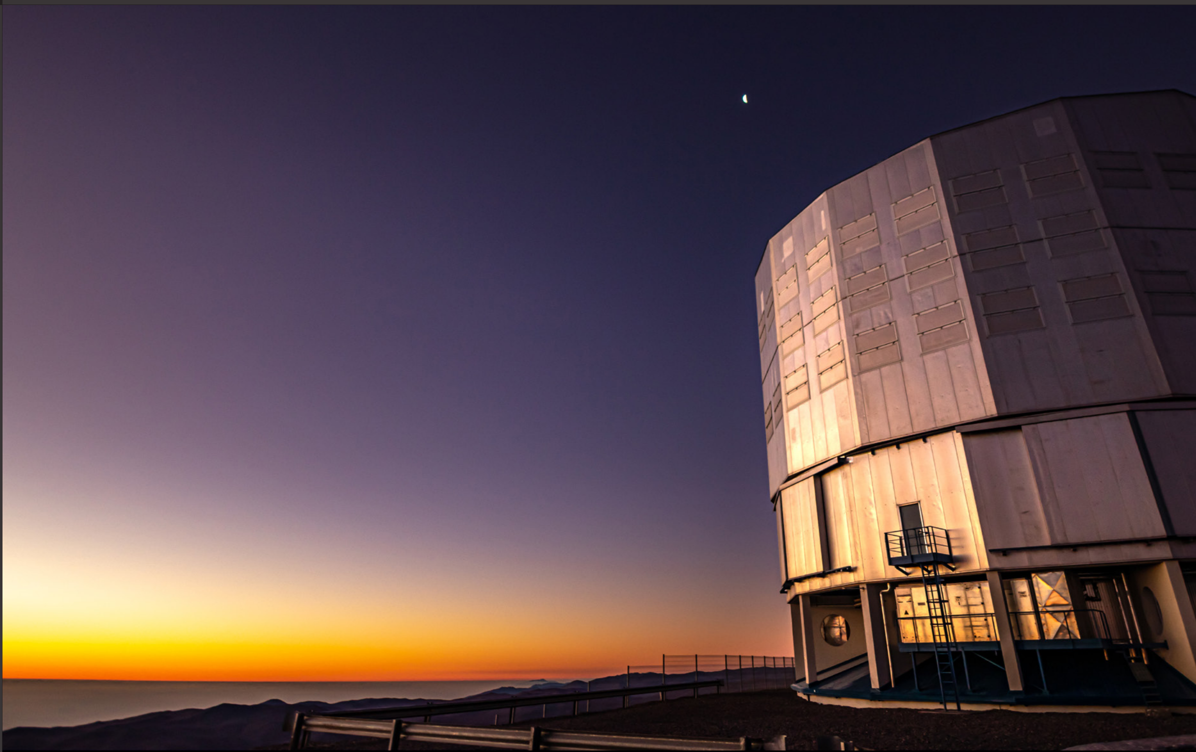
Perio Interview
with Steven Hoekstra

Gridt: the Network for Connecting Social Movements
Yori Ong & Jorn Wildering

Periodiek

Recurring Magazine | Issue 2019-2



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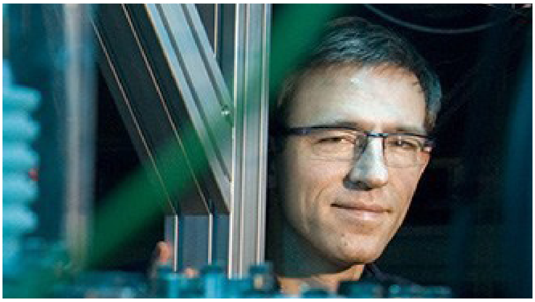
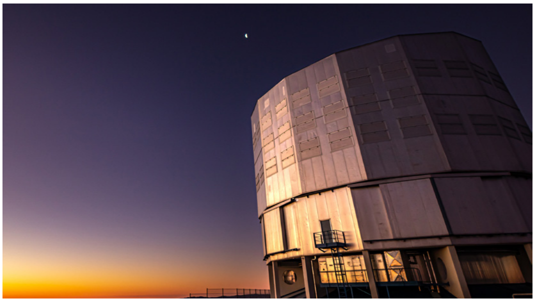
FMF

8 - Interview with Steven Hoekstra

Steven Hoekstra is the participant for the Perio Interview in this edition. He has a picture of his favourite molecule on a shirt, toured internationally playing the clarinet, and he didn't want to follow his father in becoming a professor.





16 - Lejano '19

The people from the big foreign excursion (GBE) have returned from Chile and Argentina! And they come bearing the gift of stories and pretty pictures.

21 - Radio Signals from the Cosmic Frontier: A Discovery of New Physics?

The VSI has had a recent addition to the staff: Daan Meerburg has joined. He wrote an article about the importance of the 21cm line in radio astronomy and its possibilities for the future.

In this Periodiek

From the Editor in Chief

Two Perio's this close after one another? No, you are not dreaming, it is real. Before the end of the academic year we wanted to bring you one more Perio.

In this edition:
The GBE has returned from Chili and Argentina with stories for us. A new staff member of the VSI wrote a fascinating piece for us. What is Gridt? And, of course, a brand new Perio interview with Steven Hoekstra.

On behalf of the board of editors I wish you a lot of pleasure reading this Perio and a nice summer vacation!

Jonah Stalknecht

Editors
Robert van der Meer
Robert Modderman
Jonah Stalknecht
Gerrit van Tilburg
Jasper Somsen
Robert Mol

Authors
Robert Modderman
Thomas van Belle
Manuela Vecchi
Daan Meerburg
Jorn Wildering
Manoy Trip
Yori Ong

Advertisers
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In the News: Fundamental Constants Redefined

AUTHOR: **JASPER SOMSEN**

You might have noticed some changes on the 20th of May. When you stepped on the scale in your bathroom, you may have found your mass to be slightly off what you expected. It was colder outside than you expected. An unreasonable, but interesting explanation for this phenomenon could be the fact that on that date, the whole system of SI base units was redefined by setting multiple constants of nature to an exact numerical value.

In November 2018, the 59 member states of the General Conference on Weights and Measures approved of the redefinition of the SI unit system. Probably the most notable effect of this (which you probably have heard about) is the redefinition of the kilogram.

The old kilogram

In the old system of SI units, the kilogram was defined by the mass of a single object: The "International Prototype of the Kilogram" (IPK). It is a Platinum Iridium alloy cilinder with height and diameter of about 39mm made in 1879. As they could not measure any mass difference between this object and the previous defining object, the IPK was established to be the definition of the kilogram in 1889. At the time, the *Conférence Générale des Poids et Mesures* considered "*that the differences between the national* [old] *Kilograms and the international* [new] *Kilogram lie within 1 milligram*"

Copies of this object, with mass equal as precisely as possible have been shipped out from Paris to all over the world to calibrate the masses and scales of objects and instruments. But in the 130 years since the mass difference of 1 mg was enough to establish mass equality, some scientific progress has been made and mass can be determined much more precisely. It has been recorded that some of the copies are now over 50 µg heavier then they were 100 years ago. This is established of course by comparing it with the defining object, the IPK. There is no reason to assume the IPK cannot drift in mass itself. Also there exists no historical data on mass measurement of the IPK releative to a "constant of nature".

This can become problematic. There is no way to tell if the mass of the IPK has been changing, and if so, by how much. What we do know is that it has not caused huge problems (think about wars over the price of a kg of oil), yet. Together with the nuisance of having to keep an object under the exact conditions, the potential problem of having it centralised in one place, and any other risks tied to physical objects in general, this motivated a redefinition of the SI units.

The new kilogram

The motivation was there, but before the old definition could be thrown away, there should be a new definition possible. This could only happen after the increase in precision with which the Planck constant could be measured using a Kibble balance apparatus.

This apparatus uses a test mass to determine the Planck's constant up to uncertainties lower then 10^{-7}. This test mass was of course derived from the IPK, but we can turn it around. You might remember the units of the Planck constant to be J·s which of course is equal to $kg{\cdot}m^2{\cdot}s^{-1}$. This means that if we fix the Planck constant, we have a definition of the test mass in the Kibble balance, dependent only on the definition of the second and the metre. This eliminates the need for a physical object. The second and metre are both defined using the light that comes from the hyperfine transition of caesium-133 (which is of course a physical object, but one that can be reproduced exactly at any location as far as we know). The frequency of this light is exactly 9192631770 Hz, which sets the definition for the second. The metre then follows by the fact that we have set the speed of light constant to c=299792458 m·s^{-1}.

Now in the new system this extends to setting the Planck constant h=6.62607015·10^{-34} J·s. As of the 20th of May this is the exact value of the Planck constant. In principle, anyone should be able to derive the defined mass of a test mass in a kibble balance using these numbers.

Using the relations E=h·f and E=m·c^2, this gives the remarkable result that in some way, the kilogram is defined to be the mass of an object with the mass energy of a rational number of photons emitted by the hyperfine transition of caesium-133. This ratio can be calculated exactly by plugging in the defining values c, h, and the definition of the second:

$$\frac{299792458^2}{9192631770 \cdot 6.62607015 \cdot 10^{-34}}$$

Which comes down to that about 1.48·10^{40} of those photons have the same energy as a mass of 1 kg at rest.

Ampere and Kelvin

Ampere and Kelvin are of course the only two people who got fundamental SI units called after them, those units have been redefined too. The Kelvin was defined using the triple point of water, making very precise measurements very hard. This has now been fixed by relying on the second, meter, kilogram, and a fixed Boltzmann constant.

The Ampere was still defined by the current flowing through two parallel wires 1m apart that would produce a certain force on those wires. Similar to the setup André-Marie Ampère himself used. Now, by fixing the elementary charge and relying on the second, the Ampere is redefined.

Avogadro constant

The old Avogadro constant relied on the old kilogram and 1/12th of the mass of a carbon-12 atom, this made N_A basically the approximate weight of a nucleon in grammes. The old constant was exactly the ratio between 1u and 1g. The new constant is defined by a numerical value. As the atomic mass unit u was not redefined, N_A is now just an approximation for the ratio between 1u and 1g, but it does give the mole a definition independent of masses of physical objects.

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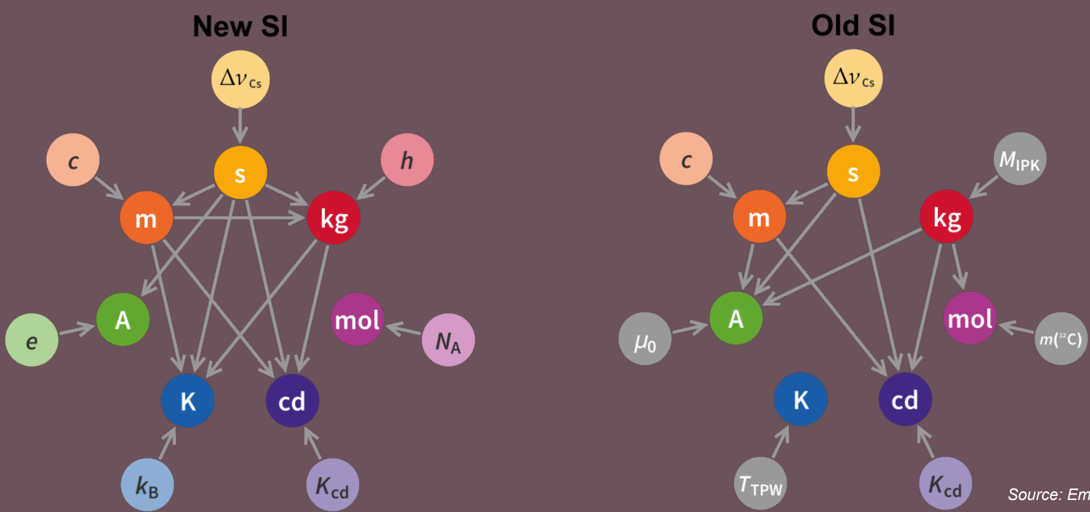
Gupta S.V. (2019) Redefining the Unit of Mass. In: Mass Metrology. Springer Series in Materials Science, vol 155. Springer, Cham

Draft of the ninth SI Brochure, BIPM. 28 December 2018

FIGURE 1: Comparison of the relations between the base units and fundamental constants.



Source: Emilio Pisanty

From the Board

Secretary

AUTHOR: **MANOY TRIP**

Hello! My name is Manoy Trip, I am this year's secretary of the FMF. I have been hanging around in the FMF room quite a bit this year, so you have probably seen me there. I decided to do a board year when I finished my Bachelor programmes, because I wanted a change before I would start my Master. As I was already quite involved with the FMF, doing a board year was a very exciting next step for me.

I was specifically looking forward to carrying responsibilities for a relatively large organization, and I wanted to force myself in more social situations. These expectations were definitely fulfilled. Besides meeting a lot of new people, working together very closely with my fellow board members is a very unique and educational experience.

As the secretary of the board, I am in the first place responsible for communication between the FMF and outside parties. Apart from that I also write minutes for every board meeting and GMA. You might understand that a lot of my personal tasks are done behind a computer screen. For this reason I usually claim one of the computers in the FMF room, because then I have a lot of opportunity to get to know all members, and to let everyone know about the awesome activities we have planned!

This year I am the one taking care of ordering the snacks and drinks we sell at the FMF. This gives me the nice privilege of choosing what to order :). I tried to bring a bit more variety in the things we offer, which is why you won't find the same snacks and drinks every time.

As secretary, I am also involved in the Archie, which is the archive committee of the FMF. This committee makes sure that all paper files the FMF stores get archived (or destroyed) properly. Part of our archive is stored at the Groninger Archieven, the official archive of our province. Together with Sietse and Leander, the other members of the Archie, I went to the Groninger Archieven to find out how we can store our important files there. The woman that received us gave us a nice tour, during which we got to see the rows and rows of file cabinets, with documents as old as from the 13th century!

FIGURE 1: Manoy during the Sweet Summer Roomdrinks activity.

At the moment of writing this, the FMF May month has just come to an end. It was amazing to see how much effort committees put in setting up the most awesome activities! I also liked to help setting up a few activities, among which the French Room drinks, the "Bakborrel" (baking competition) and the Karaokeborrel. This month was a very exhausting, but rewarding part of the board year.

But after May comes June, and then it is already almost summer… When you will read this, our candidate board will already have been announced. A lot has happened since the date of our own announcement as candidates, and I can only say that I am very happy with the choice I made to apply for a board position.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Perio Interview: Steven Hoekstra

Steven Hoekstra teaches the courses “Electricity and Magnetism” and “Atoms and Molecules”, from which you might know him. He studied here at the UG himself. Are you interested to learn what a professor does in his free time, and what his student time was like? This, and much more in this week’s Perio Interview.

What did you have for breakfast?

I had muesli this morning, I normally set up breakfast at home. I have two sons and a wife, and I check what they would like to have. The choice is usually muesli or bread. Sometimes the boys eat cruesli, but there’s more sugar in that… They also eat Brinta sometimes.

Did you vote today?[1]

I still have to, I forgot my voting ballot. I was planning to do that when bringing the kids to school, but I will certainly do it.
What do you consider to be your field of research?
Kind of a mix of different fields. I’ve been trained as an experimental physicist, using lasers and atoms and molecules. But recently I’ve been turning into more of a particle physicist. Because I work in the VSI, and we’re a part of Nikhef. All Dutch universities that do particle physics a part of that, I’m leading one of the research programs of Nikhef, so in that sense I’m a particle physicist, but I do use lasers and atoms and molecules. Molecules of course come close to chemistry. I did my postdoc in Berlin in physical chemistry. So the boundary of chemistry, atomic physics, laser physics and particle physics.

Do you leave the “real” particle physics to others then?

We also do real particle physics. Normally when people think about particle physics, they think about accelerator physics, like smashing particles into each other in CERN. But what we do is a different approach, to measure a property of a molecule with extreme precision, we get access to a fundamental aspect of a fundamental particle. Which is also real particle physics, just in a different way.

Do you have a favourite atom or molecule?

Yes! My favorite molecule is barium monofluoride, it’s just a Barium atom and a Fluorine atom combined. It is a very interesting molecule because it just has all the right properties for us to be able to measure particle physics with this molecule. Because it has these very specific properties.

Do you have some of it laying around in your office?
There is an energy level scheme on the whiteboard. And I have a running shirt with a picture which we had made for the Plantsoenloop (see figure 2). But it is also a toxic molecule. It is a radical molecule, so it wants to react with everything, because it effectively has an unpaired electron, so as soon as the molecule sees anything else it wants to react. We need to make it inside our experiment and use it before it is exposed to anything else.

What is your favourite equation?

I don’t really think in equations so much. Of course I use equations, and some of them are really important. And usually if I give presentations, I use one equation, which is on the poster in my hallway (see figure 3).
That is an equation I use a lot because it expresses how sensitively we can measure the electron EDM using our molecules. But more than equations I like to use graphs and pictures. Some people think much more in terms of equations than I do, I always try to draw graphs and figures to think more in terms of pictures when I communicate science. Of course if you code, when we simulate our experiments in a computer and we use numerical methods, and of course you cannot explain to the computers in figures what it should do. But when I talk to people I usually use more pictures than equations.

[1] The interview was held on the 23rd of May, the day you could vote for the European Parliament.

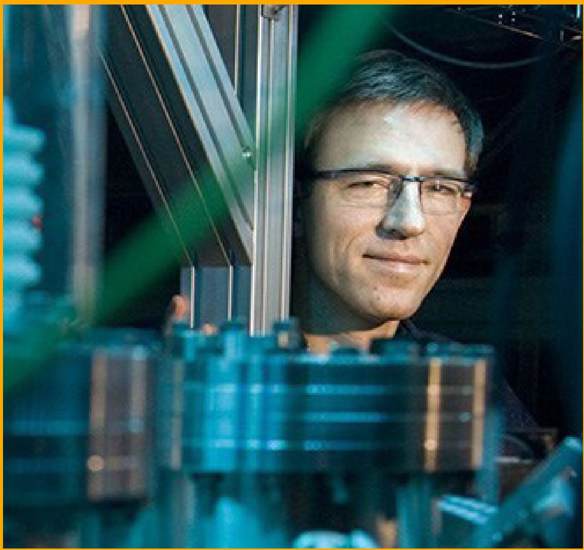


FIGURE 1: Steven Hoekstra.

What was your favourite physics subject to study?

One of the courses I liked the most was "Applications of Quantum Physics". Later that changed into the course that I'm teaching: "Atoms and Molecules". Based on that course I did my master research in that field. So essentially applications of quantum physics is what measurements using quantum systems is, so lasers, atoms and molecules. What I'm doing right now. Except for the particle physics.

Were there any subjects that you really did not like?

There was one mathematics course that I had to do three or four times. I really didn't like it. In retrospect I don't know really what made it so bad. It was mathematics three or four or so. I just didn't go to the lectures in the beginning and then at the exam I found out I was not prepared, I guess everybody has that sometimes. So then I had to study it on my own and I found that I was not really motivated to do that.

Are there still any professors around that also taught you?

Yeah actually many of the people that taught me physics are now my colleagues, so that's kind of funny. I had lectures from Ronnie Hoekstra (not family) but he was around then. I had a lecture by Maxim, and now I'm teaching Electricity and Magnetism with him. And many more.

Did you have a favourite professor at the time?

I liked Ronnie Hoekstra's lectures because he was teaching Applications of Quantum Physics. I did my master research about that with him. Afther that I went to the United States for a year to do research in a more applied environment. And I noticed there that even though California was great and to be there for a year was wonderful, it frustrated me that they didn't really explore why the experiment worked best under certain conditions. I asked them after a couple of weeks or so where's the library; I'd like to look up some background. They said, well we don't really go to the library. Later I came back for a PhD and I ended up again back in Groningen with Ronnie Hoekstra. So I can say he was my favorite professor.

Do you like teaching?

Yes I do. It's nice and it costs a lot of time, but a part of my job is managing all the different things I need to do. Part of which is teaching, but also research and proposal and paper writing but I like teaching a lot and it always gives me an opportunity to look at the material in a different way. I've now been teaching E&M for a couple of years but before that I just did it as a student, and then you just forget about it, But when you teach it you look at it in a different way.

What do you like teaching the most?

One thing I've been doing a lot is demonstration experiments for example in E&M and I really like that. Sometimes people think of physics as mostly being equations and Einstein and all the fundamental stuff, which of course is fascinating, but in the end you have to test it by doing smart experiments. And that is something I think we could do more in the curriculum: show really clever experiments and also how you design an experiment. If you see something with your own eyes it is different than when you read someone's report that someone saw something. It really has a different impact. And that is something I really like and I would like to do more still; to put more demonstrations in. So next year I will be teaching Waves & Optics, and I would like to put more demonstrations in. It is not always being done because of time pressure or something.

Did you have any memorable moments while teaching you would like to share?

I like showing the beauty of physics to different groups than just students. So one thing I did not too long ago that I liked was that I took a bucket of liquid nitrogen to the primary school where my children go, and we had a fun workshop there with kids that are

FIGURE 2: The barium monofloride running shirt Steven had made for the Plantsoenloop.

like nine and ten years old. That is also teaching in a way, and that was something that I thought was really fun. Just to explore what it means that it is both very cold and still a liquid, while nitrogen is normally a gas. And these kids were super eager to learn. And of course, sometimes, you also have that at the lectures at the university, and that is what I try to get back to: that feeling that we all want to know how it is. But sometimes you have to do a course because you decided you wanted to study physics and now you need to get this course, so you are not always as motivated as young kids seeing liquid nitrogen for the first time. I really liked that.

When you were a kid yourself, did you have a 'dream job'?

I thought I wanted to be an architect for some time, I liked that. And then I had a friend in high school who decided pretty early on that he wanted to study mathematics, so I thought: okay, I'll do something else, I'll study physics. My father was also a professor, a biology professor. So I decided that I wanted to do something completely different. In the end I'm not sure that really worked out. So of course that also influenced me and what I like, so I think I was also inspired by that.

What are your hobbies and interests?

I have a few. I play the clarinet, I like to make music. I used to play in the student orchestra Mira when studying physics, it is the nicer student orchestra of the two that mattered (at least back then it was the nicest). I also met my wife there, so that is also important. She plays the cello. I played a lot then, and I also played in the national student orchestra and I even did an international tour. It was pretty serious back then. I stopped playing music when my children were born, so about ten years ago when my oldest one was born. Pretty recently, about year and a half ago, I started playing again. Now I play in a woodwind ensemble, classical music, and that is great fun.
I also like to do photography. I'm in a photography club and every month or so we go out and do something fun or learn something new there.
And I run quite regularly. I like running outside to stay fit and get your mind off the other stuff. I like cooking too. Food, eating, cooking it myself, that's also something that I like.

Do you manage to be home early enough for that after your workday?

So yeah it is a matter of priorities right? For example, on Wednesday I go home around twelve, and I compensate that with all the other hours I work. I think I work sufficiently hard. But sometimes you need to also do different things. For example, I then bring the children to their music lessons, or sports things, and take the time to cook. Those kind of things. I think it is important to keep that balance, but that is a challenge sometimes.

What kind of music do you like to listen to?

That is a mix of a lot of things. Sometimes classical music. But also other things —especially when I was at the end of high school, at the beginning of my student times— I explored lots of different music. Lots of jazz, but also alternative weird pop music like Captain Beefheart, and Frank Zappa, those kind of things. The Cure I listened to quite a bit.

My children listen to stuff that's happening now, and it is nice to stay connected to that. So yeah, I would say that it is really a mix of everything.

Are there any books that you would like to recommend to us/to the readers?

For a period when I was studying I was reading quite a bit. Also weird poetry, like this Dutch poet, H.H. ter Balkt (you can look him up). They are interesting poems, weird in a way, which is nice. At least it triggers questions when you read it. But recently I find that I do not have too much time to read. There are some books on my nightstand. There is a German author Juli Zeh, she is really good, I like to read her books. And now I am reading a book on the history of the Six family by Geert Mak. One book I really like is by

Canetti, he won the Nobel Prize in Literature. I can't quite remember the name of the book, but I think it was his most well known work.

Are you able to fix your own bike?

Yes, that I can do. It is something my father taught me how to do, I can fix the rear and the front tires if they are flat, and I think I can do more than that. I recently bought a nice bike and I put a mudguard (nl: spatbord), I had to take the wheel out and such. I like doing that stuff.

Do you have any professional accomplishments that you are proud of?

In my PhD work I build a magneto optical trap to trap atoms. So essentially you 'see' with a camera, or even with the naked eye, a glowing ball of trapped atoms, they fluoresce in the laser beams. We then made a fluorescence detection system that was so sensitive that you could see individual atoms appear in the trap. At first there would be no signal, and then a jump, and another jump and in this way you could count the amount of atoms. I really liked that, even though I don't think we were the first to do it. It was difficult to achieve and it was nice that it worked out.

And another thing that I did that I really liked was during my postdoc in Berlin. I trapped OH molecules for a few seconds in an electric trap and we found that after about one second the molecule would get lost from the trap. There were two contributions, one was the background gas that kicks the molecule out, and the other one was the blackbody radiation (every object emits radiation depending on how hot the object is: blackbody radiation). The vacuum chamber around the molecule which was at room temperature would irradiate the molecule and that would drive rotational transitions in the molecule (molecules can, besides electronic transitions, also have rotational transitions). So we could really nicely quantify that about once per second the molecule would be excited by this blackbody radiation. This means that you can make the vacuum as perfect as you want to, but still you cannot keep the molecules for longer than one second. What you would then need to do is cooling down the vacuum chamber with liquid nitrogen or something. So that is a fun thing that we discovered which I really like.

Have you ever considered being a theorist?

No. I already mentioned what I like about teaching: showing experiments to children or bringing demonstration experiments to the lectures, that's what I really like. I'm fascinated by simple things like magnets, just the simple stuff that makes you wonder how it is possible and that surprises you a little bit. Like these two glasses that I bought for high school students that came to the university, they are just glasses for the 3D cinema. We did experiments about polarization and I had them figure out how it works. And that I really like: take something that you can see and figure out how it works, and then design an experiment such that you can carefully get a step further. To be amazed by something is a trigger to really learn more. It's that step that I really like and I mostly get that from stuff that I can see. So no theorist in me. No disrespect to the theorists of course, but it is not for me.

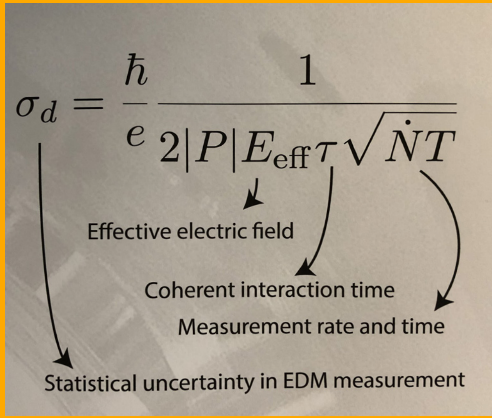


FIGURE 3: The one equation Steven likes to use in his presentations.

Any other things you would like to share with us?

What I like is that we have such a mixed group of senior staff and also PhD students. At the moment we do measurements of the electric dipole moment with a pretty large team, close to ten PhD students and a lot of bachelor and master students so all in all we have close to 25 people working on this topic. Which makes a really nice environment for any students interested in the project to join, because there is a lot of different aspects of it.

It is important that it shouldn't be all business, it should be fun also. The next thing we are planning is a barbecue, and also this running team for example. It is fun, and I think it's important to see that that also happens.

What Can Cosmic Ray Antimatter Tell Us About the Universe?

AUTHOR: **M. VECCHI**

Antimatter is perceived as sometimes far-off from our routine, eventually related to some unknown type of "Angels and Daemons" science fiction topic, in view of the famous Dan Brown's best-selling book. However, antimatter is something actually present in our everyday life, and the research on cosmic antimatter is telling us a lot about the universe. We live in a world mainly made of matter, which consists of three types of particles called electrons, protons and neutrons. Each particle has a specific mass and electric charge. For example, the electron is a negatively charged particle, and the proton is a positively charged particle. So, what is antimatter? Antimatter particles have the same mass as these particles, but the opposite sign of charge. For example, the anti-electron (also known as the positron) has the same physical properties of the electron (like the mass), except that it is positively charged, while the antiproton has the same properties of the protons, but it is negatively charged. When a particle and an antiparticle meet, they destroy each other. This process is called "annihilation", and the energy of the two particles is converted into gamma rays. Don't worry, these gamma rays cannot be used to destroy the Earth, that's science fiction. It's alright.

The existence of antimatter was initially postulated by P. Dirac in 1928, and experimental evidence was provided by C. Anderson, who was studying cosmic rays, and discovered the positron in 1932. This was a big deal at the time, so much so that Anderson got the Nobel Prize in 1936 "for his discovery of the positron." The positron detected by Anderson was produced when cosmic rays, high energy particles produced in outer space, hit the Earth atmosphere and produce particle cascades that travel through the atmosphere and eventually hit the ground. For the record, Anderson shared the prize with V. Hess "for his discovery of cosmic radiation".

Positrons are also present in our daily life, since they are produced in radioactive decays of unstable elements, for example in potassium-rich foods, like bananas! And in sea salt, where another unstable element decays producing positrons, too. Again, no panic! That's a low dose of radioactive elements, you can safely keep eating bananas and swimming.
Moreover, while using powerful radioactive sources, we can produce positrons and use them to perform precise imaging of human bodies with the Positron Emission Tomography (PET) scanners. High energy antiparticles can also be produced at accelerators on the ground, like the Large Hadron Collider.

Going back to space, high energy antiparticles constitute a tiny fraction of cosmic rays, that are mainly made of positively charged particles (protons and heavier nuclei), with about 1% of them being electrons. The Alpha Magnetic Spectrometer (AMS-02) is a cosmic ray antimatter hunter, taking data on the International Space Station since 2011. It will take data until 2024, when the International Space Station will conclude its mission. AMS-02 is an international collaboration including about 600 scientists from 16 institutions in Europe, America and Asia. The University of Groningen is also a member of the collaboration since a couple of years, when Manuela Vecchi joined as a Rosalind Franklin Fellow assistant professor, creating her group here.

AMS-02 is a state-of-the-art particle detector (see figure 1), performing precise measurements of the cosmic ray properties, namely the energy, the velocity, the charge magnitude, the mass, and the momentum. Moreover, the key to access the antimatter component of cosmic rays is provided by the magnet that —together with the silicon tracker— measures the particle charge sign, this allows for differentiating particles from antiparticles, based on the way particles bend in a magnetic field of known strength. AMS-02 is currently the only experiment taking data equipped with a magnetic field, so it allows for unique access to the antimatter in the universe. There is currently no approved future space experiment that will replace it in the long-term.

FIGURE 1: The AMS-02 experiment on the International Space Station.
(AMS.NASA.GOV)

Using the data collected by the AMS-02, scientists performed precise measurements of cosmic ray particles of different species, like protons, helium, electrons, carbon and oxygen. Precise measurements of light cosmic ray antimatter were also performed: AMS-02 provided the most precise measurements of cosmic ray positrons and antiprotons to date, exploring an energy range that was unexplored before. These measurements allowed us to see unexpected behaviors that are far from being fully understood. While protons and heavier nuclei provide information on the astrophysical sources of cosmic rays and their propagation in the interstellar medium, the study of cosmic ray antimatter may be closely related to the existence of more exotic phenomena occurring in the universe such as the existence of dark matter and the matter-antimatter asymmetry.

Until a few years ago, it was believed that cosmic ray positrons and antiprotons, measured in cosmic rays since decades, were mainly produced in well-known astrophysical processes, like collisions of cosmic rays with the interstellar medium. Nothing particularly fancy. The measurements gathered by AMS-02 and its predecessor satellite experiment PAMELA show an unexpected abundance of positrons: this hints at the presence of positron sources in the vicinity of the solar system (within a few kpc), whose nature is not yet known. There are basically two classes of sources that can be invoked to explain this “anomaly”: astrophysical sources or exotic sources. While astrophysical source include pulsars and supernova remnants, exotic sources include the presence of dense halo of dark matter in the galaxy that could produce positrons by decay or annihilation. While positrons provide a quite limited detectability horizon, in view of the severe energy losses they experience during their propagation, antiprotons have a more extended horizon, that can reach the boundary of our galaxy. The measurements of antiprotons are also of great interest but, because of large theoretical uncertainties, it is not yet clear if the measurements are in agreement with the expectations, leaving unclear whether or not there is room for believing that antiprotons could be related to dark matter.

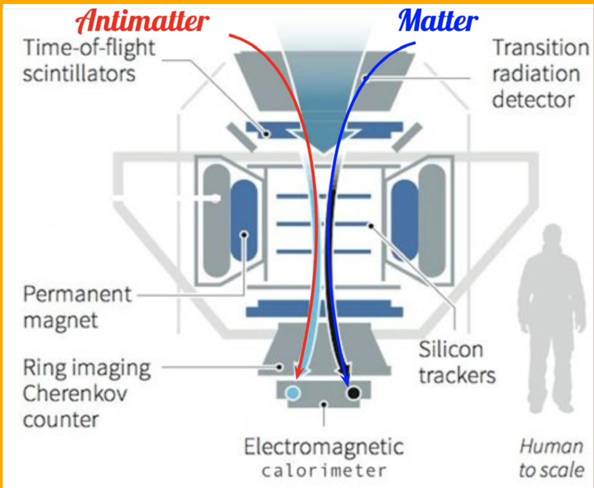


FIGURE 2: Schematic description of the AMS-02 experiment.
(REUTERS)

To summarize, cosmic ray antimatter could be related to the presence of dark matter in the galaxy, but so far we do not have conclusive evidence for this. Moreover, antiprotons are so far providing the most significant results in this direction. But the best has yet to come: the next milestone in cosmic ray physics is the detection of antinuclei, like antideuterons and antihelium from extraterrestrial sources. Their detection could provide a groundbreaking discovery that has important consequences in particle physics, nuclear physics, and cosmology.
The detection of a few antihelium candidates have been announced a few months ago by AMS-02, and if this result is confirmed, this would provide a groundbreaking discovery. The detection of cosmic ray antideuterons would provide a "smoking gun" evidence for the existence of particle dark matter, essentially free of astrophysical background.

The AMS-02 team at RUG has a lot of experience in the search for cosmic ray antimatter. Manuela Vecchi worked for several years on the identification of cosmic ray positrons with AMS-02, and now she is working, together with her PhD student Eduardo F. Bueno, on the search for cosmic ray antideuterons. The two analyses are quite different: positrons are light, elementary particles, while antideuterons are antinuclei, made of an antiproton and an antineutron. At the time the search for positrons with AMS-02 started, back in 2012, the challenge was to understand the detector and its performance, because positrons constitute a tiny signal that is about a few thousand times less abundant than the background, made essentially of protons and misidentified electrons. Eight years after, a deep knowledge of the detector has been gathered, and the present challenge is searching for a signal that has never been observed in space, and that is thought to be at least a billion time less abundant than the background. The main experimental challenge in the search for anti-deuterons comes from the reconstruction of both the charge sign and the mass. Precise measurements of these quantities are essential to identify the signal and to reject the background made of protons, antiprotons and deuterons.

The main goal of the work of the AMS-02 group in Groningen is to develop sophisticated statistical estimators able to tag the anti-deuteron signal, keeping high efficiency on the signal. AMS-02 has unique capabilities in the domain of isotopic separation. The good accuracy on measuring the velocity, allied to the precision in the momentum measurement, provide the mass of the element. To distinguish anti-deuterons from their background, the team is developing statistical mass estimators that will be used as template distributions for different velocity regions. In the coming years, AMS-02 will continue taking data, and another experiment will soon join the race. The General Antiparticle Spectrometer (GAPS), which is optimized specifically for low-energy cosmic ray antinuclei, will begin several Artic balloon campaigns in late 2020. GAPS is not equipped with a magnet, but anti-deuterons will be captured in the GAPS target material, resulting in an exotic atom in an excited state. This exotic atom will then quickly decay, producing X-rays of precisely defined energies and a correlated pion signature from nuclear annihilation.

You will for sure hear back from us in the forthcoming years. Stay tuned!•

Suggested Reading

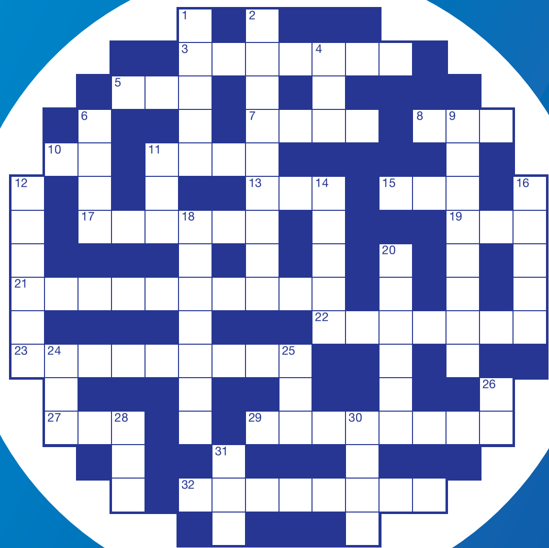
https://home.cern/science/physics/antimatter

https://en.wikipedia.org/wiki/Alpha_Magnetic_Spectrometer

Puzzle
to win a Bluetooth speaker!

Across
3. Second profession of the inventor of Morse code
5. Frozen water
7. Component considered to be ASML's heart of the DUV system
8. State of the … technology
10. Japanese board game
11. Starting material for wafer production
13. Carpenter's tool
15. Chemical elements: Hydrogen + Iodine element + Sulfur
17. Transistor layout
19. Environment friendly
21. First person to win two Nobel prizes for Science
22. Part in ASML system that contains the customer's pattern for chip production
23. Location of ASML's headquarters
27. One of the partners in the 'Metropoolregio Brainport Eindhoven' sponsorship
29. Famous physicist who became a guitarist
32. Decade in which ASML was founded

Down
1. Type of web browser
2. ASML system to measure on-product overlay
4. Metal used in ASML's EUV light source
6. One of the two sports that has been played on the moon
9. Department that conceives ASML's future technologies
11. Star at the center of our solar system
12. Science fiction writer that invented the three laws of robotics
14. Chips are cut from a …
16. The Law driving the semiconductor industry
18. Production facility to manufacture a complete ASML system
20. Program language developed in the Netherlands
24. ASML's latest lithography technology
25. Near-infrared
26. Internet country domain for Malaysia
28. Laboratory
30. ASML's biggest market
31. Device that makes you able to interact with a computer



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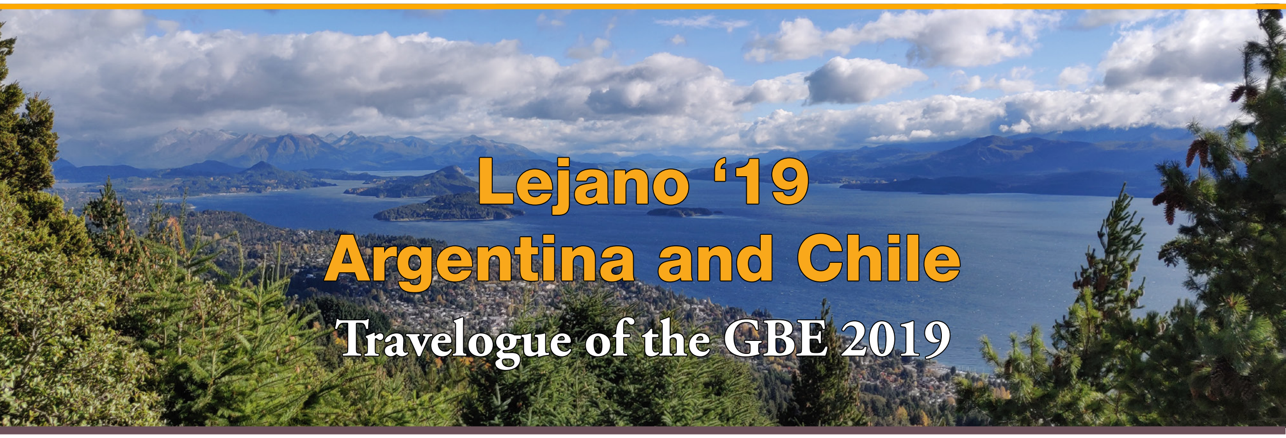

Lejano ‘19 Argentina and Chile

Travelogue of the GBE 2019

AUTHOR: **THOMAS VAN BELLE**

It was a very lovely afternoon on the 23rd of April, when we gathered to leave to Schiphol. It was the start of the GBE, an excursion to Argentina and Chile.

When we got through customs at Schiphol, we were notified that our flight to Buenos Aires was delayed by two hours. Fortunately, we got a voucher to get some extra food at Schiphol, to compensate for our delay. However, one hour before our new flight time, it was announced that our flight would not go at all. We were all booked into a flight 24 hours later, and told to arrange a hotel in Amsterdam. Since our flight would leave at 21:00, we were told that we could spend a day in Amsterdam, and gather at Schiphol again at 18:00. This meant that I could actually still attend my lecture of Stochastic Processes. This course was taught by Daniël Valesin, one of the staff members who would also join our trip. This time, our plane actually left, and 24 hours later than planned, we were on our way to South America.

The first destination of our excursion was Buenos Aires, where we had a free day to recover from our jetlag. Most of us used this day to go sightseeing and exploring the city. Some of the famous places are Casa Rosada, Plaza de Mayo, and the Obelisco de Buenos Aires.

Our second day in BA, we had our first company visit to INTA, which is a government owned company that supports local business industrial technology. Here we visited a laboratory that is in the process of defining the Argentinian standard for the meter (you can read more of this in “In the news”).

After only two days, it was time to go to our next destination; San Carlos de Bariloche. This is a town known for its beautiful lakes, and German heritage.

The first day there, we rented cars and drove around the Llao Llao peninsula, which is located in the Nahuel Huapi lake. The nature around the lake is quite similar to the big alpine lakes in Europe (like the Bodensee or lake Geneva). This is one of the reasons that Bariloche is also known as small Switzerland. Of course, we also visited companies here, one of which was INVAP. This company specialises in nuclear reactors, aerospace, and defence and security. Furthermore, they won the bid to build a nuclear reactor in the Netherlands.

After this beautiful intermezzo, we flew back to Buenos Aires. This time, we mainly focussed on visiting companies. We had a visit to Central Puerto, which is the main power producer for the city. During the tour of their facilities, we went up their main tower, and enjoyed the view from there. The next day, we went to NA-SA, which should not be confused with the American NASA. NA-SA is a company that operates the nuclear power plant about 150 kilometres northwest of Buenos Aires. Since we had rented cars to visit the power plant, we drove by the Tigre delta on the way back.

This was our last day in Argentina, as we were flying to Santiago de Chile the next afternoon. Since the first day in Chile was a Sunday (and companies and universities are closed then), we started with trekking or rafting in the Andes mountain range. Since the group was split at this point, I can only say that the trekking part was really nice. We walked to a small waterfall, to have some food and drinks there.

← **FIGURE 1**: **The Nahuel Huapi lake.**

On the Monday, we started our streak of visiting universities. Our first stop was Universidad de Chile, where we had a tour around their campus and visited a few of their labs. The next day we visited USACH, where we were received by the Dutch ambassador, and the head of the faculty of science. After some talks about their research, we had a very nice lunch and a tour around their facilities as well. In the evening we had a dinner with staff members and PhD students from USACH. The next morning, we had to gather really early to take a bus to Valparaíso, a coastal city near Santiago. Here, we visited Federico Santa Maria University, and spend a free afternoon at the Pacific. The remaining two days in Santiago, we visited a hydro dam and a defence contractor which were both quite interesting to see. Finally, we went up the Costanera tower, which is the highest tower in Latin-America at 300 meters. From here, we had nice views over the city.

Finally the time had come to leave Santiago, and get in a plane towards the Atacama desert. Here, we would visit both the VLT (Very Large Telescope) and ALMA (Atacama Large Millimetre Array). Since we had to drive to both institutes ourselves, we rented cars for the next couple of days, which also meant that we would be able to do some road tripping as well. The first day in the desert, we went to VLT where we first had the standard tour for visitors. When the sun was setting, we could go up to the telescopes again to see one of them open for the observations the following night. Furthermore, we could see the sunset from Cerro Paranal *(figure 1).*

"The highest FMF-sticker in existence sticks at 4512m above sea level"

After a day of road tripping to San Pedro de Atacama, we visited ALMA. Here we could see one of the antennas they use for observations, as it was in maintenance. Unfortunately, due to the very high altitude we were not allowed to go up to the observation platform. The next day, we drove to Calama. During this trip we went over a mountain pass of 4512m above sea level. Obviously, we pasted a FMF-sticker here, which now is most likely the highest FMF-sticker in existence.
The next day, we had our final serious activity, which was visiting the Chuquicamata Coppermine. We went to the viewing point inside the mine, where we could see the transportation of the materials that contained small amounts of copper.
In the evening, we were flying back to Santiago, where we would have a final free day to buy some souvenirs and do some sightseeing. Unfortunately, this marked the end of our amazing excursion to Argentina and Chile. After a long 18 hour flight, we landed at Schiphol airport and could touch Dutch soil again.

I would like to give a big thanks to the GBE committee for organising an amazing excursion which all participants enjoyed a lot.

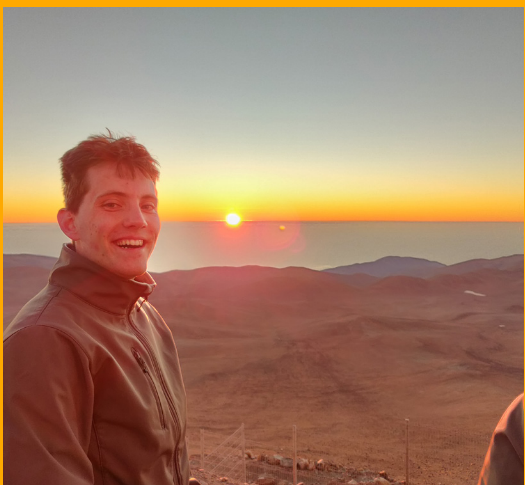

FIGURE 2: Sunset at Cerro Paranal. And Bas.

FIGURE 3: View from the Costanera tower.

Gridt: The Network for Connecting Social Movements

AUTHORS: **YORI ONG, JORN WILDERING**

What does flossing your teeth have to do with graph theory? In this article we will explore the answer and introduce Gridt, a non-profit open source project with strong FMF roots. You'll be pleased to find out throughout this text that having done your math homework can give you an edge in understanding a new trick in sociology and behavioral psychology as well.

FIGURE 1: This is Bob. Bob is on the Gridt.

Making people floss

Flossing your teeth is arguably the least sexy activity in the universe. It involves contorting your face, then shoving your fingers in your mouth while making saliva and debris spat onto your bathroom mirror. Good thing we don't do it in public. Although there are more subtle ways to clean your interdental spaces, like dental woodsticks, none of them bring actual joy. There is no immediate reward for doing it, nor is there a punishment for neglecting it a few times. And yet, this habit is essential, as it is the only effective way to avoid the physical, emotional and financial pain of dental procedures. If you're under 25 and thinking "I've never had any problems despite not flossing", please remember that your grown-up teeth have yet to reach 20% of their expected lifespan. (If you're 50, it will be around 50%.)

So how do we let millions of people acquire a lifelong habit of doing something that is intrinsically so very lame? A common answer is to make people more knowledgeable. However, most of us will have the experience that knowledge does not at all imply discipline. External rewards, threats, or gamification also do not provide the perspective of converting millions to dental hygienism for a lifetime, because they would cost too much and lose their power over time. To tackle this problem that has existed forever, the solution must be cheap and omnipresent: we have to make it social.

How behavior spreads

Facebook, Twitter and Instagram are three of the biggest online social networks that have connected billions of people by 2019. Chances are that you have an account on one of these networks, even though you're not even that fond of using them. In that case, it is likely that you just created an account at a point in time when it seemed that everyone was doing it, which suggested that there was at least some appeal to it. Interestingly, we learned by now that fake news, photos of catbreading or throwing cheese on babies spread like wildfire on social media. At the same time, people who use the same platform to call for action on climate change are less successful. This might be explained by the well-tested hypothesis that people do things that they see other people doing (like monkeys). In the end, the reason for most of us to join social media is because we noticed people around us doing it. Putting a slice of bread around your cat is clearly something that other people do as well, as the pictures prove it. But behind a call for action to save our planet, there usually is no clearly visible action, except for clicking the 'share' button. This can also explain why many people don't floss regularly: we just never see other people doing it. Maybe we should do it in public! However, the danger of exhibiting your good behavior is that you will be seen as a twerp. What can we do about this?

Gridt: the network for social movements

The Gridt is an online network in development designed to spread behavior and to give people social support in learning new habits. Here we explain how it works, based on the story of our model user, Bob. Bob wants everyone, including himself, to floss their teeth daily. He also wants to spend an hour of his time each day to study for his upcoming exam on statistical physics. To nudge himself into behaving in accordance with his goals, he joins the Gridt.

- For each of his goals, Bob joins a movement on the Gridt. A movement connects all people who share the same goal, formulated in a concrete action that they all want to undertake and that repeats with a certain interval.
- In each movement, Gridt connects Bob to four peers that lead him...
- ... and gives him a switch to inform those who follow him when he has completed his daily goal.
- Now here's the trick: Bob can only see the four people who lead him, but cannot see the people who follow him.
- On the Gridt, every user in every movement is connected in the exact same way.
- Did you see what we did there? We made a digital conga line! By giving each user four unilateral connections, the Gridt Network provides its users with a permanent social incentive to turn goals into action *(figure 2)*.

> *"Maybe we should floss in public!"*

Graphs and digraphs

Graph theory is a discipline in mathematics with applications ranging from computer science to sociology and biology. Graphs are mathematical structures that model the relations between two or more objects, mostly visualized as nodes connected by edges. Most social communication networks that we use can be represented as undirected graphs, meaning that there is no direction associated with the connection and communication between person *A* and *B*. This makes a lot of sense, since we like equality among people. However, the spreading of behavior occurs through people leading and following, a type of connection that definitely has a direction associated with it. The Gridt Network would be the world's first online social network which is represented by a directed graph or digraph. To be more specific, it is a digraph in which every node has a fixed indegree, meaning that there's a fixed number of incoming connections (leaders) per user. The outdegree (number of followers) is undefined and can

FIGURE 2: Gridt helps Bob to train 'grit', the mental endurance for pursuing long term goals. In every peer group of give people, the user is nudged to fulfill one of five crucial roles: leading (1st), being the first to follow (2nd), making a majority (3rd), isolating the last person (4th) and completing the movement (5th). Since the connections are unilateral, Bob's role in his peer group is a matter of perspective: by completing his action, he would be the first follower on his own screen, while as seen by Alice, he would be taking the lead. In any case, Bob is nudged to act on his own goals and by doing so, he spreads the action as well.

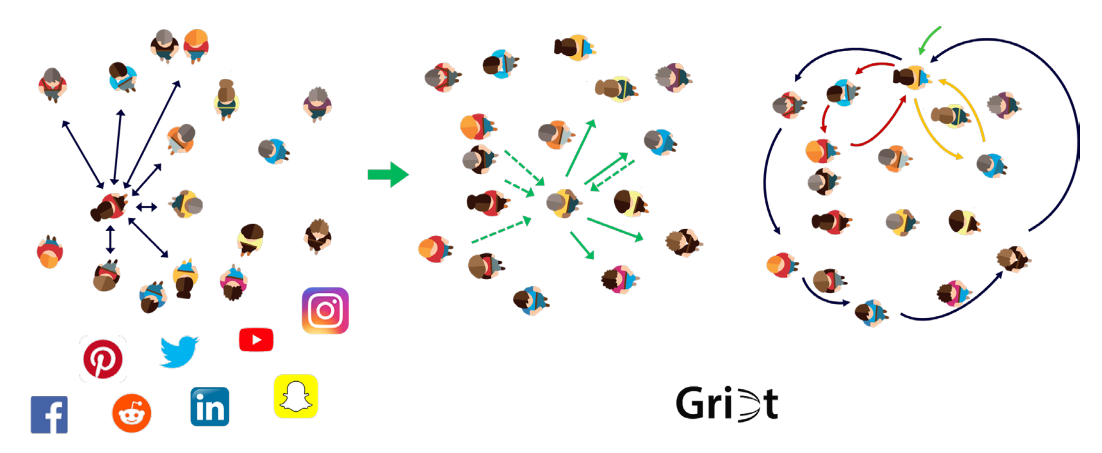

FIGURE 3: Existing online platforms are can all be represented as undirected graphs, whereas The Gridt Network is represented by a digraph. In this digraph, information will eventually travel in cycles, adding the aspect of karma to the behavior of people on the network: what goes around, comes around!

range from zero to a lot, but will remain unknown to the user. This ensures that their good behavior is never an act of attention seeking, but rather one of conscious leadership. Figure 3 gives a colorful representation of the way people are connected on the Gridt, taking into account that Gridt only connects people who share a common goal.

One of the interesting questions that we will explore with this experiment concerns the relation between the network's connectivity and the individual cognitive processes leading to behavior. One can imagine for instance that some types of behavior spread more easily depending on the degree of connectivity, or that here is a relation with personality traits. It has already been shown experimentally that behavior spreads more efficiently in networks with larger diameters, meaning the number of edges that need to be traversed between nodes with the largest separation. Networks with high connectivity per node, such as existing online platforms, are typically associated with smaller diameters, since the degree of separation between users is small. For undirected graphs however, limiting the number of connections one can make comes at the cost of the user's freedom to connect with whom he or she wants, or might result in the network not being able to support an arbitrary number of nodes. Gridt, corresponding to a digraph with fixed indegree, does not have this problem.

"For healthy teeth, diligent students, a cleaner planet, a free and open internet and highly interesting science."

Join the movement!

To get the job done, we started our own movement for healthy teeth, diligent students, a cleaner planet, a free and open internet and highly interesting science. Such an endeavor for public values can of course only succeed without the pursuit of profit. We're currently looking for people who want to strengthen our board and entrepreneurial team, help build the open source community or who want to come up with a student project. If you're interested to read or hear more from us, visit our webpage at **www.gridt.org** or shoot us an email via **info@gridt.org**.

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[2] Duckworth, A., Peterson, C., Matthews, MD., and Kelly, DR., Grit: Perseverance and passion for long-term goals, J. Personality and Social Psychology 92:1087–1101, 07 (2007)

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Radio Signals from the Cosmic Frontier: A Discovery of New Physics?

AUTHOR: **D MEERBURG**

Our understanding of the Universe and the physical laws behind it has seen tremendous progress in the last several decades. The most compelling piece of evidence that supports the theory of an expanding Universe emerging from a hot dense soup, is provided by the Cosmic Microwave Background (CMB). Its accidental discovery in 1964 and subsequent precision measurements of the fluctuations on top of this background, has established a paradigm in cosmology that estimates our Universe to be 14 billion years old and to consist of three parts matter and seven parts dark energy.

Furthermore, the matter itself consists only 1 part out of 5 of matter we know, so called baryonic matter, while 4/5 is made out of matter which we thus far can only measure through gravitational effects (and hence is called dark matter). Dark energy was introduced to explain the recent accelerated expansion. Its origin and make-up are also unknown although it has become mainstream to associate this energy with the vacuum, since its equation of state shows that it does not dilute as the Universe expands. Furthermore, we have found that the early Universe, before matter and radiation took part in the evolution of the Universe, there must have been a process that generated fluctuations with almost constant power as a function of scale, i.e. the distribution of these initial fluctuations can be described by a Gaussian with a variance that does not depend on the physical dimensions (wavelength) of the fluctuations. The most widely supported and tested model that can lead to such a distribution is known as inflation, which is a period of exponential expansion in the very early Universe. Inflation can furthermore explain the current observed curvature (which is close to Euclidean) and provides a mechanism to explain the isotropy and homogeneity on large scales. A remarkable aspect of modern cosmology is that it relies on only 6 degrees of freedom[1] + the assumption of General Relativity. Although this model is elegant and has stood the test of time thus far, it does not provide us with fundamental understanding of dark energy and dark matter, nor the physics behind inflation. The overal goal of cosmology in the next years will be to obtain some proof of deviations from this simple model that would allows us to shed light on these fundamental questions.

The Dark Ages and Cosmic Dawn

In order to search for clues in the Universe, the CMB has thus far provided the most robust observations. The main reason why the CMB is such a powerful probe is that it is the most ancient observable we can study in our Universe, originating a few hundred thousand years after the Big Bang, while at the same time the physics is relatively simple, where linear physics suffices to describe the fluctuations we observe to a high degree of accuracy. CMB photons have an amplitude (temperature) but in addition are also linearly polarized. While CMB temperature has been very well measured, in the next several years experiments will make precision measurements of the polarization field. This could provide new clues about the early Universe, in particular the existence of primordial gravitational waves, which are hypothesized to originate in most models of inflation. Unfortunately, at some point we will not be able to extract more information about the early Universe from the CMB for two reasons. First, on small scales

[1] 2 densities (dark matter and baryonic matter), one geometrical scale (Hubble), an optical depth and two parameters that describe the Gaussian initial conditions.

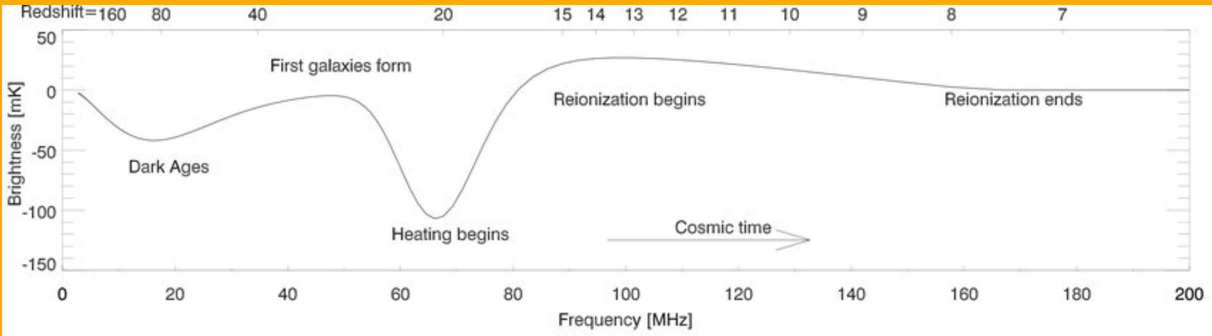


FIGURE 1: Sketch of the thermal history of the HI brightness temperature. Early on the spin temperature is coupled to the CMB, and there is no signal. Around redshift 200 the spin temperature decouples from the CMB and becomes coupled to the gas, at which point the 21cm signal can be observed in absorption (against the CMB backlight). This period is know as the Dark Ages. At later times, the gas becomes too dilute and the spin temperature no longer couples to the gas, and heats up to the CMB temperature. Following this brief period of no signal, the first stars turn on and the so-called Wouythuizen-Field effect couples the spin temperature back to the gas. This period is known as Cosmic Dawn. Early in this period the gas is still cooling, but soon after (X-ray) radiation from the first stars quickly heat up the gas which sets the stage for the process of reionization. Most hydrogen is stopped off its electron (ionized) and the signal again dies away.

CMB fluctuations are washed out by the frequent interactions between the photons and free electrons before the CMB was formed. Second, the CMB is fundamentally only a 2 dimensional image of the Universe and hence contains only a limited amount of information. To go beyond this 2 dimensional picture of the Universe, would require us to map out the large scale structure (LSS) in the Universe. One obvious way we can map out LSS is through measurements of galaxies and galaxy clusters. They provide us with a biased (since we observe only luminous matter) image of the structure, but a full 3 dimensional picture of the Universe can be obtained as long as we can find a decent tracer. Unfortunately, one major limitation of LSS as a probe of fundamental physics and in particular the early universe is the fact that LSS is described by highly non-linear physics. In other words, even though fluctuations have not damped out like they are in the CMB, coincidentally the non-linear scale in the recent Universe is almost identical to the CMB damping scale.

The CMB formed when the Universe was about a thousand times smaller then it is today (redshift $z \approx 1100$), while the first galaxies only formed when we the Universe was about a tenth of the size it is today ($z \approx 10$). Large scale structure cosmology by means of measuring galaxies typically concerns redshifts between 1 and 5. This leaves a large volume in the Universe unexplored ($z > 10$ and $z < 1100$). Since there are no galaxies at those redshifts, this is commonly referred to as the Dark Ages. Although there are no self-luminating objects, there is a way to measure structure during the Dark Ages. Neutral hydrogen, existing of a proton and an electron, is omni present in the post CMB (recombination) universe. The proton and electron in the hydrogen atom have spin. It turns out that there is a small energy difference between a state of the atom where the spins are aligned and where they are opposite. This energy corresponds to a photon with frequency 1440MHz or wavelength of 21cm. We can associate a temperature to this spin state, the so called spin temperature. Just like other objects, a hydrogen will either absorb or emit a photon with a wavelength of 21cm if its spin temperature is below or above some background temperature. Luckily, such a background temperature bath exists in the form of the CMB. Very crudely speaking, if the spin temperature is below that of the CMB, we can observe hydrogen through absorption against the CMB, and in emission in cases where the spin temperature is higher than that of the CMB. The spin temperature itself is driven by collisional and radiative interactions with the gas and the CMB. For most of the history of the Universe, the spin temperature is below that of the CMB ($20 < z < 200$) and hence we can observe hydrogen in absorption. One of the benefits of 21cm observations is that we know the source distance (redshift) once we make a measurement because we know how wavelengths redshift as they propagate through the expanding Universe. Several experiments aim to measure this signal, where LOFAR might be the most well known and important experiment to

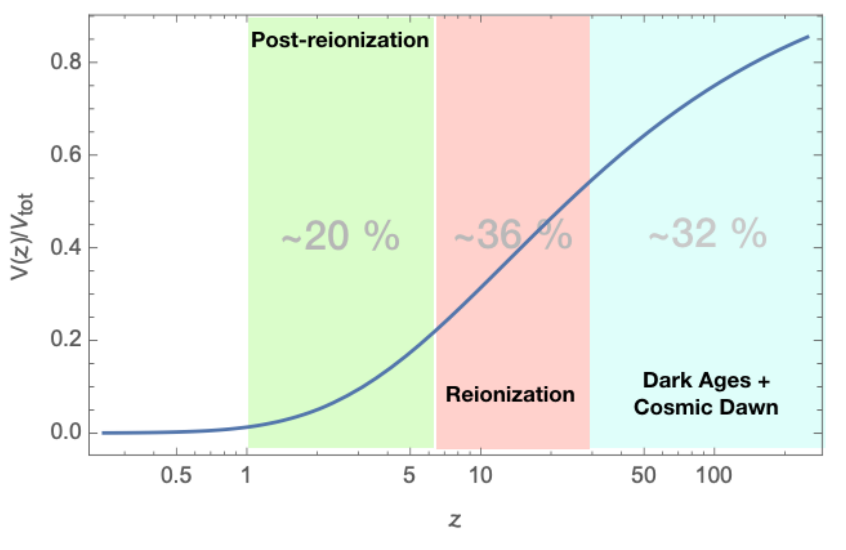


FIGURE 2: 21cm cosmology can one day become an extremely powerful probe of cosmology since it potentially provides access to a large faction of the volume of the entire observable Universe. The signal around reionization and the signal from the Cosmic Dawn and Dark Ages each present about a third or the entire observable Universe.

the Netherlands. Its goal is to measure this signal between the Dark Ages and the light from the first galaxies ($6 < z < 12$). More precisely, LOFAR aims to measure the fluctuations in the 21cm signal. However, in principle it should be possible to observe the background evolution of the 21cm brightness temperature (i.e. the monopole). Figure 1 shows how the brightness temperature evolves as a function of redshift. In March 2018 a group experimenting with the EDGES dipoles in Australia claimed a detection of the monopole. This would present a groundbreaking discovery because it would open up the field of 21cm cosmology as a true contender to more traditional LSS cosmological surveys. In Figure 2 we show the comoving cosmological volume as a function of redshift. This show that 21cm could possibly provide access to a very large fraction of the entire observable Universe.

“This would present a groundbreaking discovery as it would open up the field of 21cm cosmology as a true contender to more traditional LSS cosmological surveys.”

The EDGES detection

On Februari 28, 2018 a group operating the EDGES experiment announced the detection of “An absorption profile centered at 78 megahertz in the sky-averaged spectrum” (Bowman et al. Nature, 555, 67, 2018). The article claimed an apparent feature in the radio emission coming from all parts of the sky (suggesting a monopole) which could be interpreted as a signature of the Cosmic Dawn –the moment, early in the history of the Universe, when the first stars came into being following the Dark Ages as indicated in Figure 1. The general prediction for this feature, is that if the first stars were created about 200 million years after the Big Bang (i.e. at a redshift of $z \approx 18$) this be found at about the frequency of the reported profile. The feature observed by the EDGES experiment was however much deeper than that predicted and its flat-bottomed shape was also unexpected. Figure 3 shows the observed feature and the predictions for a wide range of models based on our current understanding of the conditions at this stage in the evolution of the universe.

The predicted absorption feature has a well understood depth, because it depends critically on the expansion history of the Universe and fundamental properties of the gas. The former provides a fairly robust prediction when the gas temperature decouples from the CMB temperature, while the latter tells us that gas cools adiabatically. As a result, at any given redshift, since the spin temperature is either coupled to the gas or the CMB, can only be as low as the local gas temperature, which at a given redshift can only be as cold as allowed by the aforementioned well understood physical principles. In other words, for the absorption feature to be as large as that observed would mean that there is something important that has been missed –some new physics or perhaps a previously unseen constituent of the universe. Following the publication of the EDGES result, a very large number of theoretical papers have been published trying to explain the observations along these lines. The general approach is to eiher find some way to make the gas extra cold (by coupling it to an ever colder components, such as cold dark matter) or to heat up the background. The first scenario requires new physics as it would suggest that the gas can somehow couple to dark matter (which would make it less 'dark'), while the latter could be astrophysical, but would require a rethinking of the thermal history of the Universe. Neither solution is very compelling since there exist various other observations that limit the amount of new physics that is allowed which generally require finetuning of the models in order not to be totally excluded by complementary observations. It became clear that it is more likely that something else is causing the apparent depth and shape of the profile.

Concerns about the EDGES detection

It should be mentioned that observing the monopole or 'global' 21cm signal is very challenging because the sky is very bright at these low frequencies: the cold (3 Kelvin) CMB radiation is tiny compared to the several thousand degrees "foreground" emission produced by the energetic particles in our own Galaxy. In addition, there are the emissions from other radio sources and significant absorption and emission by the electrons in the Earth's ionosphere. These unwanted signals all need to be removed before the apparent absorption profile can be seen.

With a group at Cambridge, lead by Richard Hills, we carried out an in depth analysis of this aspect of the observation. We found that the proposed absorption profile can only be extracted from the data if the processes producing the foreground emission are assumed to have unphysical properties. For example we found that the fit of the profile requires a negative temperature for the electrons in the ionosphere, which is physically impossible. If the parameters describing the properties of the foregrounds are restricted to physically reasonable values, then the remaining profile has a completely different shape from that shown in the EDGES paper. This is shown in Figure 4.

This suggested that there might be some residual systematic errors in the measurements of the sky brightness. After various discussions with the EDGES team they agreed that there may indeed be some effects arising in the instrument or in the way in which the calibration was done. Although it is true that if one chooses to use the particular model adopted by the EDGES team, then we do recover the profile that they published, we found that simply by making changes to

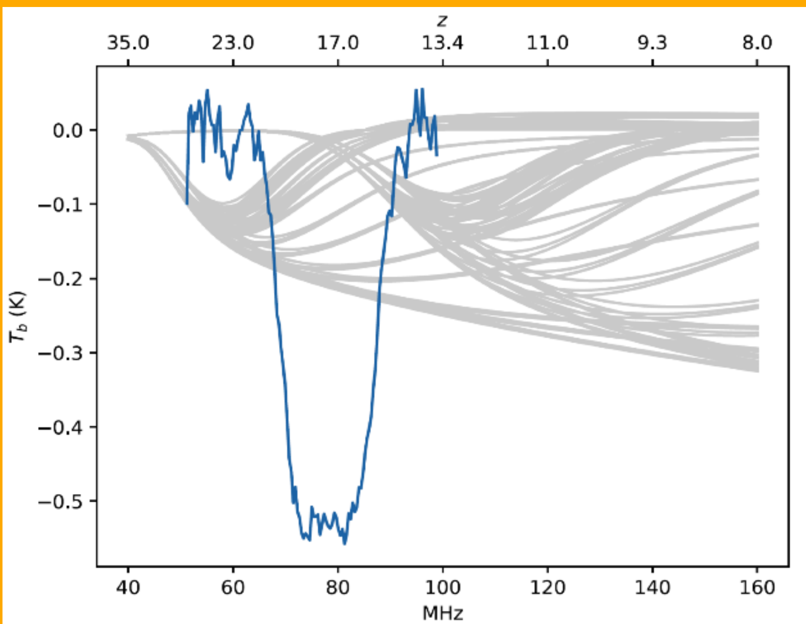


FIGURE 3: The signal published by the EDGES team (blue) compared with a wide range of physically plausible models (derived using the ARES code Ref. Mirocha, J., MNRAS 443, 1211, 2014).

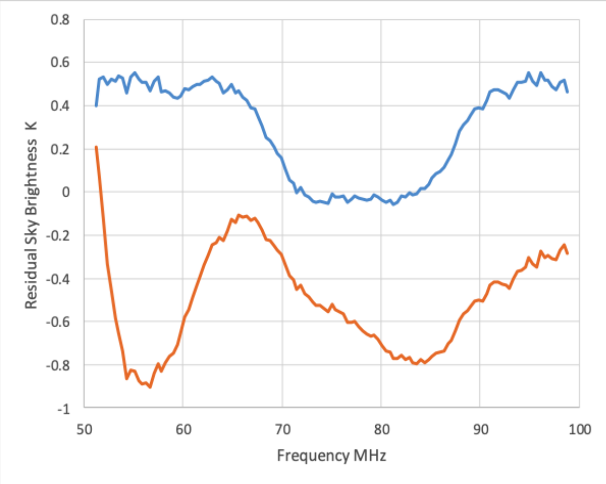


FIGURE 4: Top line: the signal after subtraction of foreground emission as modelled by the EDGES team. Lower line: the same signal when the parameters of the model subtracted are constrained to have physically plausible values.

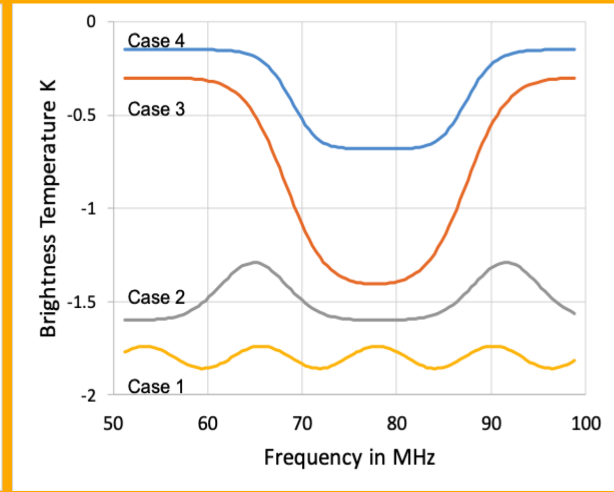


FIGURE 5: Alternative models fitted to the EDGES data. Case 1: the profile found by the EDGES team. Case 2: using the same formula for the profile but with a different model for the foreground. Case 3: using the original model for the foreground but a different formula for the profile. Case 4: with changes to both the foreground model and the profile formula. All these cases have the same number of free parameters (nine) and leave a similar level of residuals between the data and the fitted model.

the assumptions about the foregrounds and/or the form of the profile we obtained very different results. Figure 5 shows some examples of this.

“The problem we face now, however, is that it is not clear what is the correct model to use.”

Therefore, these findings call into question the interpretation of the EDGES data as an unambiguous detection of the cosmological 21cm absorption signature. In particular it seems premature to suppose that new physical theories are needed to explain it. The problem we face now however is that it is not clear what is the correct model to use to account for systematic effects, and any accounting of residuals at the instrument level can only be done by the group running the experiment. Fortunately, there is a clear path forward, which is to verify the findings by the EDGES team using independent experiments. Numerous experiments are already observing the global 21cm sky and have preliminary results, although none have reached the precision of the EDGES experiment. At Cambridge a new global 21cm experiment, called REACH, is under development that will be operating from the radio quiet zone in South Africa. Even more exciting, recently a Chinese/Dutch antenna was launched into orbit, with as its goal taking data from the back side of the moon. The advantage (and most likely the path forward for 21cm cosmology) is that the moon is free of human made radio interference. The far side of the moon provides the most radio quite zone in the nearby Universe. Any signal this antenna detected will most definitely be from outer space. The first data from this device is expected soon and Groningen will play a part in analyzing this data. If the EDGES detection is confirmed, it would open up the field of 21cm cosmology and provide a window into a large fraction of the volume of the Universe that was deemed unobservable and possible hint at physics beyond the standard 6 parameter cosmological paradigm.

The results of our the re-analysis were published in Nature, with immediate comments by the EDGES group•

“Concerns about modelling of the EDGES data” by Richard Hills, Girish Kulkarni, P. Daniel Meerburg and Ewald Puchwein. appeared in Nature 564: E32–E34, 2018

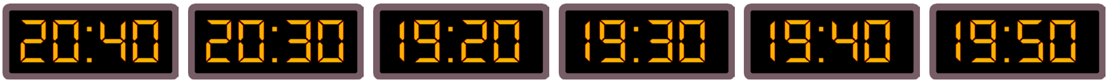
Brainwork

What time is it?

AUTHOR: **ROBERT MODDERMAN**

Exam weeks! The most wonderful time of the year. You got yourself into trouble again – will you make it to the end?

Today you're doing your first exam. It's an evening exam, from 18:30 to 21:30. You take a look at the 6 clocks hanging in front of the hall and wonder how much time you have left. There are two slight problems: the clocks don't give the same time anymore though they did at the exact instant the exam started, and you don't have a watch or time reference apart from these clocks whatsoever! This situation doesn't make you more comfortable. Still, you decide to figure out what time it is. For the first time during your exam, you take a detailed look at the 6 digital clocks that (how poorly) don't have any digits for the seconds:



It's publicly known according to what (intelligent) rules the clocks deviate:

1. any clock either runs forward at normal speed or doesn't run at all;
2. there is a pair of *non-neighbouring* clocks such that, at all times, *exactly one* of them runs;
3. at 20:00, all clocks indicate the exact same (but wrong) time.

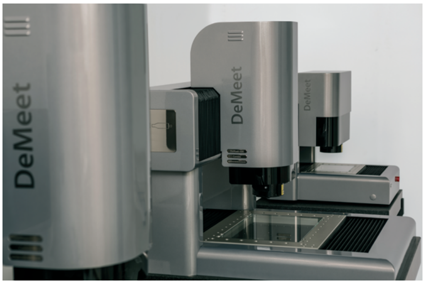
The question then is:

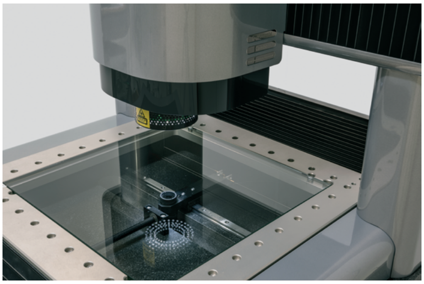
How much time do you have left before your exam finishes and how do you *know* so?

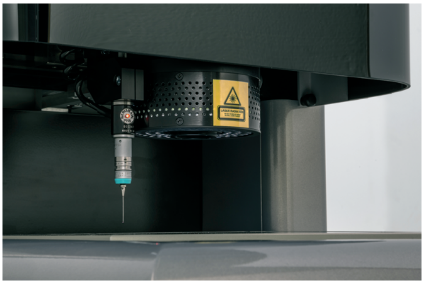
Previous Brainwork:
7 Pictures

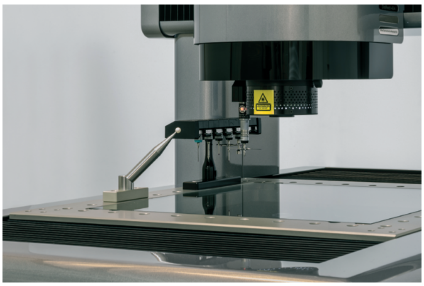
**Unfortunately, we have not received any solutions to the previous Brainwork.
We realize that you had less time to solve it than is usual, so we have decided to extend the deadline!**

To have a chance at winning a prize, you can send your solutions to "What time is it?" and "7 Pictures" to perio@fmf.nl before October 1st!









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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.

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