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Perio*diek

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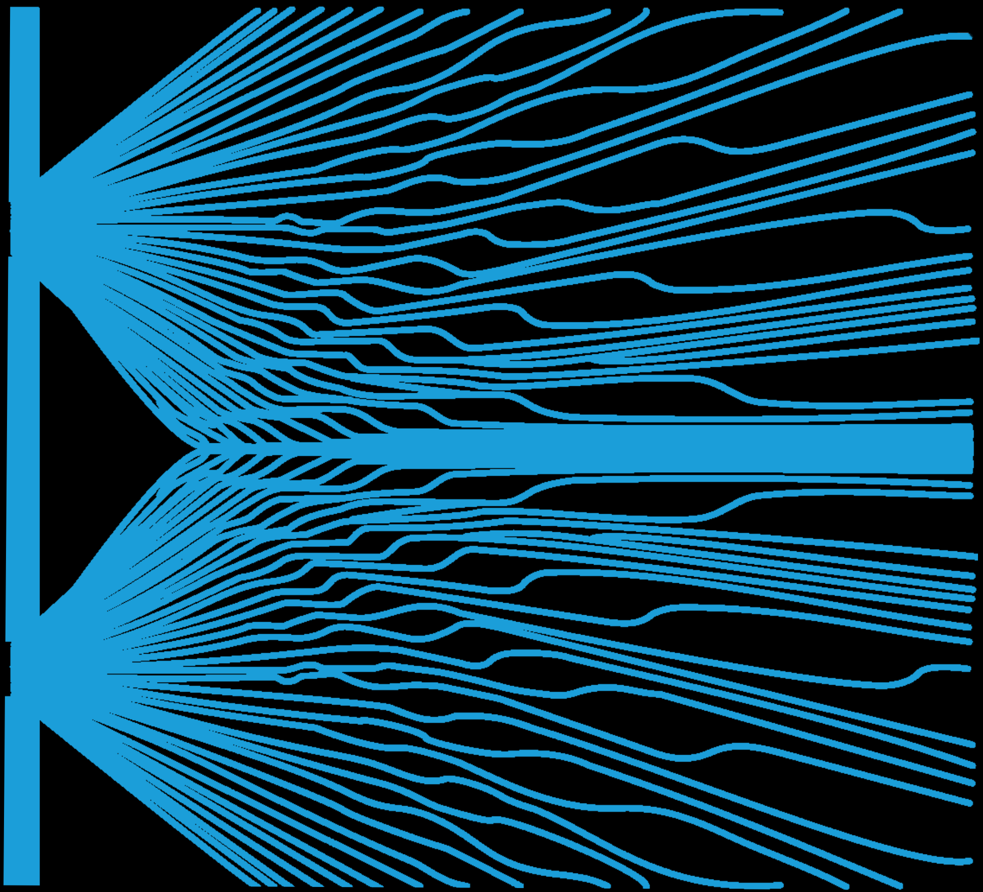
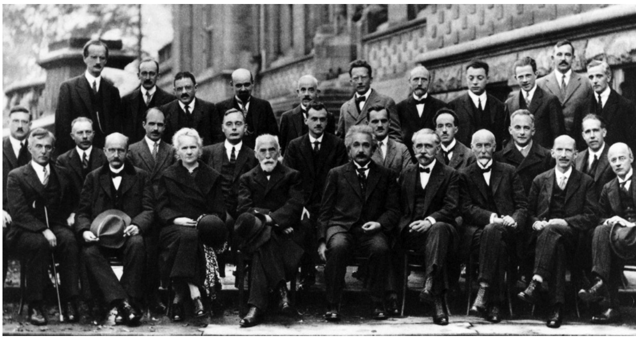


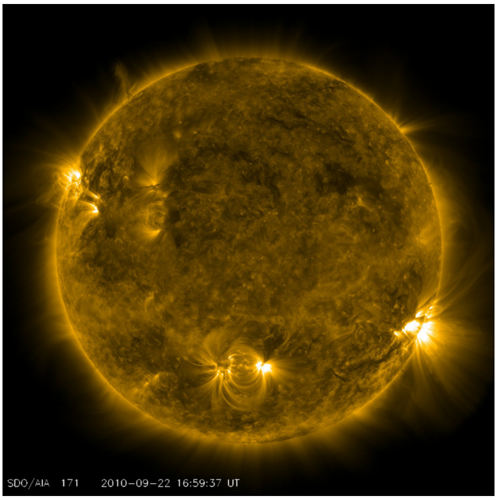
Quantum Revolution
Have we been brainwashed by Bohr?

Christian Maes - p. 6

6 - Quantum revolution now

Revolution! In this edition of the Periodiek, one of the articles was written by professor Christian Maes, a man from Leuven with some rather controversial views. Is the form of Quantum Mechanics we are being taught all wrong? In this six page article he tells us all about it!





16 - Solar Flares and the Illumination of History

New in ‘From the Frontiers of Knowledge’, the Energy and Sustainability Research Institute Groningen (ESRIG). Michael Dee tells us about his work on Radiocarbon Dating.

27 - The Kapteyn Radio Telescope

For their bachelor project Bram Lap, Willeke Mulder, Frits Sweijen, and Maik Zandvliet designed and built a radio telescope. The Kapteyn Radio Telescope is designed to measure residues of the early Universe, namely the Cosmic Microwave Background.

In this Periodiek

From the Editor in Chief

The creation of the last Periodiek of 2016 went rather slowly, as we didn't exactly know how to put together this magazine. On the last day of the Perio weekend (The weekend in which the magazine is put together by the editors), Douwe Visser, the editor in chief of last year, helped us out, which enabled us to make some quick progress. This time, it all went a lot faster, which gave us more time to make this edition even better than the last, as far as the aesthetics go.

What also makes this edition of the Periodiek great, are the articles the authors sent us this time. As usual, several RUG institutes present some of their work in our column 'From the Frontiers of Knowledge'. Also, we have some other diverse articles, including one from the chairman of the FMF. On the last page you will of course find a recipe and a brainwork, including the answer to the well-received brainwork of last time.

Enjoy!

-Rick Vinke

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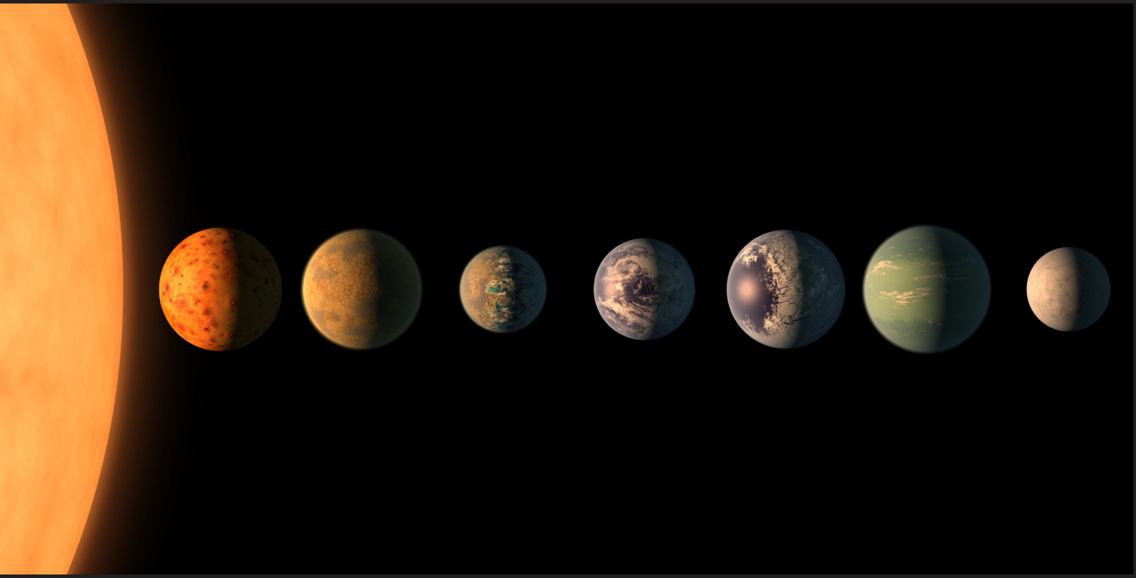
In The News



NASA

Organic Electronic Synapse

The neurons of our nervous system share information by electrical or chemical signals. A synapse is the junction of two neurons. Electrical synapses share information by ion flow between two neurons. The ion flow is stimulated by the potential arriving at the end of a neuron. When the ions flow into the terminal, neurotransmitters are released. The neurotransmitters depolarise or hyperpolarize the other neuron. The potential is passed or not passed on depending on the polarisation.

Researchers of Stanford University created a synapse of organic material. The artificial synapse comprises a saltwater electrolyte connected to two flexible films with three terminals. One of the terminals controls the electric signal between the two other terminals. The artificial synapse is a good alternative to modern digital transistors because a synapse can contain more states than 0 and 1 and takes up less energy for state switching.

The Engineer

Plastic Film Cools any Surface by 10K

Imagine a material that can cool down any surface it sits on. Imagine that same material to be cheap and easy to produce. Glass powder mixed with polymethylpentene is such a material.

Material scientist Xiabo Yin produced a thin plastic film with small glass spheres. The film is a strong infrared emitter because infrared photons resonate in the 8 mm glass beads. When the film is coated with silver the material can cool any surface it lies on by 10 K. Due to the silver coating only 4% of the incoming photons is absorbed. The glass spheres absorb heat and emit the energy in the mid-infrared. Few air molecules absorb photons in the infrared. Therefore the temperature of the surroundings of the cooled surface stays constant and the surface can cool down.

Science

Seven 'Earths' Discovered

Discovering liquid water in the universe is the higher ground for any astronomer. Research on a dwarf star 39 light-years removed from earth revealed seven planets orbiting their host star TRAPPIST-1. All seven planets resemble earth in size and mass.

The seven so-called temperate terrestrial planets were discovered by an international team of astronomers. Three of the exoplanets have a surface temperature that suits a possible presence of liquid water. Spectroscopy on the exoplanets will reveal whether humans have found a potential new habitat.

NRC

Buttercups Use Optical Interference to Appear Glossy

Buttercup flowers stand out by their yellow coloured petals. Besides the flower's bright colour, the petals are extraordinary shiny. What could be the mechanism behind the buttercups' appearance?

Casper van der Kooi studied the buttercup during his PhD at the Rijksuniversiteit Groningen. Van der Kooi found that the petals of the buttercup contain two properties that give the butter cup its shiny yellow colour. First, the petals have a thin layer, the epidermis, that contain the yellow pigment. Below the single cell layer are air chambers. The air chambers reflect the light and optical interference occurs. This creates the shine on the petals.

Second, the petals have a starch layer that scatters light. The geometry of the petals combined with the starch layer causes the light to scatter back into the epidermis. The starch layer explains the bright yellow colour: The pigment is activated twice by the light.

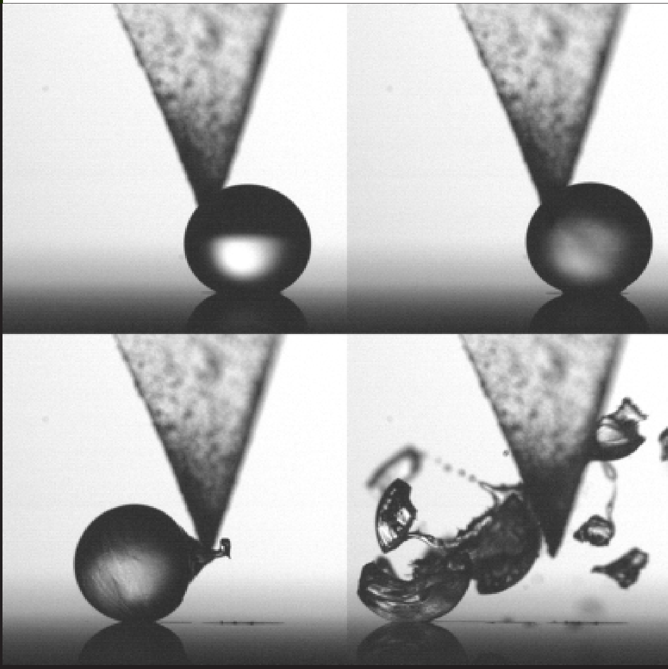
RUG
Casper van der Kooi

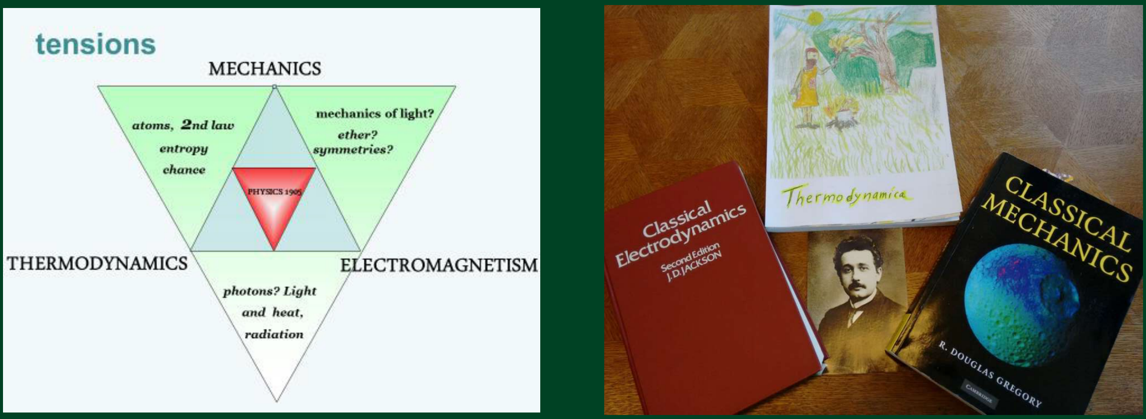
Frozen Water Droplets Explosion

When water droplets are frozen they can explode. The physical process of the exploding droplet was captured with a high-speed camera by researchers of the University of Twente. The water droplet was placed in a vacuum and cooled to just below the freezing point, after which the droplet is touched with a tip of silver iodide.

The outer shell freezes and thickens inwards. The inner fluid part of the droplet wants to expand but is captured in the frozen shell. The rising pressure causes the shell to crack and the water droplet explodes. Whether the droplet explodes depends on the radius of the droplet.

UTwente.nl
S. Wildeman et al., Phys. Rev. Lett. (2017)





FIGURES 1 AND 2: The Pillars of Classical Physics.

AUTHOR: **PROF. DR. CHRISTIAN MAES**

Quantum Revolution Now

Christian Maes is a professor at and head of the Theoretical Physics department of the University of Leuven. At the FMF symposium, he argued the case for a new revolution in Quantum Physics, as he deems the form in which it is currently presented in de scientific world is not only vague, but also wrong.

While revolutions often appear to be mass movements, especially afterwards, the seeds can be few and the beginnings can be much more modest. That is not different for the scientific revolutions of the beginning of the twentieth century. Let us go to Bern to find there around 1905 the young Albert Einstein in the patent office. His thoughts run over the many tensions between the three pillars of classical physics, that is to say mechanics, electromagnetism and thermodynamics (Fig. 1).

Between mechanics and thermodynamics, there is the problem of dealing with fluctuations and developing statistical arguments that derive macroscopic behavior from microscopic laws. Einstein would write his famous paper on Brownian motion there, cornerstone of colloidal physics and of dynamical fluctuation theory, fundamental also for suggesting a method to measure Avogadro's number and hence providing evidence for the atomistic view on matter. It was also the time of writing the paper on special relativity and on the equivalence of mass and energy, suggesting a solution to problems between electromagnetism and mechanics. The laws of Maxwell do indeed not have the same symmetry as those of Newton, and Einstein had been fascinated by the mechanics of light from his early age on. Finally there were many tensions between thermodynamics and electromagnetism. Here we deal with the interaction of light and matter, the entropy of radiation and the relation between energy and spectroscopic data. It was around the subject of black-body radiation that Einstein wrote then his most revolutionary paper and where he proposed the concept of light particles, which we call photons today. He used these ideas in the same paper to explain the paradoxical findings of Hertz concerning the photoelectric effect, and a little later to give the first quantum theory of specific heats of solids where the light particles must be replaced by vibrations (phonons).

The First Phase

The next development, the initial phase of quantum physics, proceeded by the application of quantisation rules to classical mechanics. The Bohr-Sommerfeld rule equated quantum numbers with adiabatic invariants. It worked very well: important empirical puzzles were solved and spectroscopic data were beautifully reproduced. The theory advanced also thanks to new discoveries and technology, which informed physicists better about the subatomic world.

The Second Phase

The second stage of quantum mechanics must have started around 1926. From then on we get the more systematic solution of quantum problems, quantum physics becoming quantum mechanics, and the development of the quantum formalism. That was of course thanks to the discovery of wave mechanics by Schrödinger, directly inspired by combining the work of Hamilton on the unification of mechanics and optics with some important suggestions of de Broglie. More algebraic was the matrix mechanics of Heisenberg. We also see there the beginning of scattering theory, and successes were building up. To this day, students of quantum mechanics learn about the Born approximation in scattering theory, dating from 1926. Yet, in the midst of all that also appear the first dissidents like Einstein and Schrödinger, pioneers and critics at the same time. In that period we also find the origin of a variety of quantum thought experiments, which only much later, in our times, have become possible in reality. It has often been said that Einstein was already behind in 1927, the time of the famous Solvay conference in Brussels (Fig. 6), where Einstein in discussions with Niels Bohr challenged the new quantum mechanics. In reality Einstein was far ahead, seeing clearly the essence of the quantum revolution and its conceptual difficulties. In 1928, Einstein wrote to Schrödinger:

> *The Heisenberg/Bohr tranquilizing philosophy - or religion? - is so delicately contrived that, for the time being, it provides a gentle pillow for the true believer from which he cannot very easily be aroused.*

In another letter to Schrödinger, Einstein referred to Bohr as the *Talmudic philosopher for whom reality is a frightening creature of the naive mind.* Einstein also referred to Bohr as *the mystic, who forbids, as being unscientific, an enquiry about something that exists independently of whether or not it is observed,* for example as to whether the Schrödinger cat is alive at a particular instant before an observation is made.

The Third Phase

The third phase of quantum mechanics can perhaps be said to have started after the war, in 1945, with the outbreak and development of nuclear physics, quantum field theory, and solid state-physics taking full advantage of the new mechanics. Especially new techniques in perturbation theory and in scattering theory enable unseen precision and experimental validation. At that point, there is more and more the connection with Big Science (a term used by scientists and historians of science to describe a series of changes in science which occurred in industrial nations during and after World War II – editors), and the birth of large centers for exploring elementary particle physics. It goes hand in hand with the optimism of the atomic age, symbolised by the Atomium at the universal world fair of 1958 in Brussels (Fig. 4).

In mainstream physics, there is little or no attention to the foundations of quantum mechanics, despite multiple dissidents. In 1926 Schrödinger wrote:

> *Bohr's […] approach to atomic problems […] is really remarkable. He is completely convinced that any understanding in the usual sense of the word is impossible. Therefore the conversation is almost immediately driven into philosophical questions, and soon you no longer know whether you really take the position he is attacking, or whether you really must attack the position he is defending.*

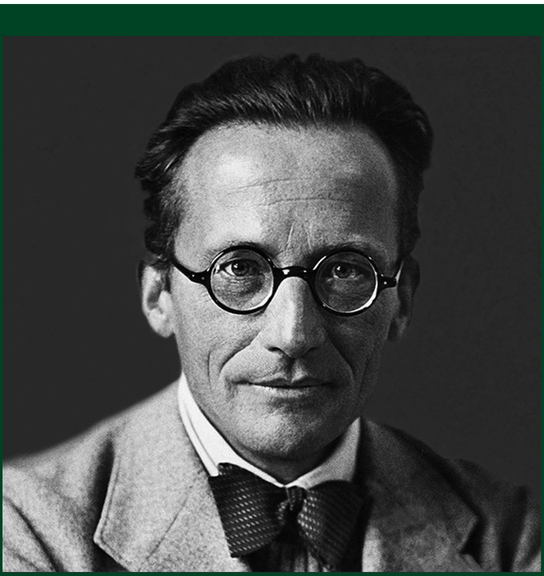


FIGURE 3: Erwin Schrödinger

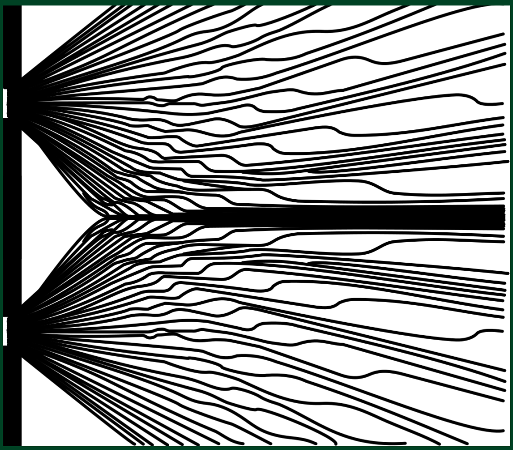


FIGURE 4: In Bohmian mechanics, a particle travels on a pilot wave and has a well-defined trajectory. It yields in measurement situations the same probabilistic results as predicted by the statistical formalism of quantum mechanics

And still thirty years later, Schrödinger said in 1959:

> *With very few exceptions (such as Einstein and Laue), all the rest of the theoretical physicists were unadulterated asses and I was the only sane person left. [...] If I were not thoroughly convinced that the man [Bohr] is honest and really believes in the relevance of his - I do not say theory but - sounding word, I would call it intellectually wicked.*

Such phrasing has been repeated, for example by Murray Gell-Mann in 1979:

> *Bohr brainwashed a whole generation of physicists into thinking that the job was done 50 years ago. and by John Nash, To me it seems like "quantum theory" is in a sense like a traditional herbal medicine used by witch doctors. We don't REALLY understand what is happening, what the ultimate truth really is, but we have a "cook book" of procedures and rituals that can be used to obtain useful and practical calculations (independent of fundamental truth).*

In fact, since the very beginning of quantum mechanics, especially Einstein and Schrödinger have been pointing to the measurement problem, and have raised the question of completeness. They thereby emphasised the remarkable features of entanglement and possible nonlocal effects.

The Measurement Problem

The measurement problem has various faces. At first it appeared in the Copenhagen Collapse postulate to make the bridge between wave mechanics and the real world. Something was needed indeed: when we would stick to the wave function and only the wave function, how does the world appear then? Or already more precisely, if the wave function for the largest system relevant at measurement (system plus apparatus plus environment) gives a complete description, and evolves linearly in time, how can it be then that measurements yield definite results? [1] However the proposed solution, the old quantum mechanical collapse postulate, is rather vague. Here is a comment of John Bell:

> *I think there are professional problems [with quantum mechanics]. That is to say, I'm a professional theoretical physicist and I would like to make a clean theory. And when I look at quantum mechanics I see that it's a dirty theory. The formulations of quantum mechanics that you find in the books involve dividing the world into an observer and an observed, and you are not told where that division comes [...]. So you have a theory which is fundamentally ambiguous [...].*

Various better solutions (modifications and interpretations) have been proposed for that measurement problem, such as the Ghirardi-Weber-Rimini model with a nonlinear Schrödinger equation, the de Broglie-Bohm pilot wave formulation (Fig. 4), and the many worlds interpretation. Especially that Bohm theory, nowadays called Bohmian mechanics, has provided a mathematically and physically consistent quantum theory of particles.

Completeness was the issue raised by the Einstein-Podolsky-Rosen paper of 1935. The argument was that the physics of entangled pairs of particles, in particular the perfect (anti)correlations between certain distant measurements, would imply nonlocal influences if there

FIGURE 5: The Atomium in Brussels

were no certain hidden variables. The paper remains a crucial contribution to the understanding of quantum mechanics. The larger debate of the existence of hidden variables was much more blurred. John Bell had in fact started his foundational research by investigating so-called no-hidden-variable-theorems:

> *I found not that they were wrong, just stupid. And, after reading the publications of David Bohm (1952): I saw the impossible done.*

Compare this with a quote of Richard Feynman:

> *Nobody knows any machinery. Nobody can give you a deeper explanation of this phenomenon than I have given; that is, a description of it.*

Or of Lev Landau and Evgeny Lifshitz:

> *It is clear that [the results of the double-slit experiment] can in no way be reconciled with the idea that electrons move in paths. [...] In quantum mechanics there is no such concept as the path of a particle.*

Bell writes about his motivation:

> *...as a professional theoretical physicist I like the Bohm theory because it is sharp mathematics. I have there a model of the world in sharp mathematical terms that has this non-local feature. So when I first realised that, I asked: ''Is that inevitable or could somebody smarter than Bohm have done it differently and avoided this non-locality?" That is the problem that the theorem is addressed to. The theorem says: No! Even if you are smarter than Bohm, you will not get rid of non-locality.*

Bell writes here about the origin of (his) Bell inequalities. The violation of the Bell inequalities shows that nonlocality is a necessary property of any reformulation of quantum mechanics. It is the natural continuation of the Einstein-Podolsky-Rosen argument.

Bell was able to show that the Einstein locality assumption not only implied certain hidden variables, but also specific inequalities related to correlations between entangled particles. Those Bell inequalities are violated, as expected by formal quantum theory and as tested experimentally by many groups, e.g. in 2015, the Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometres, by B. Hensen et al. [1]. Bell intended this result as a defense of Bohmian mechanics: nonlocality is not a defect, but a feature! By a small twist of faith though, the result has become known in certain circles as the main argument against hidden variables. And confusion remains, here is Stephen Hawking:

> *Einstein's view was what would now be called a hidden variables theory. Hidden variables theories might seem to be the most obvious way to incorporate the Uncertainty Principle into physics. They form the basis of the mental picture of the universe, held by many scientists, and almost all philosophers of science. But these hidden variables theories are wrong. The British physicist, John Bell, who died recently, devised an experimental test that would distinguish hidden variables theories. When the experiment was carried out carefully, the results were inconsistent with hidden variables.*

Notwithstanding such misunderstandings, some no-hidden-variable-theorems, such as the one of Kochen

FIGURE 6: The 1927 Solvay Conference

and Specker remain valid and useful. In fact they are relevant also today to exclude some interpretations such as the decoherent or consistent histories approach to quantum mechanics. The main thing in general is to avoid a naive realism about operators.

Nonlocality, the main new feature of quantum mechanics is, as mentioned above, made possible by entanglement. Here is Schrödinger in 1935:

> *When two systems, of which we know the states by their respective representatives, enter into temporary physical interaction due to known forces between them, and when after a time of mutual influence the systems separate again, then they can no longer be described in the same way as before, viz. by endowing each of them with a representative of its own. I would not call that one but rather the characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought. By the interaction the two representatives (the quantum states) have become entangled.*

I repeat, we are in 1935 here – yet, this aspect has been mostly ignored in the development of quantum mechanics and quantum field theory till far in the twentieth century. The point is however simple: wave functions are functions of the positions of all particles together, not functions on physical space, but on configuration space. Quantum states are states of all particles together – nonseparable in general. Schrödinger continues:

> *A sophisticated experimenter can, by a suitable choice of operations carried out on one system, 'steer' the second system into any chosen mixture of quantum states. That is, the second system cannot be steered into any particular quantum state at the whim of the experimenter, but the experimenter can constrain the quantum state into which the second system evolves to lie in any chosen set of states, with a probability distribution fixed by the entangled state.*

Schrödinger thought that so strange that he supposed that entanglement can only happen very locally. As we saw already, Einstein, Podolsky and Rosen in 1935 essentially used the effect to show that locality implies certain types of hidden variables. Most other physicists did not care and concentrated on calculations or the mathematical formalism often combined with a Bohr-like reaction that physics is not about nature but about measurements. As a consequence, entanglement was not truly discussed until 1964, when John Bell recalled the EPR set-up, and inspired the first experimental tests as by Aspect in 1982. Still, the bulk of the physics community considered entanglement business either as wrong, or as philosophy, or as trivial and uninteresting…

The Second Quantum Revolution

I suggest that around that time, say 1980, the second quantum revolution started. It entailed various related things. A big part of it was trying to get to terms with the nonlocality of nature as exhibited via entanglement in quantum mechanics. What is exactly that spooky action at a distance, and how to reconcile it with relativity? Even though there exists no Bell telephone (A hypothetical device named after physicist John Bell which allows signals to be sent faster than the speed of light - editors), certainly on an intuitive level there remains an issue and friction. Despite appearances, reconciling relativity theory with quantum mechanics cannot but take that hurdle some day. Will it be related to the emergence of space-time, to the appearance of wormholes? Nobody knows for the moment.

Secondly, entanglement has consequences for certain phases of matter, topological in nature mostly, which constitute a new interesting research domain in condensed matter physics. Related is the possibility to consider global order parameters whose values are topologically protected, important also possibly for the construction of quantum memories. Here we touch the enormous efforts related to new quantum machinery, in terms of computation, simulation, cryptography, teleportation, etcetera.

Furthermore, entanglement and how to deal with it is also directly connected with the rapidly developing many-body quantum physics. Twentieth-century quantum mechanics has dealt mostly with independent or weakly correlated particles. Scattering, tunneling, and interference were the main quantum issues; now we deal with truly interacting quantum systems where nonlocality plays a great role and where the main challenges are the strong correlations and the non-perturbative effects. There we see new techniques being invented going from applying the so-called holographic principle to the application of tensor networks. All that is part of the new second quantum revolution.

Finally, especially on the conceptual front, young physicists have become more skeptical and more serious about the quantum formalism. Mathematical understanding is no longer the central problem; linear algebra and the necessary tools from functional analysis or operator theory have become common in teaching. Yet we can no longer accept the old slogans. Let me put some together, in arbitrary order, ignoring authorship so as not to possibly embarrass the authors:

> *If you do not look it is a wave, and if you look, it is a particle.*
>
> *Some things you cannot ask of nature, like position and velocity at the same time.*
>
> *Uncertainty is the essence of quantum mechanics.*
>
> *The observables are the self-adjoint operators.*
>
> *Particles have no position; there are no trajectories.*
> *The idea of an objective real world whose smallest parts exist objectively in the same sense as stones or trees exist, independently of whether or not we observe them is impossible. There is no quantum world. There is only an abstract physical description. It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature.*
>
> *So, what is the message of the quantum? I suggest that the distinction between reality and our knowledge of reality, between reality and information, cannot be made.*

Instead the new generation wants to understand the quantum world without observers - how else would you start physical cosmology? - to give only one example. There cannot be a central or foundational place for 'measurement.' With the words of Bertrand Russell:

> *I still hold that any proposition other than a tautology, if it is true, is true in virtue of a relation to fact, and that facts in general are independent of experience. I see nothing impossible in a universe devoid of experience. On the contrary, I think that experience is a very restricted and cosmically trivial aspect of a very tiny portion of the universe.*

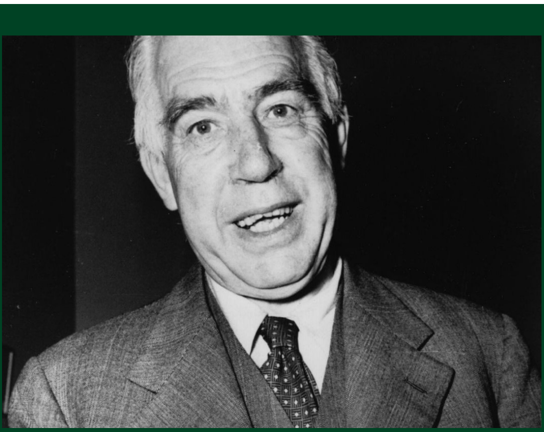


FIGURE 7: Niels Bohr

The ambition of a complete description gets restored and the purely formal treatment of quantum mechanics is left behind. Roger Penrose writes in 1994 in that sense:

> *It is nonsensical to use the term `reality' only for objects that we can observe, like a certain measurement apparatus, and to deny that that terminology can be used on a deeper level. Surely the world is strange and unfamiliar on the quantum level, but it is not 'unreal'. Indeed, how could real objects consist of unreal parts?*

Entanglement (more than tunneling) becomes the key to quantum many-body effects and quantum technology. What once was considered impossible, will become routine, like the measuring and controlling of individual atoms or single quantum units. The physics of condensed matter will advance in exploring quantum phase transitions and new collective quantum states, for example based on topological effects. Strongly correlated electron systems and non-perturbative physics as for example high temperature superconductivity will require a radical departure from known territories like the Fermi liquid image and various perturbative regimes. Many-body entanglement will play an important role in relaxation and dissipation, and changes the problems of today's statistical mechanics. Quantum nonequilibrium physics will deal with nonlocal effects in transport and self-organisation.

That revolution, the quantum revolution of today, asks new textbooks, new sources of knowledge. We need new groups, leaving the paths of Big Science, tackling also the experimental challenges of quantum optics. We need a scientific-technological front to stimulate the development of quantum machinery and quantum computation, and we need you. Good luck! •

Further Reading

Jean Bricmont, Making Sense of Quantum Mechanics. Springer (2016). Olival Freire Junior, The Quantum Dissidents, Rebuilding the Foundations of Quantum Mechanics (1950-1990), Springer (2015).

[1] S. Goldstein en J.L. Lebowitz, 1995

[2] B. Hensen et al., Nature 526, 682–686 (2015)

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FROM THE FRONTIERS OF KNOWLEDGE

JBI

Researchers from the various institutes affiliated with the RUG in the fields of physics, mathematics, astronomy, computing science, and artificial intelligence report on the cutting-edge science that is conducted there.

Bifurcations and Chaos in the Lorenz–96 Model

AUTHORS: **DIRK VAN KEKEM, MSC.** AND **DR. ALEF STERK**

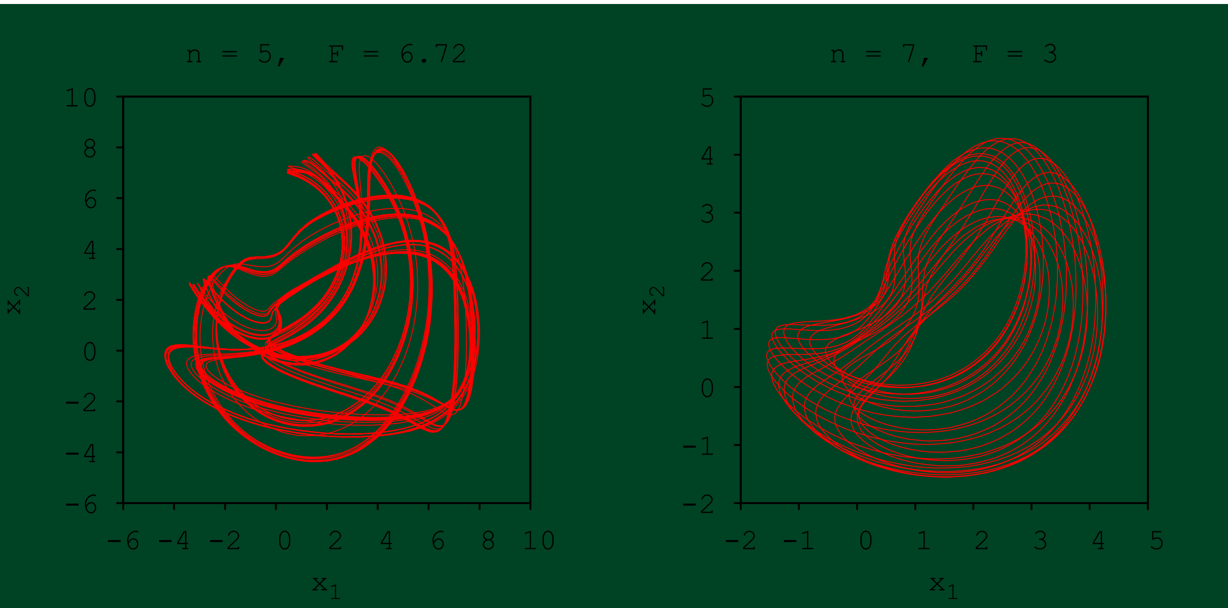

FIGURE 2: A chaotic attractor (left) and a quasi-periodic attractor (right) of the Lorenz–96 model projected on the (x1, x2)-plane.

The Johann Bernoulli Institute for Mathematics and Computer Science (JBI) conducts research which addresses fundamental questions both within the disciplines of mathematics and computer science and research directed towards applications. The JBI aims for a fertile transfer of knowledge between mathematics, computer science, and other fields. Cross-disciplinary research with a focus on earth and life sciences (in particular including climate modeling, healthy ageing, and energy) is an important theme within the JBI.

The Lorenz-96 Model

In his 1996 paper the mathematician and meteorologist Edward Lorenz introduced a toy model to study fundamental issues regarding the predictability of weather and climate [2]. He did not aim to design a complicated and realistic model of the atmosphere, but he rather designed it as a simple test model with some basic physical properties.

The Lorenz–96 model describes atmospheric traveling waves along a circle of constant latitude. We divide the latitude circle into n equal parts and define for each j-th part a distinct variable x_j. The index $j = 1, \dots, n$

indicates the longitude at which the variable is measured and the variable x can be interpreted as a scalar meteorological quantity (such as temperature, pressure or vorticity). The equation for the j-th variable is given by:

$$\frac{dx_j}{dt} = x_{j-1}(x_{j+1} - x_{j-2}) - x_j + F, \qquad (1)$$

and a 'boundary condition' $x_{j-n} = x_{j+n} = x_j$. The parameter F represents external forcing. The aim is to understand the long-term dynamics of equation (1) and qualitative changes in dynamics upon variation of the parameters F and n. The transition from orderly to chaotic dynamics is particularly important.

Hopf Bifurcations of Equilibria

The first step is to find the equilibria of equation (1), i.e. $\lambda_{1,2}$ solutions which are independent of time. Clearly, $x_F = (F, F, \dots, F)$ is an equilibrium for all $n \in \mathbb{N}$ and all $F \in \mathbb{R}$. The stability of x_F follows from the eigenvalues of the Jacobian matrix of equation (1) evaluated at x_F. For example, for $n = 4$ this matrix is given by

$$\begin{pmatrix} -1 & F & -F & 0 \\ 0 & -1 & F & -F \\ -F & 0 & -1 & F \\ F & -F & 0 & -1 \end{pmatrix}$$

of which the eigenvalues are given by

$$\lambda_1 = -1 + F + Fi, \quad \lambda_2 = -1 + F - Fi, \quad \lambda_3 = -1 - 2F, \quad \lambda_4 = -1.$$

At F = 1 the real part of the complex eigenpair becomes positive and thus the equilibrium loses stability. After this bifurcation a stable periodic solution appears. This change in qualitative behaviour is known as a Hopf bifurcation [1, 4]. For all $n \geq 4$ we can prove that this bifurcation occurs for $\frac{8}{9} < F < \frac{3}{2}$, see [3].

The periodic attractor has the physical interpretation of a traveling wave, which is illustrated in Figure 1 by means of a so-called Hovmöller diagram for $n = 10$ and $n = 20$. Note that the period and the wave number depend on the dimension n. We can prove analytically that the wave number ℓ_n satisfies

$$\frac{n}{10} < \ell_n < \frac{3n}{10}\ .$$

The period T_n is an oscillating function of n, but we can prove that it has a limit

$$T_\infty = \lim_{n\to\infty} T_n = 2\pi \tan(\tfrac{1}{2}\arccos(\tfrac{1}{4})) \approx 4.86.$$

Hence, for different values of the dimension n the dynamics of the Lorenz–96 system can be *qualitatively* similar, but different from a *quantitative* perspective.

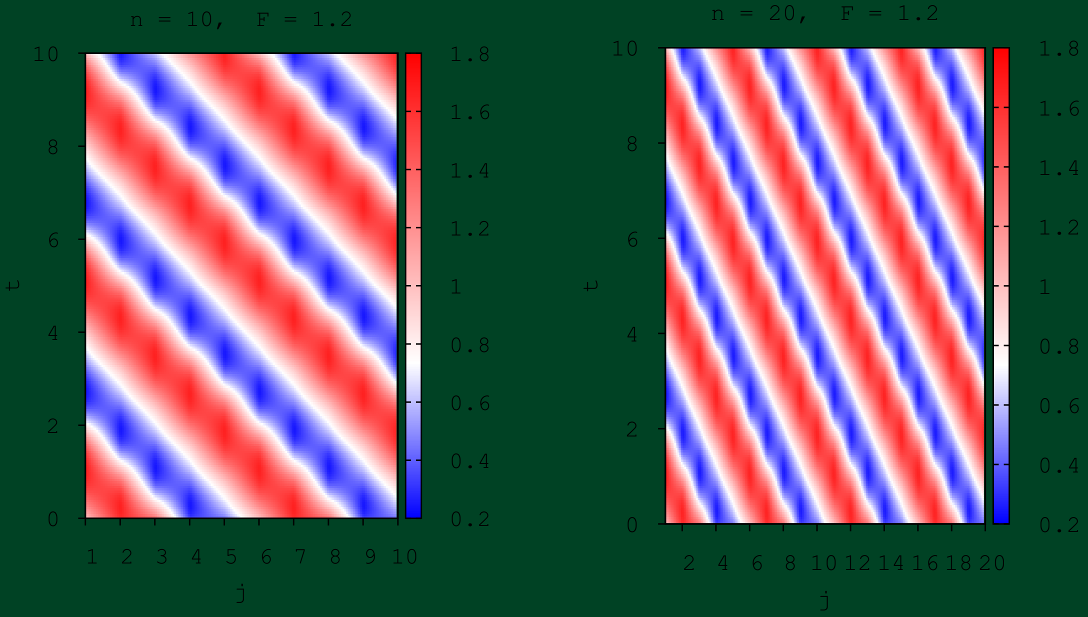

FIGURE 1: Hovmòller diagrams of periodic attractors in the Lorenz-96 model. The value of $x_j(t)$ is plotted as a function of t and j. The red and blue bands clearly illustrate that wave crests and troughs propagate in the direction of decreasing j.

Bifurcations of Periodic Attractors

The next step is to study the stability of the periodic attractors as a function of the parameters n and F. For example, for $n = 5$ we find that an infinite sequence (also known as a *cascade*) of period doubling bifurcations takes place. At each bifurcation a stable periodic attractor loses stability and after the bifurcation a new periodic solution appears with roughly twice the period. At the end of the cascade we detect a chaotic attractor, see Figure 2 (left panel). Periodic attractors can also lose stability through a so-called Neimark-Sacker bifurcation. After this bifurcation one finds a quasi-periodic attractor in the form of a two-dimensional torus. An example of such an attractor is shown for $n = 7$ in Figure 2 (right panel). For $n = 36$ we have also detected three-dimensional tori. Further bifurcations of these tori can lead to chaotic attractors.

The goal is to obtain a coherent dynamical inventory of the Lorenz–96 model. We study the geometry of chaotic attractors and the bifurcations leading to their formation. We classify attractors by means of dynamical indicators, such as Lyapunov exponents and fractal dimensions. Some dynamical properties, such as the existence of Hopf bifurcations, of the Lorenz–96 model can be rigorously proven. However, beyond the Hopf bifurcations most results have to be obtained by *experimental mathematics*, which means that mathematical theorems are replaced by educated guesses obtained from detailed numerical explorations.

Conclusion

The Lorenz–96 model is a dynamical system with very rich dynamics. Rather than studying individual solutions, our goal is to obtain a global and qualitative overview of the dynamics by studying the geometry in the product of state space and parameter space. We have been able to uncover some aspects of the dynamics, but there are still many open questions. Some of these open questions could be a addressed in follow-up Master or PhD projects •

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Johann Bernoulli Institute for Mathematics and Computer Science

The Johann Bernoulli Institute for Mathematics and Computer Science comprises two sections: Mathematics and Computer Science.

This set of programmes as a whole has as its main goal performing research at a high international level, leading to publications in international scientific journals and a steady stream of highly qualified researchers (at PhD level). The intended audience consists of the academic research community on one hand and social and professional practice (e.g. industry, hospitals and administration) on the other hand. The institute aims to provide an attractive research environment for graduate students by maintaining a modern infrastructure and by appointing highly competent and active scientific staff members.

From the Frontiers of Knowledge

Researchers from the various institutes affiliated with the RUG in the fields of physics, mathematics, astronomy, computing science, and artificial intelligence report on the cutting-edge science that is conducted there.

ESRIG

Solar Flares and the Illumination of History

AUTHOR: **DR. MICHAEL DEE**

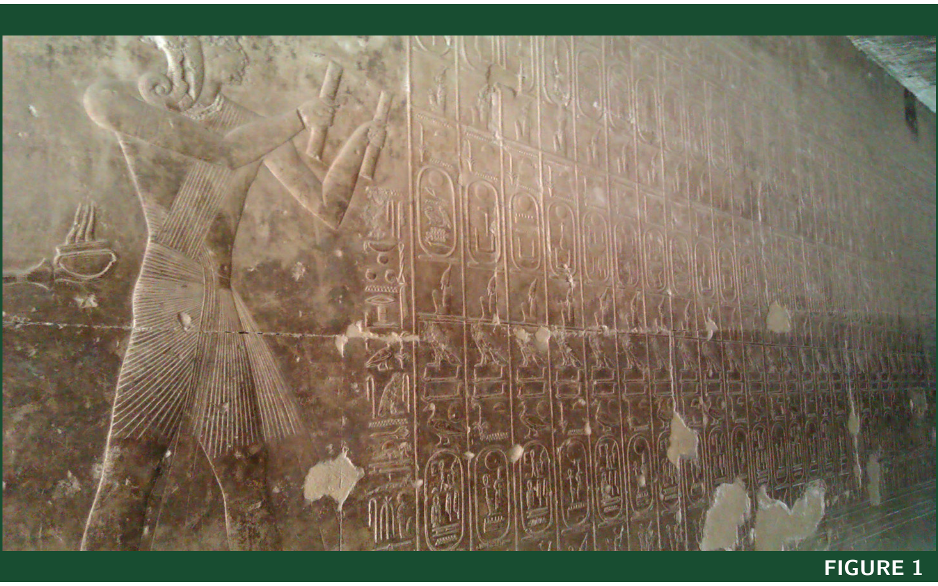

FIGURE 1

In the years 775 and 994 AD, the Earth was struck by intense bursts of radiation from space. The impacts resulted in dramatic increases in the concentration of radiocarbon in the atmosphere, and were most likely accompanied by widespread aurorae.

The years of the two strikes are precisely known because the enriched levels of radiocarbon were absorbed by growing trees, and archives of wood exist within which the age of each tree-ring is known to the exact calendar year. More ominously, a strike of such magnitude in modern times would be devastating for satellite, avionic and telecommunication systems. As a result, the two events have become the focus a considerable amount of research across a diverse range of academic fields.

The incessant particle radiation incident on the Earth's atmosphere sets in train a cascade of nuclear reactions that result in the liberation of neutrons. Radiocarbon is a by-product of these reactions, mainly formed by the capture of neutrons by nitrogen. However, neutrons may also be liberated by intense electromagnetic strikes. Consequently, a wide variety of mechanisms have been proposed for the spikes in radiocarbon production in the first millennium. These include gamma ray bursts from galactic supernovae or compact object mergers, cometary impacts on the sun or the Earth, and intense solar energetic particle events. The leading hypothesis is currently solar superflares. Superflares are stellar emissions up to one hundred thousand times greater than any flare ever observed on our sun. Research has already confirmed that superflares do occur on sun-like stars; however, there is still no consensus on whether this the correct explanation for the events detected on Earth.

Natural Archives

One of the central aims of my research is to uncover further impact years, by analysing more dendrochronological (tree-ring) archives. This should reveal if there is any patterning to the events and also help determine their cause. Additional information may also be gained by examining the cosmogenic isotope data available from the ice cores. Indeed, I recently convened an international research group with the intention of exploring the longer-term potential of this work for understanding the natural history of the near-Earth environment.

My background, however, is in radiocarbon dating applied to archaeological and palaeoenvironmental sequences. Over recent decades, Bayesian modelling has been the procedure of choice for refining such radiocarbon-based chronologies. Whilst sufficient for some research questions, the date ranges produced are still rarely less than 100 years (at 95% probability). This kind of resolution remains of limited value for events occurring on human time-scales. The discovery of the two major radiation strikes, however, provides an opportunity to surpass this limitation.

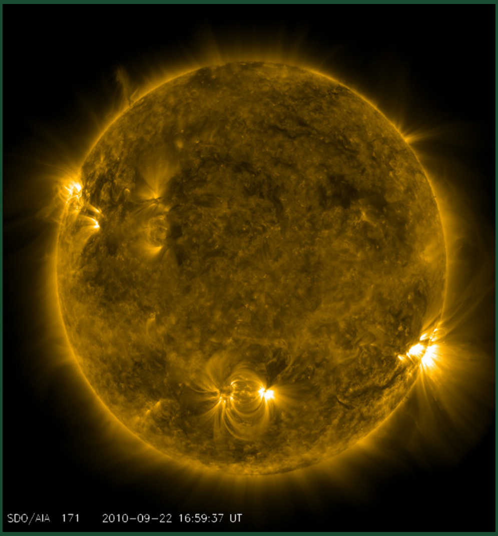

FIGURE 2: The sun (NASA)

Radiation Dating

The key point from a chronological perspective is that the enriched levels of radiocarbon would not only have been absorbed by tree-rings but also by all other growing plants. Materials such as papyri harvested for documentation, timber collected for construction or autumnal leaves preserved in lake records will also have retained the anomalously high levels of radiocarbon. By matching their measurements with those in tree-ring archives, it should be possible to date the archaeological and environmental samples to the exact calendar year. If a network of chronological tie-points of this nature could be established, it would revolutionise our understanding of ancient civilisations, such as the Maya and the Egyptians, and allow for human-environment interactions to be scrutinised as never before. Late last year, I was awarded an ERC Starter Grant to develop this line of enquiry. Exact Chronology of Early Societies (ECHOES) is a five-year project that aims both to uncover more radiation events, and to use them to pinpoint key developments in the early history of civilisation •

FIGURE 3: Tree-rings

FIGURE 4: Chichen Itza

FROM THE FRONTIERS OF KNOWLEDGE

Researchers from the various institutes affiliated with the RUG in the fields of physics, mathematics, astronomy, computing science, and artificial intelligence report on the cutting-edge science that is conducted there.

ZIAM

Bridging Photosynthesis and Nano-Electronics

Towards a Bio-Hybrid Graphene Nano-Device

AUTHOR: **XU YANG**

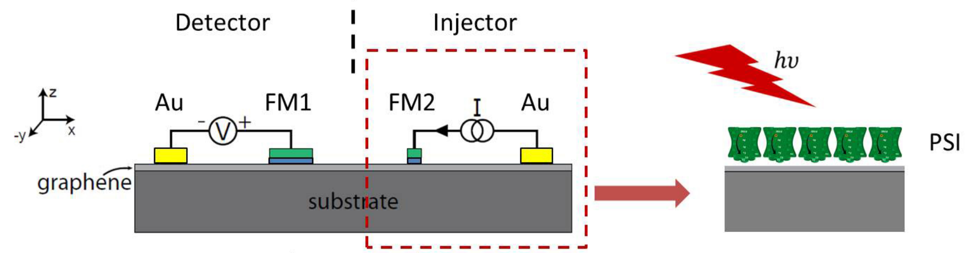

FIGURE 2: Schematic of a non-local spin-valve and the idea of replacing the spin injector with a layer of oriented PSI units.

Being stuffed with Facebook posts and Pokémon, your smartphone may not have a chance to show its incredible processing power. But the truth may put you at a loss for words. When comparing the floating-point operations per second (FLOPS), the latest iPhone 7 outruns the fastest 1997 supercomputer by a large margin. Not even mentioning that the iPhone 7 is 30000 times cheaper, and can make phone calls. Twenty years of technology advancement can now literally be held in your hand. Isn't that amazing?

The field of electronics is definitely demonstrating to us what humanity is capable of. Gordon Moore once predicted that the amount of transistors in an integrated circuit doubles every two years. The law has been effectively and successfully directing the whole semiconductor industry over half a century. However, in recent years people have been facing difficulties keeping up the pace. Fundamental problems such as quantum tunneling and overheating will arise when people further down-size the industry into the nano world. There will definitely be an end to Moore's Law, and this may happen within just 5 years. But for all the scientists working in this field, this news is exciting rather than upsetting. And it is what 'beyond Moore' that puts them on the edge of their seats.

What Comes Next?

Spintronics, or spin-electronics, might be what comes next. The most essential part of electronics is, obviously, electrons. Conventional electronics uses electron charges to carry information. But we should never overlook another degree of freedom electrons can provide – spin. By translating 1 and 0 into electronic up and down spin states, individual electrons can become carriers of information. Furthermore, because spin originates from the deep root of quantum mechanics, it opens a door to quantum information and quantum computing.

How Do We Make Them?

Here at the Zernike Institute for Advanced Materials, we are trying our best to make spintronic nano-devices work. Professor Bart van Wees uses graphene and other two-dimensional materials to preserve and transport spins. Professor Caspar van der Wal takes another approach: he tries to use light to control spins in solid state materials. Inspirations also come from Nature. Scientists have shown that Photosystem I (PSI), a protein complex that helps plants harvest energy from sunlight, can also generate highly polarised spin signals. Professor Andreas Herrmann is the expert here in extracting and purifying PSI from living organisms. All these ideas and expertise come together to one single project: combine PSI with graphene and build a bio-hybrid spintronic device that can be controlled with light.

How Would That Work?

The goal of this project is to realise a device that is known as a non-local spin-valve, as shown in Figure 2. In order to inject spins into graphene, conventionally we send an electric current through a ferromagnetic contact (FM2). Since ferromagnetism is a collective behaviour of oriented spins, by running a current through a ferromagnetic material, we are able to push those oriented spins into the transport channel, in our case graphene. We choose graphene not only because it's the thinnest material on earth, but also because it is a 'highway' for spin transport. In graphene the injected spins can travel a long distance without losing their spin orientation. This makes it possible for us to detect the spins with another ferromagnetic contact (FM1), at a distance far away from the injector. However, these ferromagnetic materials do not respond to light illumination, a huge external magnet is always needed to control the spins. Moreover, the spin polarisation, i.e. the net percentage of oriented spins in a common ferromagnetic material, is only around 30%.

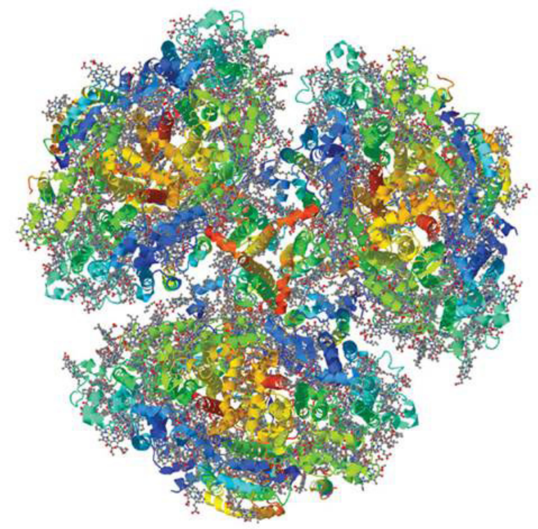

FIGURE 1: Top view of Photosystem I trimer extracted from cyanobacteria. The membrane protein has a diameter of about 20 nm and a height of 6 nm.

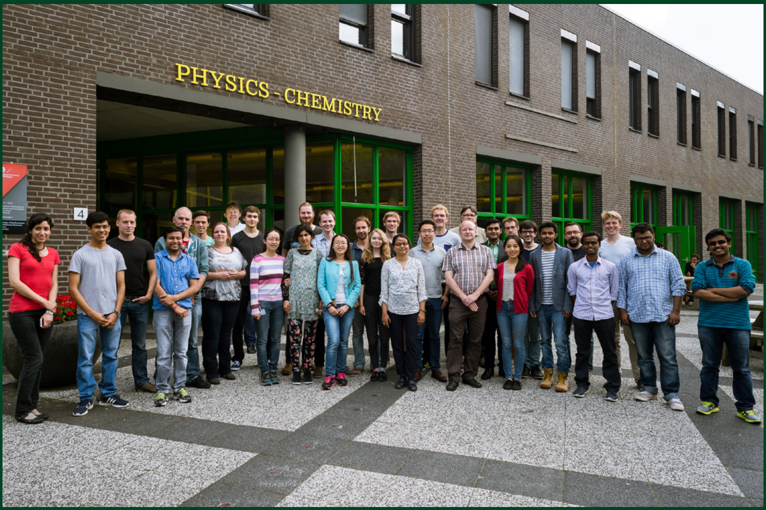

FIGURE 4: A photo of the Physics of Nanodevices group at ZIAM. "We explore new physical phenomena that occur in electronic and opto-electronic device structures with nanoscale dimensions. The dynamics of such devices is often quantum mechanical in nature, but much richer than the dynamics of isolated atoms due to interactions with the solid-state environment. Our research investigates this quantum dynamics, and aims to apply it for new device functionalities."

This limits the strength of the spin signals, and therefore limits the distance the spin signals can travel. It is these limits that highlights the potential of PSI.

As a result of billions of years of evolution, PSI has an astonishing internal quantum efficiency of (nearly) 100%.

This means for every single photon PSI captures, an electron will be excited and will be emitted. What's more exciting is that these photo-excited electrons have been shown to have a spin polarisation of 80%. This makes PSI a perfect candidate as an optically-active spin injector.

Any Downsides to Using PSI?

It is known to be extremely difficult to bind membrane proteins, such as PSI, on solid surfaces while preserving their biological functions. Fortunately with the help of the biologists in the institute, we found out that we can use a special peptide to bind PSI to graphene. A peptide is a short chain of amino acids. It can fold into a special shape in 3D space and can bind to other molecules or surfaces via supramolecular interactions. This peptide is also designed to provide a controlled orientation of PSI. Orientation is a crucial factor in this research, only if most of the PSI units orient themselves in the same way, can we get a net spin-injection in graphene, so that the whole device would work. We check the orientation by acquiring the I-V characteristics of PSI. We use an ultra-sharp conductive tip to locate and pinpoint each individual PSI unit. Then we use the tip to apply a varying voltage across the PSI unit, and measure the current that goes through it. Due to its photo-electric functionalities, oriented PSI should exhibit asymmetric I-V curves. We quantify this asymmetry with a rectification value R (defined as $R=|I_{(-0.5V)}/I_{0.5V}|$). An asymmetric I-V curve will show non-zero log(R) values. Figure 3 shows how the log(R) values we measured are distributed. Without using the peptide we have a distribution centered at 0, indicating the missing of controlled orientation. While using the peptide the log(R) value is significantly larger than 0, meaning that now the majority of the PSI units are oriented in the same way.

Where Do We Go from There?

With the PSI oriented and safely bound to graphene, we are ready to go one step further. We are currently using state-of-the-art nano-fabrication techniques and bio-engineering skills to construct the first ever bio-hybrid graphene spintronic device. And we will try our best to get it work. You might wonder what it means if the device works. Will it bring us a new types of smartphone chips before Moore's law ends? The answer is, sadly, no. But being at the crossroad of nanotechnology, materials sciences and bio-engineering, hopefully a prototype of this hybrid device will shed some light to a new, promising direction •

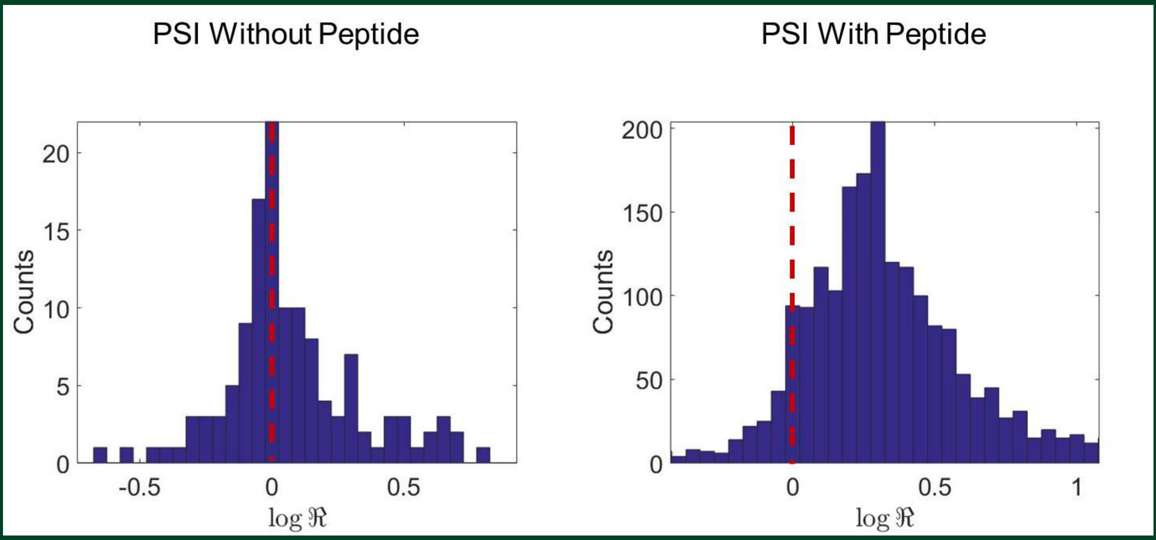

FIGURE 3: Histograms of rectification of PSI I-V curves. The significant increase of rectification when using peptide indicates that the peptide is helping control the orientation of PSI units. that the peptide is helping control the orientation of PSI units.

Exploring New Physics with Cold Molecules

Searching for the Electron's Electric Dipole Moment

AUTHOR: **PROF. DR. STEVEN HOEKSTRA**

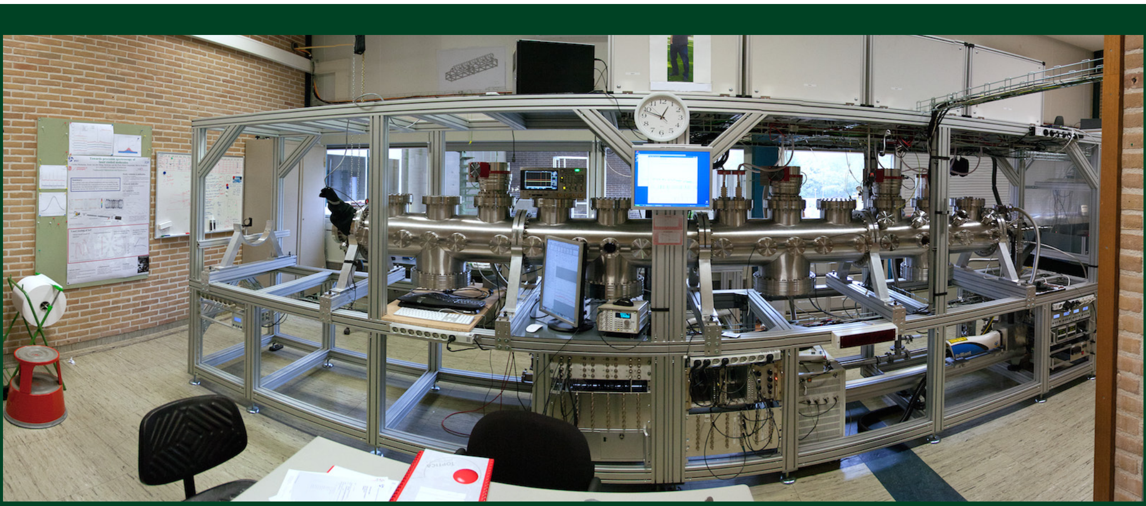

FIGURE 1: A panoramic view of the world's longest molecule decelerator.

Consider the electron. Surely we know all about this fundamental particle? As it turns out, the hunt for the measurement of a basic property - that it so far doesn't seem to have - is motivating a new type of particle physics experiment at a number of research labs worldwide, including here, in Groningen, at the VSI.

This elusive property is the electric dipole moment (EDM), which reflects an uneven distribution of the charge. All measurements so far have indicated that if the electron has an EDM (from here on called eEDM), it is smaller than can be measured. This is at first sight not surprising, because the Standard Model of particle physics predicts the electron to be essentially perfectly 'round', and the resulting eEDM is about 10 orders of magnitude smaller than the current measurement sensitivity. So why bother trying to measure this property? It turns out that theoretical models that extend (and thereby try to fix the shortcomings of) the Standard Model all predict an eEDM that is much larger than the Standard Model value! The current best measurement of the eEDM has already put a number of such models under pressure. We are starting a new research program in 2017 to measure the eEDM with unprecedented sensitivity.

Tabletop Precision Experiment

So how to measure the dipole moment of the electron? In the last decade, it has become clear that the most sensitive method is to do the measurement not on a 'bare' electron, but on an electron that is inside a heteronuclear diatomic molecule. If such a molecule is placed in an strong electric field, the molecule is polarised. As result, the electron is exposed to a strongly amplified electric field, and this field can be exploited to probe the structure - and thus the EDM - of the electron. The molecule thus effectively amplifies the signal from the EDM. The aim of our experiment is to manipulate, control and probe these molecules in such a way that we can extract the EDM of the electron with optimal sensitivity. This requires extreme measurement precision, since the effects will be small. In contrast to large high-energy collider experiments, in our approach we slow down and cool the molecules in a table-top experiment.

Cold Molecules and Lasers

We have designed a low-energy precision experiment, based on a pulsed beam of neutral BaF molecules that is being cooled and decelerated using a combination of recently developed techniques. These techniques are cryogenic buffer gas cooling, traveling wave Stark deceleration, and molecular laser cooling. The eEDM is read out using optical, microwave and RF fields in a Ramsey-type spin interferometer in a carefully shielded and controlled interaction zone. Since we are just starting this research program, a large part of the experiment will be designed, constructed and taken into operation in the coming years. This research programme is integrated as a new activity of the National Institute for Particle physics Nikhef, in a collaboration of the Van Swinderen Institute (VSI) in Groningen, where the experiment is located, and the VU Amsterdam. One central part however, the traveling-wave decelerator, has already been constructed and is operating routinely in the cold-molecule labs at the VSI in Groningen (see also Figure 1). Also a large part of the laser infrastructure that is needed to cool, control and readout the molecules is already available, based on a range of low-energy precision experiments that have been operated at the VSI.

An Exciting Outlook

In the coming year a number of new PhD students will join the current students and staff in our common task to design, simulate and construct the eEDM experiment. And there are certainly opportunities for bachelor and master research project - please contact us if you are interested. We look forward to an exciting eEDM search! •

FIGURE 2: PhD student Sreekanth Mathavan is at work operating the molecule decelerator.

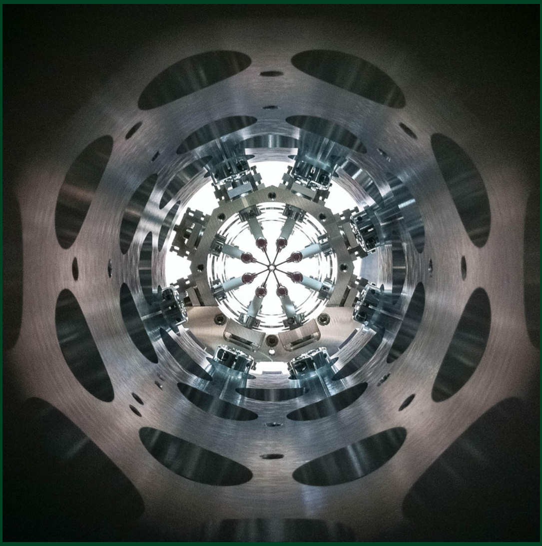

FIGURE 2: A view inside the molecule decelerator. A travelling potential is created by a time-varying electric field, applied to over 3000 ring-shaped electrodes that together form a 4 meter long tube. The molecules travel through this tube, and are decelerated in the process. The resulting low velocity allows us to increase the measurement time on the molecules, thereby boosting the sensitivity in the search for the electron's electric dipole moment.

Research Around the Island of Stability

AUTHOR: **DR. JULIA EVEN**

The heaviest elements in the periodic table, with a proton number higher than 100, can only be produced at accelerator facilities in nuclear fusion reaction by applying highly intense ion beams.

Recently, the IUPAC/IUPAP Joined Working Party validated the discovery of the elements 113 (in RIKEN, Japan) and of the elements 115, 117, and 118 (in Dubna, Russia). Thus, these elements were named and received their place in the periodic table. The hunt for these elements is extremely time consuming and challenging. The production rates are in the worst case about one atom within several months and their half-lives range from a few minutes down to a millisecond. So why do scientist take the challenge and study these elements?

First of all we would like to know where the ends of the nuclear chart and the periodic table are. Does the predicted island of stability exist? If so, where is it exactly located on the nuclear chart? Is it possible that we can find these elements in nature? Is there a possibility that the heaviest elements have been formed in stars?

According to the liquid drop model, nuclei with a proton number higher than 103 cannot exist. The stability of these elements can only be explained by nuclear shell effects. Technical developments in the last years opened the door to tackle the structure of such superheavy nuclei. I was involved in precise decay spectroscopy studies of moscovium (proton number 115) and its daughter nuclei, which allowed the derivation of excitation schemes of isotopes along the decay chains starting with elements $Z>112$ for the first time [1].

In the recent years, also atomic physics techniques were pushed to the one-atom-at-a-time limit. The mass of nobelium and lawrencium could be determined in Penning trap mass spectrometry. These allowed to pin down the strength of the neutron shell closure around $N=152$ [2].

Also the electronic structure of the heaviest elements and their chemical properties are in the focus of interest. Due to the heavy nuclear mass, relativistic effects on the atomic orbitals are stronger pronounced than in lighter elements. In Japan, the ionisation potential of lawrencium (proton number 103) was measured with surface ionization [3]. This experiment triggered a discussion at IUPAC to move the elements lawrencium and its lighter homolog lutetium from the f-block to the d-block [4].

Recently, the first laser spectroscopy studies in the heavy-elements region became feasible. I was involved in an international collaboration in the first laser spectroscopy studies on nobelium (element 102) to investigate its atomic properties at GSI, Germany [5].

As a chemist, I am also curious if the heavy elements chemically behave as their lighter homologs or if the trends within the periodic table were broken. We synthesized the first carbonyl complex of a superheavy element, namely seaborgium hexacarbonyl, in experiments at RIKEN, Japan [6]. In these experiments, seaborgium behaved similar as its lighter homolog elements tungsten and molybdenum.

At KVI-CART, we develop new experiments combining chemical, atomic and nuclear physics techniques to learn more about these fascinating nuclei and elements •

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{kxa} De **data**specialisten

Software Innovations

KxA software innovations is gevestigd in de provincie Groningen. Het is een uniek bedrijf dat innovatieve, gekke, grote, kleine, duurzame, sociale, maar natuurlijk ook normale maatwerk software-opdrachten uitvoert. De overeenkomst tussen al deze projecten is dat het gaat om data in alle soorten en maten, bijvoorbeeld:

Het Nederlandse verkeer in 400 miljard metingen toegankelijk opslaan

In een stal het gedrag van koeien monitoren

Software ontwikkelen voor de gigantische SKA radiotelescoop

van BIG BANG tot

Hulpverleners in de zorg ondersteunen met VCA

Werken bij KxA

Bij ons vind je allerlei achtergronden (natuurkunde, informatica, AI, etc). Iedereen deelt het enthousiasme voor softwaretechniek en wat je daar allemaal mee kunt doen.

We hebben regelmatig afstudeeropdrachten, stageplekken én vacatures. Je krijgt hierbij een opleidingstraject om je helemaal in ons vakgebied te bekwamen. Het vervoer naar Visvliet kan geregeld worden.

Ben jij geïnteresseerd in het werken bij een High Tech bedrijf? Kijk dan eens op **www.kxa.nl**, of neem contact met ons op via mulder@kxa.nl

From the Board of the FMF

The State of the Association, or How a Board Member Spends Their Time

AUTHOR: **BEREND MINTJES**

FIGURE 1: The praeses of the FMF reflects on the state of the association over a delicious ice cream cone.

"So what do you study?"

"Well, I study physics and maths, but at the moment I'm taking a break from my studies and doing a board year at my study association."

I have given this answer to the above question many times. It tends to complicate the conversation. When people ask about my studies, they usually use it as a conversation starter, and expect to continue about the subject I'm studying, or what I'll be able to do with my studies once I finish. Instead, they get this.

Some then do not know what a study association is. I explain that it is a social group, contributing to the education and career orientation of its members (if I feel like it I'll throw in "hundreds of members" or "lots of sponsor money").

Others know about study associations. They are usually a member of one, or have been in the past. Then, the conversation becomes more FMF-specific, and I talk about the studies the FMF provides for, our specific activities, and what we do for our members.

In both of the above cases, however, the inevitable follow-up question is always: "What do you do as a board member?"

I must say, that is not the easiest question to answer. It is a diverse and sometimes very demanding job. Days are not standard 9-5, but often you are required to spend your evenings on something board related as well. Then again, can you call attending activities and borrels "work"?

"What we do, is hard to answer. What we do it for, is much easier."

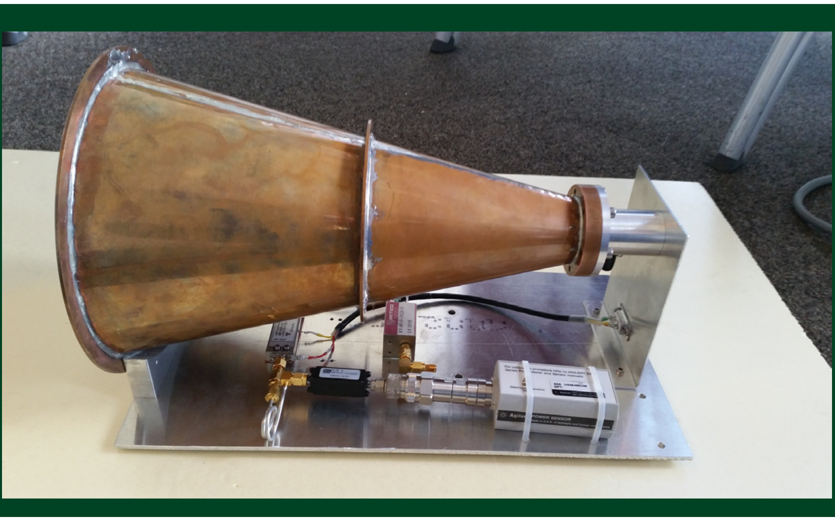
We have a large number of enthusiastic new active members. We see faces in the FMF room we did not see before this year. Our concept of having a lecture every Tuesday is taking shape. The past two months we've had two NIXX-bios events, two company excursions and two board game evenings, and many more activities I forget to mention.

Of course, most of the credit for this goes to the committees, and summing these up does not give a good overview of a board members' tasks. But they, among other things, are what makes being a board member very rewarding •

FIGURE 3: The full board of the FMF, pictured here at the annual FMF Christmas dinner, is visibly marked by the immense stress and hardships the sheer magnitude of their tasks and responsibilities entails.

The Kapteyn Radio Telescope

AUTHORS: **MAIK ZANDVLIET, BRAM LAP, WILLEKE MULDER,** AND **FRITS SWEIJEN**

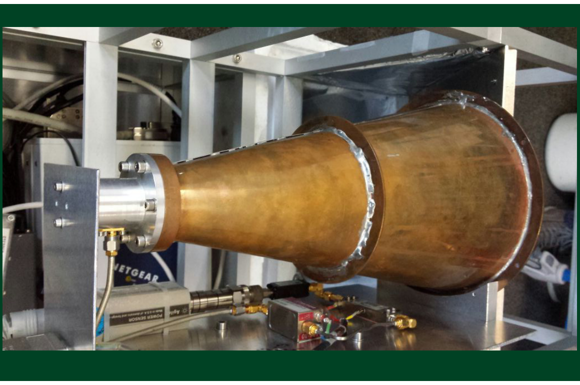


In 1965 Arno Penzias and Robert Wilson measured the Cosmic Microwave Background by accident. The 'excess temperature' of 3.5 K was measured with a 20-foot horn reflector. Fifty years later four astronomy bachelor students aimed to measure the Cosmic Microwave Background on purpose with a Pickett-Potter horn reflector telescope.

The Kapteyn Radio Telescope is an 11 GHz radio telescope, which was designed to measure the temperature of the Cosmic Microwave Background (CMB). It has been built by four Astronomy students as a bachelor project. All four students were responsible for a specific part of the telescope. First, Willeke had to determine the parameters of the telescope required in order to be able to measure the cold CMB temperature, T_{cmb}, of 2.72548 ± 0.00057 K [1]. With the determined parameters and further research Bram designed and made the horn antenna, after which Maik designed the back-end and frame of the telescope. Frits made the complete software that could control the telescope and read out all data and Willeke was responsible for the calibration in order to complete the final data analysis. Each part will be shortly discussed in a bit more detail.

Tuning in to the CMB

Looking at a blackbody with a temperature equal to T_{cmb}, the highest value for its brightness will correspond to the peak of the blackbody spectrum. This peak is found at a frequency of 175 GHz. Due to the fact that there were only some filters and amplifiers from SRON available, ranging from of 4 to 12 GHz, the Kapteyn telescope observes at a frequency of 11 GHz. The ultimate goal would be having a system, able to measure the CMB temperature with 10 percent accuracy. Using the exact formula of propagation of error one could determine the maximum allowed uncertainty in the measurement. In order to not overshoot this uncertainty, simple simulations show that already two observations of the sky between $0^o < z < 90^o$ are enough to measure τ_0 accurate enough to determine T_{cmb} within 10 percent.



A quick guide to radio astronomy terminology:

- z is the Zenith angle. The angle between the object of interest and Zenith. A Zenith angle of 0 means the telescope is pointing at Zenith.

- Optical depth, τ, is a measure of opaqueness of a medium [2]. The attenuation of photons in the atmosphere depends on the path length of the incident ray of photons. Therefore the optical depth depends on the incident angle, the Zenith angle. The optical depth as a function of zenith angle is

$$\tau(z) = \tau(z = 0)\sec(z). \qquad (1)$$

- T_A is the atmospheric temperature. T_A has a characteristic value of 300 K.
- T_{CMB} is the blackbody temperature of the Cosmic Microwave Background. The early universe was dense and hot enough to produce blackbody radiation. When the universe became transparent at a temperature of 3000 the blackbody photons begun to move around. The radiation cooled down to a temperature of 2.72548 ± 0.00057 K due to the expansion of the universe [1].

Hot-Cold Callibration

Until now, it is clear that we want to be able to measure the zenith opacity of the sky in order to determine T_{cmb}. To do this, incoming radio signals (mW) had to be related to a system temperature of the telescope, which is possible by using hot-cold calibration. First, the power is measured while the horn is aiming at a cold load with known temperature, typically liquid nitrogen being 77.15 K, thereafter the power is measured for aiming at a hot load, 300 K. After the calibration, a scan of the whole sky can be made. All powers can be converted to temperatures, leaving a plot of the system temperature for every z. Using the plot, the value for τ_0 could be determined. By fitting the graph to equation 2 T_{cmb} can be determined.

$$T_A = T_{cmb} \cdot e^{-\tau_0 \sec(z)} + T_{atm}\left(1 - e^{-\tau_0 \sec(z)}\right) \quad (2)$$

In order to detect the CMB we had to measure a 2.7 K signal on top of the ~300 K background of the Earth's atmosphere. To ensure that the noise from other radio sources was as low as possible, the sidelobes had to be minimised. This is where the antenna design becomes important, since the geometry of your horn determines the beam pattern. From simulations (calculating Maxwell's equations for a given geometry) it was shown that a Pickett - Potter horn would be the best choice for our goal. But how to make it? Well cut some copper, bend it and solder it together! This was easier said than done, but we managed!

The Back End

Next, we had to create the back-end of the horn, a typical back-end of a horn antenna consists of an amplifier, a mixer, a band pass filter, a square law detector, an integrator and a recorder. Though not all parts were required in the KRT. We were limited to what SRON had available, luckily we did not require much, two amplifiers and one band pass filter would do the trick for us.

Controlling the telescope was a balance between giving freedom to the user, ease of use and reliable measurements. Most importantly however we found the notion of repeatability: one should be able to do the exact same measurement again and again. Therefore we opted to control the telescope electronically. The brain of the telescope became a Raspberry Pi; a creditcard-sized computer running a Debian based Linux OS with easy possibilities for interacting with external devices through the on-board GPIO pins. As an added bonus these pins are easily accessible through Python.

Doing a Measurement

In order to control the telescope the user connects his or her own laptop to the Raspberry Pi, which acts as a server governing communications between the user, the telescope and the measuring hardware (a power meter and temperature sensors). The user connects to the server and starts a measurement. Then the server sends signals to the motor and hardware while also listening for measurements results coming back.

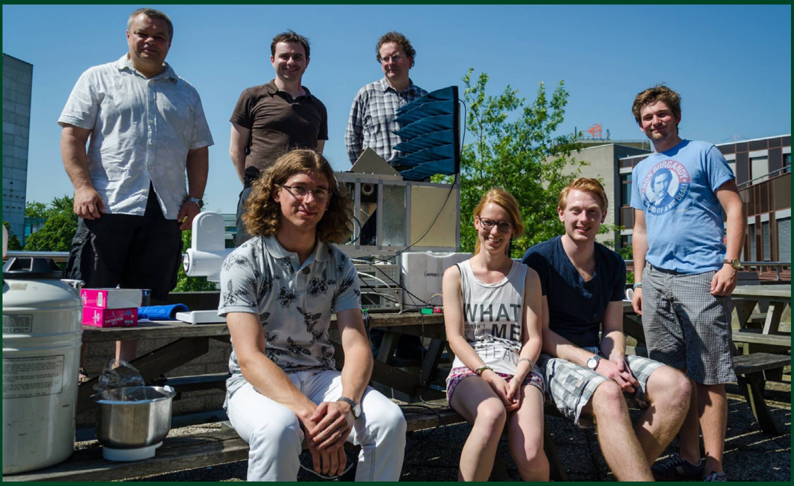


FIGURE 1: The people who designed and built the telescope. Top left to right: Andrey Baryshev, John McKean, Ronald Hesper. Bottom left to right: Frits Sweijen, Willeke Mulder, Maik Zandvliet, Bram Lap.

To do a measurement a pre-installed script can be run, but the software was written with user freedom in mind, meaning custom scripts can also be created. Controlling a telescope may seem daunting at first (and it may very well be for the larger telescopes out there), but even a AC30-ish creditcard-sized computer can get you a long way down the road.

Results

After the first observations, it became clear that the calibration was not working properly. Therefore we were not able to measure the temperature of the CMB, due to temperatures being wrongly correlated to specific powers. What we did achieve was a telescope that is able to measure bright radio sources such as the sun and geostationary satellites.

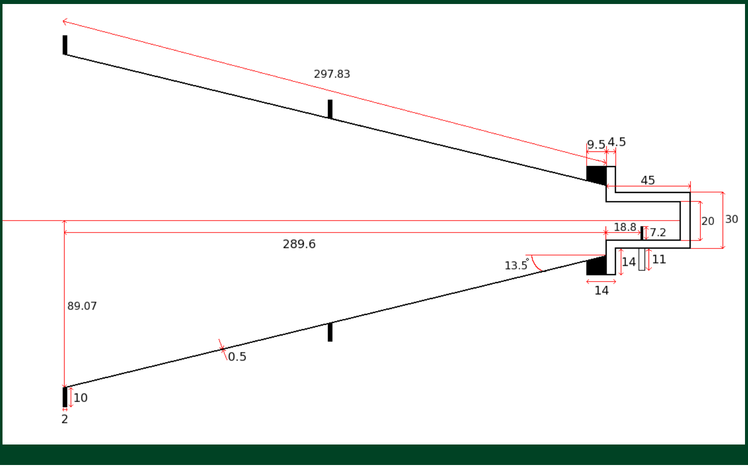
At the moment the KRT is used for the course Introduction to Radio Astronomy given by Assistant Professor John Mckean, who was one of the supervisors of the project •

References

[1] Fixsen D.J. (2009): the temperature of the cosmic microwave background; The Astrophysical Journal 707, pp 916-920

[2] LeBlanc F. (2010): Stellar Astrophysics; Wiley, Chichester

FIGURE 1: The geometry of a Pickett-Potter horn.



Brainwork

The Praeses II: propelled by the members

The praeses of the FMF cycles toward you on his bycicle. It is a magnificent sight. The praeses (mass M) comes to a complete stop directly in front of you.

The praeses is thirsty, and orders you to hydrate his magnificence. Obedient as you are, you start throwing beers at the praeses. Of course, you cannot keep up with the drinking pace of the praeses; everytime you throw him a beer, he downs it before you are ready to throw the next one.

Yet you persist, and throw beers at speed u, with a constant mass rate of k kg/s (assume the rate is continuous). Slowly and gracefully, the praeses, propelled only by the lossless transfer of momentum of the beer to the preases, kept upright and frictionless by his grandeur, starts receding away from you.

Find the speed v and position x of the praeses as a function of time.

Solution to the Previous Puzzle: The Praeses

The correct solution was 11. Jos Borger, Thomas ten Cate, Manoy Trip, and Frank Verbon sent in correct solutions. They can pick up their surprise prize and get a chance to win an exclusive meet and greet with the praeses of the FMF.

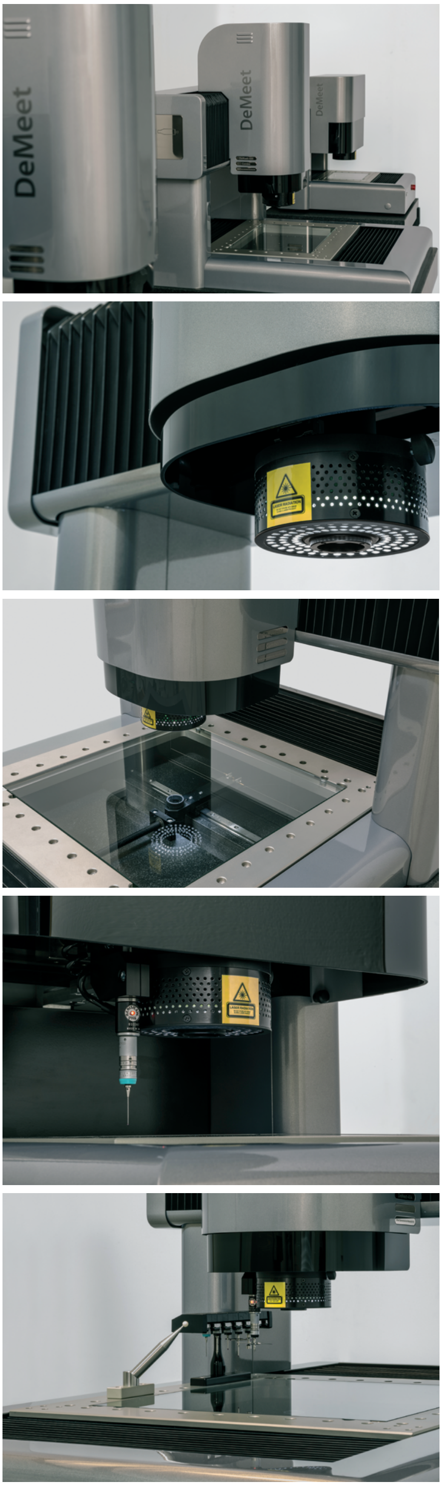
Recipe: Pi-pie

Pi day is celebrated on March the 14th. One could honour pi with a Monte Carlo simulation of the surface of a circle and find its magical value. Or one could consider making a pi-pie. Specifically, a lemon blueberry pi-pie.

For 2 little pies:

Ingredients:
- 10 ginger biscuits/speculaasjes/koffieleutjes
- 70 grams of butter
- 250 grams of mascarpone
- 3 tablespoons of sugar
- 1 tablespoon of lemon curd
- blueberries

For the pie crust mash the biscuits into fine crumbs. Melt the butter in a pan and stir in the butter with the biscuit crumbs. Put the crumb mixture in the pie tins. Press the mixture into the bottom of the tin with a spoon. Put the tins in the fridge. While the crust is cooling mix the mascarpone with the sugar. Stir in the lemon curd untill the filling is creamy. When the crust is firm, spoon the mascarpone-lemon curd filling on the crust. Place the blueberries on top in a certain configuration.



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Aangezien we onze activiteiten uitbreiden, zijn we continu op zoek naar enthousiaste medewerkers om ons team te versterken. Als jij wilt werken in een bedrijf dat mensen met ideeën en initiatief waardeert, dan is Schut Geometrische Meettechniek de plaats. De bedrijfsstructuur is overzichtelijk en de sfeer is informeel met een “no nonsense” karakter.

Op onze afdelingen voor de technische verkoop, software support en ontwikkeling van onze 3D meetmachines werken mensen met een academische achtergrond. Hierbij gaat het om functies zoals ***Sales Engineer***, ***Software Support Engineer***, ***Software Developer (C++)***, ***Electronics Developer*** en ***Mechanical Engineer***.

Je bent bij ons van harte welkom voor een oriënterend gesprek of een open sollicitatiegesprek of overleg over de mogelijkheden van een **stage-** of **afstudeerproject**. Wij raken graag in contact met gemotiveerde en talentvolle studenten.

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