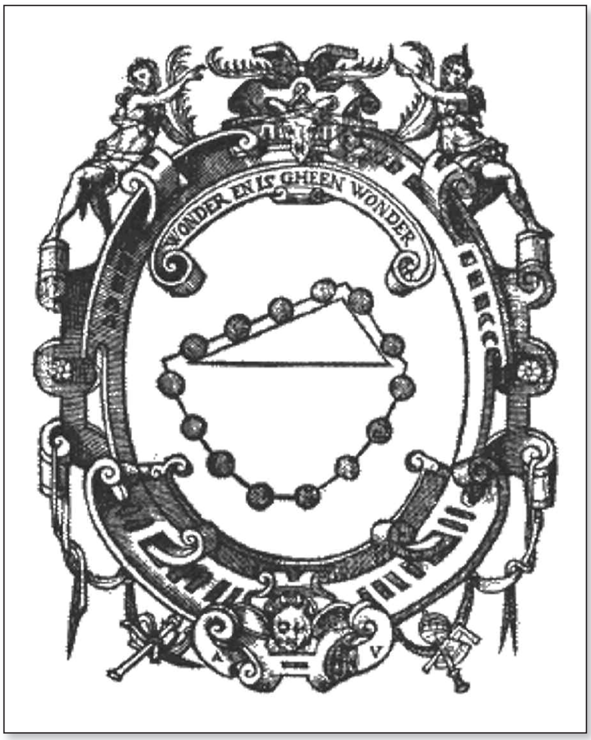


There he registered at the university, where he followed lectures in mathematics and astronomy given by Rudolf Snellius (the man behind the law of refraction). At that time Stevin had already published his *Tafelen van interest* [Tables of interest]. Many more publications would follow in very diverse areas, always original and frequently groundbreaking. As *homo universalis* and a child of the Renaissance he contributed to mathematics, physics, navigation, bookkeeping, fortification, town planning, linguistics and the theory of music. Stevin also made a name for himself as an inventor. In the water-dominated Holland he patented ingenious mills, sluices and dredging machines. He also made himself highly popular with his sailing wagon, which provided a lot of entertainment on Holland's beaches.

All of these undertakings, and the historical context in which they were realised, are extensively described in the book Magic is no magic; The *Wonderful World of Simon Stevin*. It is written by two Flemish authors, the theoretical physicist Jozef Devreese (University of Antwerp; Eindhoven University of Technology) and numerical mathematician Guido Vanden Berghe (Ghent University). Their aim was not so much to provide an original contribution to scientific history, but on the basis of the available source material to clearly present the life and work of Stevin to a wider intelligent public. They have excelled in this aim, even if the person Stevin remains something of a mystery due to the lack of witnesses.

The title 'Magic is no magic' refers to Stevin's motto that represents his vision of science. Phenomena around us are only magical in the sense that we do not understand them yet. As soon as the insight presents itself the magic ceases to exist. Together with the famous *Clootcrans* (chain of spheres) the motto forms Stevin's logo, which following the publication of *De Beghinselen der Weeghconst* (The Elements of the Art of Weighing) in 1586 was continuously used by him in all his publications. Using that chain of spheres, Stevin elegantly derived the ratios of the forces per sphere along both sides of an inclined slope when the closed chain did not spontaneously revolve.

Together with adjoining transactions about weighing in practice and about the theoretical and practical aspects of hydrostatics, Stevin's *The Elements of the Art of Weighing* forms a milestone in the development of statics and hydrostatics theory. This work constituted the first scientific progress in this area since Archimedes. Unlike most of his contemporaries, Stevin believed that theory and practice went hand-in-hand. Using experimental outcomes as additional support for ▮▮▮



insights obtained by means of deduction was an extremely novel approach in the sixteenth century. It signified a rift with the Ancient Greeks. Galileo is usually credited with this new approach, yet Stevin was ahead of the Italian. Also the hydrostatic paradox, a term of Robert Boyle, was first of all recognised by Simon Stevin – Pascal came a half century later.

Prior to *The Elements of the Art of Weighing* Stevin published several works in the areas of arithmetic and mathematics. The most important of these was *De Thiende* (The Dime) from 1585, a book that also exerted a large influence abroad due to its rapid translation. At that time the sexagesimal system was still widely used. The use of decimal fractions in arithmetic was not an invention of Stevin (the idea was already circulating). However, his proposal to work with tenths not only made it easier to perform calculations but also brought order to the prevailing monetary chaos of 20 *stuivers* in a *Carolische gulden* and 8 *duits* or 16 *penningen* in a stuiver. With the publication of his interest tables (at that time still shrouded by secrecy) and his introduction of shadow bookkeeping Stevin demonstrated that he was an economist ahead of his time. His ambition was to disseminate mathematical and arithmetic knowledge as widely as possible. That explains his choice to write in Dutch and not the academic language of Latin.

Stevin enriched the vernacular language with many new words that bore witness to a considerable inventiveness, appropriate to his aim of making his work accessible to a wider public. Interestingly Stevin regarded the large number of single syllable words in Dutch and the ease with which words can be combined (water + put = waterput [well]), as evidence that Dutch was an outstanding language for precise expression. One wonders if Stevin's work might have had more international impact if it had been published in Latin, the *lingua franca* of the time, as was the case a century later for his compatriot Christiaan Huygens.

In 1608 Stevin published his largest work, *Wisconstige Gedachtenissen* (Mathematical Memoirs). It contained the mathematics lessons he gave to Prince Maurits. The Prince, who was the stadhouder and commander of the troops of Holland and Zeeland, registered shortly after Stevin at Leiden University, only to give up his studies later following the murder of his father Willem de Zwijger. In 1593 Stevin entered into the employment of the Prince and his army. His publications in the area of fortification and warfare (published posthumously) are the product of this commission. In about 1600 the prince requested Stevin to compile a curriculum for an engineer's School at Leiden University, where *Duytsche Mathematique* [Dutch Mathematics] was taught in the national language. Snellius considered the Mathematical Memoirs to be so important that he personally took care of its translation into Latin.

Magic is no magic is a richly illustrated book with page insets containing detailed background information. It is the first serious study about Stevin and his work since the publication of Dijksterhuis in 1943[1]. Devreese and Vanden Berghe have given one of the greatest minds of the Renaissance, a transition period in the natural sciences, the position he deserves. One small criticism is that the authors sometimes fail to see the shortcomings of their main character. In his enthusiasm Stevin also applied mathematics to areas where that bore little fruit. An example is the theory of music. There he proposed a division of the octave that was mathematically correct but sounded dreadful. To give them credit, Devreese and Vanden Berghe did refer to a recent study about this subject by H. Floris Cohen[2], whereas Dijksterhuis's book focussed solely on the mathematics.

An overestimation of his own abilities merely reflects Stevin's pioneering nature and does not detract in the slightest from his greatness. Richard Feynman reached the same conclusion. When considering the resolution of forces in his Feyman Lectures on Physics, the American referred to Stevin's proof (using his chain of spheres) with admiration. After explaining two conventional methods he refers to the derivation of 'Stevinus' as 'even more brilliant'. ■

Dirk van Delft

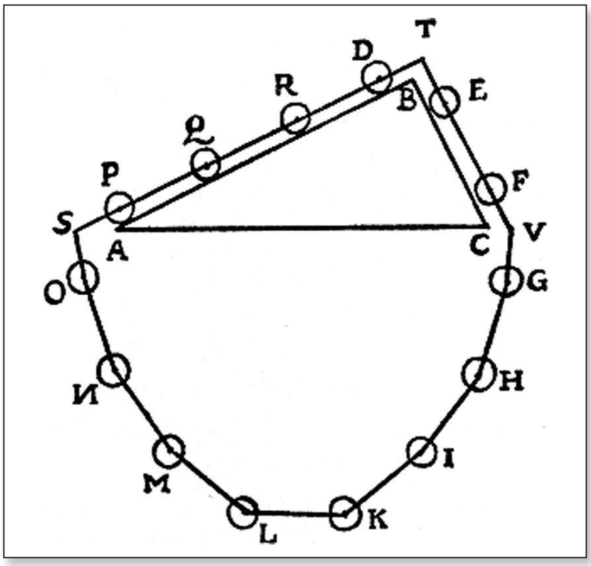
About the Author

Dirk van Delft is the director of Museum Boerhaave and endowed professor of Material heritage of the natural sciences at Leiden University.

notes

[1] E.J. Dijksterhuis, *Simon Stevin* (The Hague 1943).

[2] H.F. Cohen, 'Simon Stevin's Equal Division of the Octave', *Annals of Science* **44**, 1987 (471).



▲ Stevin's original drawing of the chain of spheres to deduce forces along a slope, termed 'brilliant' by Feynman in his Lectures on Physics.].

TECHNISCHE UNIVERSITÄT DRESDEN

At the **Faculty of Science, Department of Physics**, in the **Institute for Nuclear and Particle Physics** we have an opening for a

Postdoctoral Fellow in Experimental Particle Physics (E 13 TV-L)

The position is starting after 01.12.2009 for an initial period of three years with a possible extension of two years. The period of employment is governed by the Fixed Term Research Contracts Act (Wissenschaftszeitvertragsgesetz – WissZeitVG).

The ATLAS group in Dresden is a member of the "Forschungsschwerpunkt FSP-101" of the BMBF, the Helmholtz-Alliance "Physics at the Terascale" and of the Graduate school 1504 "Masse, Spektrum, Symmetrie" of the DFG. Activities of our group include studies of signal and background processes for Higgs boson searches both within and beyond Standard Model, reconstruction and identification of tau-leptons as well as operation and maintenance of the ATLAS Liquid-Argon calorimeter.

Duties: The successful candidate is expected to play a leading rôle in our data analysis activities. He/She will contribute to the maintenance of the local computing cluster in close collaboration with the Dresden Center for High Performance Computing (ZIH). Participation in the development of digital readout electronics at the interface to the trigger system for the upgrade of the liquid-Argon calorimeter in the context of the sLHC project and contributions to the teaching activities at the faculty are possible.

Qualification: A Ph.D. in experimental high energy physics is required. The successful candidate should have an excellent record of scientific achievements and the ability to coordinate the scientific activities of the group. Experience in the field of "Distributed Computing" or in digital electronics and fast serial networks would be an asset. Exceptional candidates will be offered the possibility of a "Habilitation".

Applications from women are particularly welcome. The same applies to disabled people.

Please submit your application by **August 27, 2009** (Deadlines refer to the date on the postmark of the University's Post Room Service) including your CV, a summary of research interests, list of publications with own contributions, a copy of the certificate of your highest academic degree and three names of referees to **TU Dresden, Fakultät Mathematik und Naturwissenschaften, Fachrichtung Physik, Institut für Kern- und Teilchenphysik, Herrn Prof. Dr. M. Kobel, 01062 Dresden, Germany** or to **IKTP@physik.tu-dresden.de** (Please note: We are currently not able to receive electronically signed and encrypted data).

EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

ESF Research Conferences
CALL FOR PROPOSALS

The European Science Foundation invites proposals for topics for its **2011** Research Conferences in

Physics, Biophysics and Environmental Sciences

The call is addressed to leading European scientists interested, if successful, in chairing the conference.

The chair will be in charge of ensuring the quality of the scientific programme through the selection and invitation of speakers, and through the selection of participants. ESF will provide full organisational and logistical support for the conference.

Proposals must be submitted electronically via the ESF Research Conferences website.

Submission deadline: 15 September 2009

For more information:
www.esf.org/conferences/call
or contact conferences-proposals@esf.org

European Science Foundation | ESF Research Conferences
149 avenue Louise Box | 1050 Brussels | Belgium
Tel: +32 (0) 25 33 20 20 | Fax: +32 (0) 25 38 84 86 | www.esf.org/conferences

KATHOLIEKE UNIVERSITEIT **LEUVEN**

Department of Physics & Astronomy
K.U.Leuven, Belgium
http://fys.kuleuven.be/

At the Department of Physics and Astronomy of the University of Leuven, Belgium, starting October 1, 2010, two faculty positions are available:

- **Tenure Track Position in Experimental Nanophysics: nanoscale fluxonics and plasmonics**
- **Faculty position in Astronomy: modelling of stellar and circumstellar media**

More information can be found on the web:

http://www.kuleuven.be/personeel/jobsite/vacatures/science.html

Closing date: September 30, 2009

The K.U.Leuven is an equal opportunity employer. Non-Dutch speaking candidates should be able to teach in Dutch within three years.

TRAVAILLER À L'UNIVERSITÉ DE GENÈVE

The Faculty of Sciences at Geneva University opens the application of position of

Full Professor, Associate Professor or Assistant Professor in Theoretical Physics

POSITION: This is a permanent full time position with 6 hours of teaching per week as well as research activities at the interface of quantum information and condensed matter theory or theoretical quantum optics. The candidate is expected to pursue a rigorous program in this field and to participate in the supervision of graduate students and teaching on all levels.

CHARGE : 100%

REQUIREMENTS : PhD in physics or equivalent.

STARTING DATE : September 1, 2010 or as agreed.

Applications, including curriculum vitae, list of publications and list of references are to be sent before 31st October, 2009 to the Secretary of the Dean of the Faculty of Sciences, 30, quai Ernest Ansermet, CH-1211 Genève 4 (Switzerland), where further information concerning this position and the working conditions can be obtained, or by e-mail to: lisette.marques@unige.ch.

The University of Geneva is an equal opportunity employer and encourages female candidates.

UNIVERSITÉ DE GENÈVE