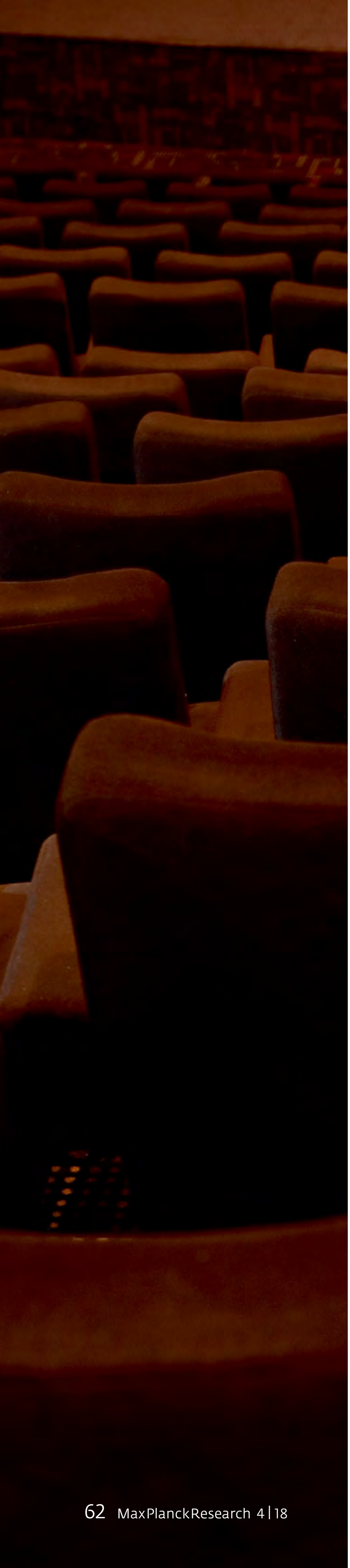


A nose for feelings

Before **Jonathan Williams** discovered atmospheric chemistry, he had a problem: he was fascinated by so many things that he didn't know which scientific discipline to devote himself to. Even today, the scientist at the **Max Planck Institute for Chemistry** in Mainz has varied research interests. In recent years, for example, another new topic has awoken his curiosity – the trace that our emotions leave behind in the air.

TEXT **KLAUS JACOB**

Jonathan Williams has come quite a long way, not just geographically speaking but also in terms of his research topics. Although he has now been a researcher at the Max Planck Institute for Chemistry for 20 years, he – like many scientists – has lived life as something of a globetrotter. The Englishman was actually born in South Africa in 1968, where his father spent a few years working as an engineer. However, Williams no longer has any memories of that time, and he completed school and university in England.

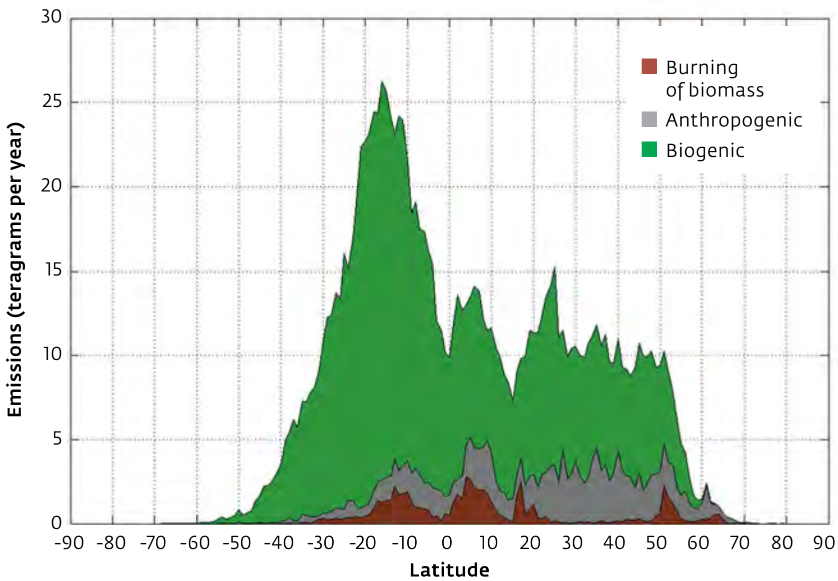
He then attended the University of East Anglia in Norwich, where he studied chemistry and French – he struggled to choose a single subject because there were simply too many things that interested him. It was not until he went to a seminar about the climate in France that he realized which field he wanted to work in: atmospheric chemistry. He was particularly fascinated to learn that, unlike in the oceans, processes in the atmosphere take place at very high speed. This makes it a varied and exciting area of research: "A normal researcher's career provides plenty of time to discover something new," Williams smiles.

THE INFLUENCE OF VOLATILE ORGANIC COMPOUNDS

With a strong tradition of atmospheric research, the University of East Anglia was the perfect place for Williams to study the field he had now discovered. And so it was here that he completed his PhD on oxidative processes in the air, which play an important role in the atmosphere's self-cleaning capacity. >

Uncharted territory for an atmospheric chemist: for several years now, Jonathan Williams has been investigating whether feelings during films leave behind traces in the air in movie theaters.

Photo: Thomas Hartmann



Left The sources of volatile organic compounds: this graph of VOC emissions by latitude and origin shows that most of the substances are released by plants, primarily in the tropical rainforests. In locations where the continents are heavily populated, VOCs also originate from the burning of fossil fuels.

Right-hand page Aiming high: to determine the average emissions of volatile organic substances in the tropical rainforest, researchers must also take their measurements at the greatest possible height – for example, using an 80-meter tower in the Amazon rainforest. The red hoses carry the air samples to the mass spectrometers at ground level.

During his doctoral studies, he also dealt with volatile organic compounds (VOCs) for the first time, and these remain the subject of his research to this day. Ultimately, they are the substances we can smell – in the scent of roses, for example, or in the heady plastic whiff of a new car. There are thousands of them, and although they are only present in trace quantities in the atmosphere, at considerably lower concentrations than carbon dioxide, their influence is nevertheless huge: "They make the music," as Williams says. For example, they play a key role in the formation of near-ground ozone and fine particulate matter.

VOCS FROM PLANTS CONTRIBUTE TO OZONE FORMATION

Soon after completing his PhD, Williams accepted a position at the National Oceanic and Atmospheric Administration (NOAA) in Boulder, Colorado, where he continued to focus on the role of VOCs in ozone formation. The authorities in the U.S. had done a great deal of work on tackling near-ground ozone, but there had been barely any reduction in the atmospheric load. For example, cars in America had been fitted with catalytic converters since the 1970s in order to remove hydrocarbons from their exhaust gases, with unburned fuel residues considered a key factor in ozone formation.

To investigate why the air in the U.S. still contained too much ozone despite the strict emissions standards, Jonathan Williams sought the help of so-called hurricane hunters, whose aircraft normally collect data on the development and path of cyclones. Outside of hurricane season, however, Williams loaded them up with his own instruments. The hundreds of hours he spent on board the aircraft paid off: the atmospheric chemist's analyses showed that, when it comes to ozone formation, VOCs of plant origin had taken on the role that was previously played by substances derived from the hydrocarbons in fuel prior to the introduction of catalytic converters in cars.

This was what aroused his interest in biogenic VOCs. In fact, most of these volatile compounds in the atmosphere come from vegetation, with only around ten percent considered to be anthropogenic. In this quest study how VOCs, above all those plant origin, contribute to atmospheric chemistry, Williams moved to Mainz in 1998. He was keen to work at the Institute of Nobel Prize winner Paul J. Crutzen and explains that Mainz "is the center of the universe for atmospheric researchers." However, the ideal large-scale laboratory for his area of research is located not in the capital of Rhineland-Palatinate, but in South America: the Amazon rainforest exudes huge quantities of VOCs and is the perfect location for Wil-liams's analyses.

A JUNGLE ODYSSEY TO THE ATTO MEASUREMENT TOWER

Twice a year, Williams travels to this lush, green wilderness, where he initially took measurements from an 80-meter scaffold. Then, two years ago, the Max Planck Society erected a 325-meter-high tower by the name of ATTO, which allows measurements to be taken at various heights. Williams uses this tower to study how the highly reactive VOCs react with components of air and how the VOCs change in the process.

The journey to ATTO is like an odyssey every time: the atmospheric chemist has to swap from a large aircraft to a small one before continuing his journey by road, and ultimately by river, in order to penetrate deep into the heart of the jungle. From there, his journey takes the form of a sweaty

Graphic: Jonathan Williams/MPI for Chemistry

Photo: Nölscher et al. Nature Communications 2016

mountain hike up to the tower. In reality, this is nothing more than an open staircase held in place by steel cables, and it takes the scientist around three quarters of an hour to climb the 325 meters to the top.

Ten years ago, at this remote research station, his research took a new turn due to the actions of a few inquisitive students. As always, the young academics were accompanying the Englishman on his excursion, when, out of curiosity, they blew into the sensitive device that was actually designed to capture the forest air. Lo and behold, their breath contained numerous substances that are also released by the jungle – and especially the major constituent known as isoprene. The obvious question was therefore whether, in addition to vegetation, humans might also be contributing significantly to the inventory of VOCs found in air. Might humans even be more important than the tropical forests? After all, there are now around seven billion of us living on Earth.

Instead of dismissing this question out of hand, Williams set about getting to the bottom of it. But how can you measure the quantity of organic substances that humans release into the air? The problem is not the equipment. The mass spectrometers in Mainz can measure several hundred different substances simultaneously in under a second. Moreover, they can do so with extremely high accuracy, to the extent that they can even detect substances in air at a concentration of less than ten parts per billion (ppb). Accordingly, the devices can be used to record respiration of any kind in real time.

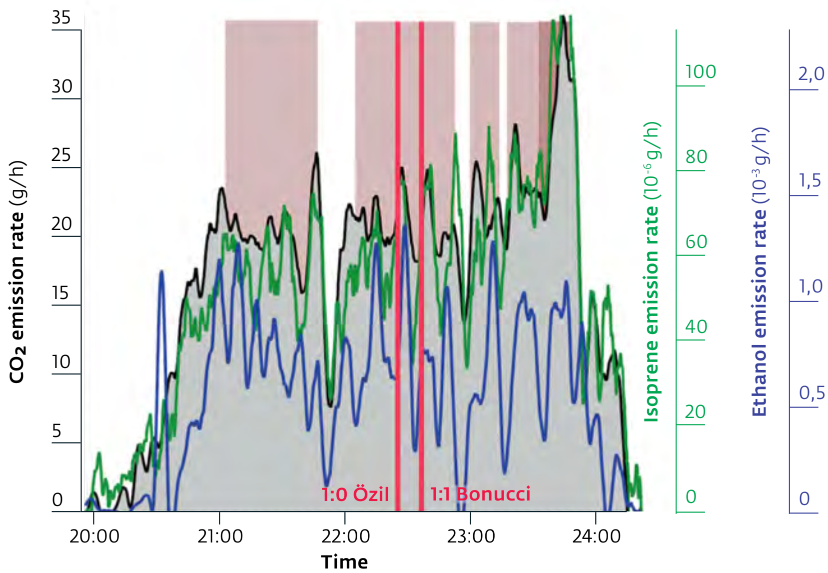
THE AVERAGE BREATH SPECTRUM OF MANY PEOPLE

You could therefore put a single test subject in a sealed box, measure the changes in the air, and multiply the results by the number of humans – that is, by seven billion. But it's not that easy, because people differ fundamentally from one another when it comes to respiration. Variations in diet, the last time they ate, illnesses, dental problems, age, individual idiosyncrasies, hygiene – all of these factors affect a person's VOC emissions. What you therefore need is an average value – a cross section of the emissions from a large number of people.

It didn't take Williams long to come up with a place where crowds of people regularly come together. As a soccer fan, he suffered a few sleepless nights during the last World Cup, which saw his home country make it to the semifinals. What's more, the Max Planck Institute in Mainz is not only the place where he met his wife, who is a geologist, but also where he developed his love of the soccer team Mainz 05. Particularly when the team was still playing in the second division, he went to their matches regularly. It therefore seemed like an obvious idea to take measurements in the stadium.

The Opel Arena is just a stone's throw away – indeed, he can see it from the Institute building. The box-like structure is partly open at the top and provided excellent conditions for a series of measurements. "Although the people from the club were initially surprised by our request, they were ultimately very cooperative," says Williams. He and his team arrived for an evening match against Wolfsburg and set up their equipment, which stands about six feet tall, in the upper part of the stadium, near the police observation post. The arena gradually filled up until, as Williams says, it eventually "resembled a red and white jungle." In addition to the VOCs, he also measured the concentration of carbon dioxide exhaled by the crowd.

While the approximately 31,000 visitors were looking for their seats, the



Soccer from a chemical perspective: Jonathan Williams and his colleagues measured the levels of various substances in the air while the Germany vs. Italy match was shown in a movie theater in Mainz during the 2016 European Football Championship. When Mesut Özil's goal in the second half put Germany in the lead on 1:0, the airborne isoprene concentration rose because the audience was excited. The ethanol concentration also increased – people were clearly drinking to celebrate the goal. When Leonardo Bonucci scored the equalizer, only the isoprene level went up. During the penalty shootout, there was a considerable increase in the airborne concentrations of both isoprene and CO_2 – in the latter case because the audience was breathing faster.

Graphic: MPI for Chemistry

CO_2 concentration in the stadium rose continuously from around 400 to 500 parts per million (ppm). The value dropped again slightly during halftime as many fans left their seats to buy beer or sausages beneath the stands. Williams was impressed to find that the graph of CO_2 concentration also reflected the course of the match, rising in response to critical situations, such as a free kick or corner – in other words, when emotions were running high. The small peaks showed that breathing accelerated as people's pulses rose.

The VOC measurements also produced some interesting results. Whereas the VOC spectrum is dominated by isoprene in the rainforest, in the stadium it was dominated by ethanol – better known as alcohol. The reason for this is quite simple: many fans came to the stadium a bit tipsy. As the stands filled up, the ethanol level therefore rose, before dropping again slightly in the first half because the fans lacked supplies. During halftime, they bought more beer and the graph went up again.

A second substance also stood out, one that is well known to Williams: acetonitrile. In the Amazon rainforest, caution is advised when levels of this substance are high, because it means that a fire is raging somewhere and distorting the measurements. In the stadium, this value is pushed up by smokers, producing a slightly different graph from that for alcohol: particularly during the halftime interval, the cloud of cigarette smoke led to peak values. "At this point, the fans are extremely nervous," says the scientist.

THEN CAME THE IDEA OF MEASURING EMOTIONS

Overall, the soccer stadium measurements showed that humankind's impact on the VOC level in the atmosphere is significantly smaller than that of the tropical rainforest, for example. The initial question had therefore been answered. But Williams was not yet satisfied, since he had now realized that the measurements could be used to gauge people's behavior. This is where the idea of measuring emotions came from. Williams was annoyed that neither side had scored a goal during the match he had analyzed; otherwise, he might have identified a chemical marker for joy and euphoria. With this in mind, he began planning further studies.

His plans are by no means far-fetched. After all, odors transmitted by VOCs play a key role in many organisms. In a sense, they were the first words that organisms exchanged, and plants still communicate extensively via VOCs. Many plants emit chemical substances to warn members of the same species when their leaves are being gnawed, or even to attract insect predators that eat their attackers.

In insects, too, the substances play an important role in the form of pheromones, and many mammals – such as dogs, for example – are guided by their noses. Although humans have other ways of communicating, we all know only too well that we also attach meaning to smells. Otherwise, nowhere near as many of us would wear perfume when we want to make a special impression. And when Germans don't like someone, they even have an – almost literal – expression that they cannot stand their smell. In that case, why shouldn't emotions also be expressed through chemicals in the air?

To investigate this question, Williams looked for a closed building with no interference from turbulence, unlike in an open-roofed stadium. His search led him to Cinestar, the local multiplex movie theater, which provides an almost perfect laboratory: the movies provide the emotions, and the people's responses reach the apparatus almost in real time thanks to the ventilation system, which

blows fresh air in beneath the seats and extracts it at the ceiling. The audience's emissions therefore ends up in the exhaust air shaft almost immediately, and so all the Max Planck team had to do was tap into the air flow.

The researchers have now taken measurements at hundreds of showings. There were no surprises when it came to the ethanol values – that is, the alcohol level. This was far higher on Saturday nights than in showings on a Monday morning, for example. The siloxanes found in deodorants and shampoos showed some interesting behavior: their concentration rose at both the start and the end of a movie, when the audience took off their jackets and sweaters or put them on again, raising their arms in the process. Over the course of the day, the siloxane concentration decreased from one showing to the next as the scents gradually evaporated. However, it rose again sharply for the evening showing: "People have had a chance to get dolled up again after work," Williams explains.

The atmospheric chemist was particularly impressed to find that his graphs even contained clues about what was going on in the film. Every exciting or moving scene led to a small fluctuation, and the graph showed exactly the same trend when the film was shown again the next day.

This was particularly evident in the levels of carbon dioxide and isoprene. The carbon dioxide behaves just as in the soccer stadium: a fast pulse, goose pimples, tense muscles – all of these things speed up people's breathing and cause a higher output of respiratory gases. Isoprene seems to behave in a similar way: the substance is stored in muscle tissue but escapes through our breath during movement. "We seem to move involuntarily when we're tense or nervous," says Williams. "This also causes us to breathe out more isoprene." In addition, the graph also rises sharply when the audience gets up at the end of the film. This was very helpful for the measurement team, who were hidden deep in the catacombs of the multiplex and couldn't see the film themselves – it let the researchers know that the auditorium was emptying.

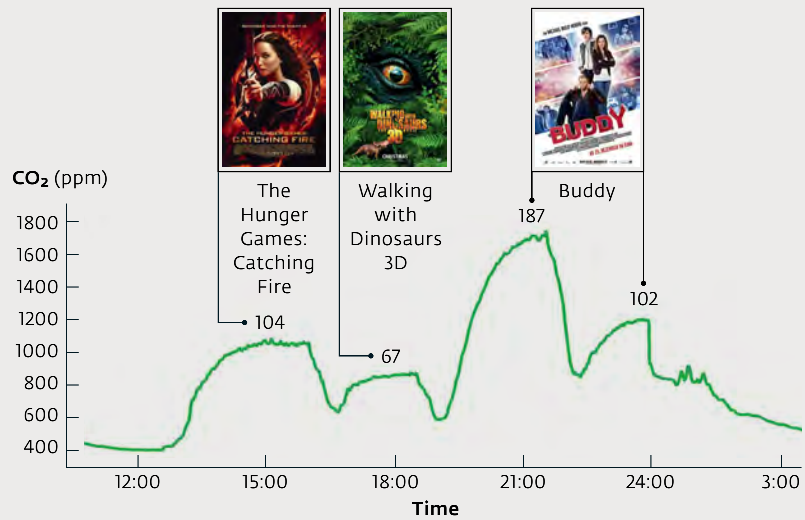
YOU COULD LITERALLY SENSE THE TENSION IN THE AIR

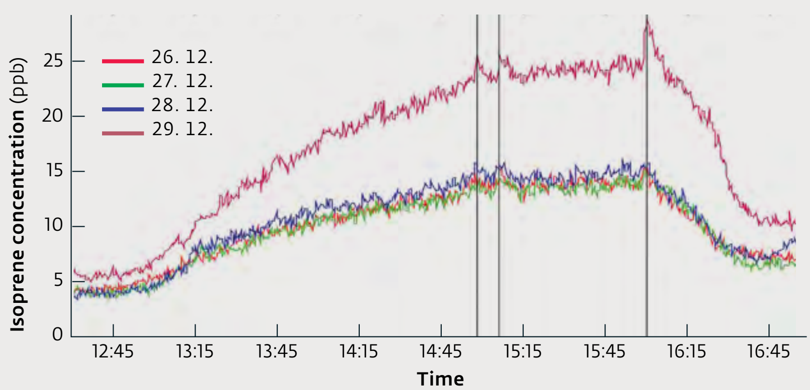
During the measurement series at the movie theater, the goal Williams had been waiting for finally came. The multiplex showed some matches in the 2016 European Football Championship, including the game between Germany and Italy. When goals were scored, the carbon dioxide and isoprene concentrations both rose sharply, and the values almost doubled during the penalty shootout. You could literally sense the tension in the air. Different responses were observed after the German and Italian goals, particularly in relation to the ethanol concentration. When the German team took the lead, people evidently drank to celebrate the goal, causing the level to rise. After the equalizer, however, the response was more muted, revealing which fans were present.

However, the question of whether feelings can be measured in the composition of breath was still only partly answered. Williams therefore dissected each movie and classified the individual schemes according to their content. The list is long and ranges from blood, death, and screaming, through dreams,

An unusual fan project: since Jonathan Williams started working as a researcher in Mainz, he has been a supporter of Mainz 05. It therefore seemed like an obvious idea to set up his mass spectrometer (left) in the local stadium in order to measure the VOC emissions from large crowds of people – especially since the arena is just 500 meters from his Institute.

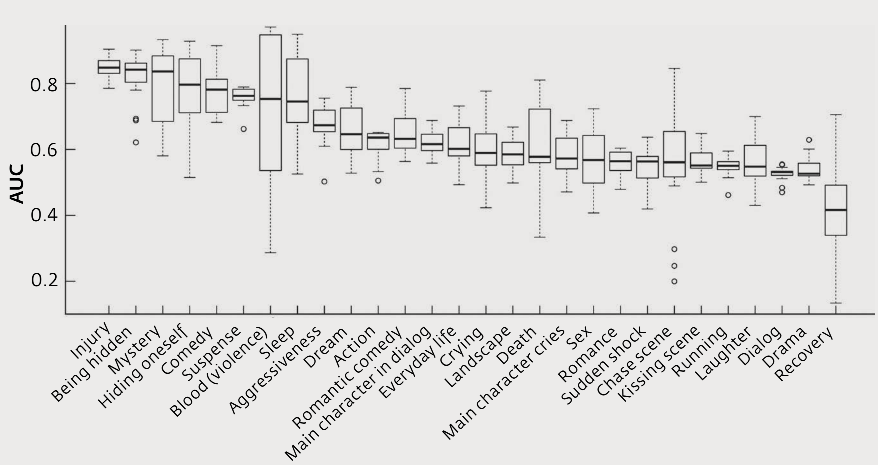
Photos: Anne Reuter/MPI for Chemistry (left), picture alliance/ZB/euroluftbild (right)





Above Showings at the multiplex movie theater in Mainz, Williams's team tracked the CO_2 concentration in the air (in parts per million, or ppm). As the viewers entered the auditorium, the concentration increased. After a while, an equilibrium was established between the audience's emissions and the influx of fresh air. The more people who watched a movie, the higher the concentration rose – as revealed by the respective audience sizes shown above the graph. During showings on four separate days, the isoprene concentration always followed the same pattern (in parts per billion, or ppb). In the movie *The Hunger Games*, for example, it rose twice at the beginning because the viewers were particularly rooting for the main character. At the end, it increased because the viewers were leaving their seats.

Below Various movie scenes can be identified from traces in the air with a differing degree of success. One measure of this is the *area under the curve* (AUC). The relationship is very clear for scenes in which the main character is injured or hiding, as well as for mystery scenes and comedy. Below a value of 0.5, the airborne VOC profile is no more meaningful than guesswork.



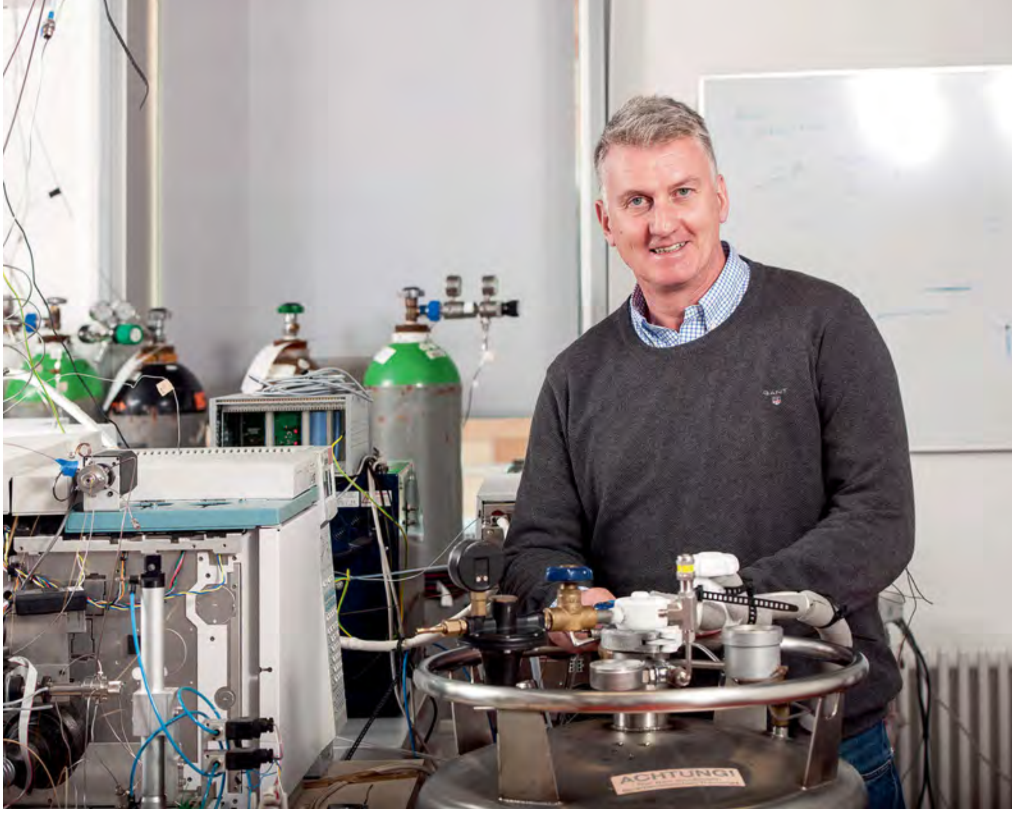
action, and kissing, to landscape, entertainment, and comedy. There were 28 topics in all, and it wasn't easy to identify a relationship between them and the several hundred VOCs. Realizing that task could not be completed manually, Williams sought the help of computer specialists at the neighboring university. This research group, which otherwise spends its time studying stock prices and other economic fluctuations, set about scouring Williams's data for traces of individual emotions in breath.

This produced a statistic indicating the likelihood that specific scenes could be detected in the measured VOCs. The relationship was clearest in scenes where a principal character was injured. Sympathy therefore appears to trigger physical responses. Likewise, scenes involving mystery, secrecy, or hiding could also be detected in the data. However, it was not possible to obtain conclusive evidence of specific feelings in the movie theater. The succession of emotions was too quick for that: one minute the hero would be fighting for his life and the next there would be a love scene.

WILLIAMS IS AN ENTHUSIASTIC COOK

However, Williams and his team did achieve a modicum of success: they discovered a relationship between the isoprene concentration in the air and the movie's age rating. As the isoprene con-

Graphic: MPI for Chemistry



centration reflects the tension felt by the audience, it also provides an indication of how stressful a movie might be for children and adults. The motion picture industry could use this as an objective criterion for age ratings, so that these would no longer depend entirely on a panel's subjective assessment.

Even in his leisure time, Williams likes to dabble with aromas: he is an enthusiastic cook and even risks the occasional foray into molecular gastronomy, such as by using liquid nitrogen to create ice cream and foams. "Cooking is chemistry," he says. In the kitchen, however, he is more passionate about the results than the underlying science. And his three children – two boys and a girl between the ages of eight and twelve – have long since inherited his love of aromas: "They're very well informed about VOCs."

Until now, Jonathan Williams has hunted for the smell of feelings alongside his actual research projects in atmospheric chemistry. For example, he took most of the measurements in movie theaters during the Christmas holidays, when the expensive equipment was just standing around and wasn't needed for his principal area of work. In the future, however, he will no longer need to rely on holidays, as this "secondary" line of investigation, so to speak, has now become a research project in its own right. Williams has been amazed by the public response, and he is virtually overrun with journalists. His years of work in the jungle generated far less interest, but it seems as if everyone wants to report on his measurements at the stadium and movie theater. Williams shakes his head in amusement.

In any case, he wants to continue pursuing his new research direction. His next step is to target his measurements at individual emotions, and to overcome the disadvantages of rapid scene changes and emotional fluctuations, such as those typically encountered in the movie theater. To this end, he is seeking a collaboration with the Max Planck Institute for Psycholinguistics, in the Dutch city of Nijmegen. There they have a virtual lab whose applications include confronting police officers with frightening scenarios with the help of virtual reality. Williams could use this technology to search for specific emotional markers during virtual roller coaster rides or in the face of virtual threats, for example. If he succeeds in finding chemical markers that humans emit when they experience certain emotions, this clearly leads to another research question: how do other people respond to these substances? ◂

Jonathan Williams and his most important measuring device: along with his team, he analyzes volatile organic compounds in the air using a combination of a gas chromatograph and a mass spectrometer. The former separates a mixture of volatile substance into its components, while the latter can be used to identify the individual substances.

GLOSSARY

Volatile organic compounds: Also known as VOCs, these carbon-containing substances evaporate even at normal ambient temperatures and low pressure. They include many substances that stimulate the sense of smell.

Mass spectrometer: This analytical device is used to identify substances. The compounds are first vaporized and ionized, often breaking up into typical fragments in the process. The particles are then sorted according to their mass-to-charge ratio, so that each compound produces a characteristic spectrum. Today, mass spectrometers are often combined with gas chromatographs, which separate mixtures of substances into their individual components.

Photo: Carsten Costard, MPI for Chemistry