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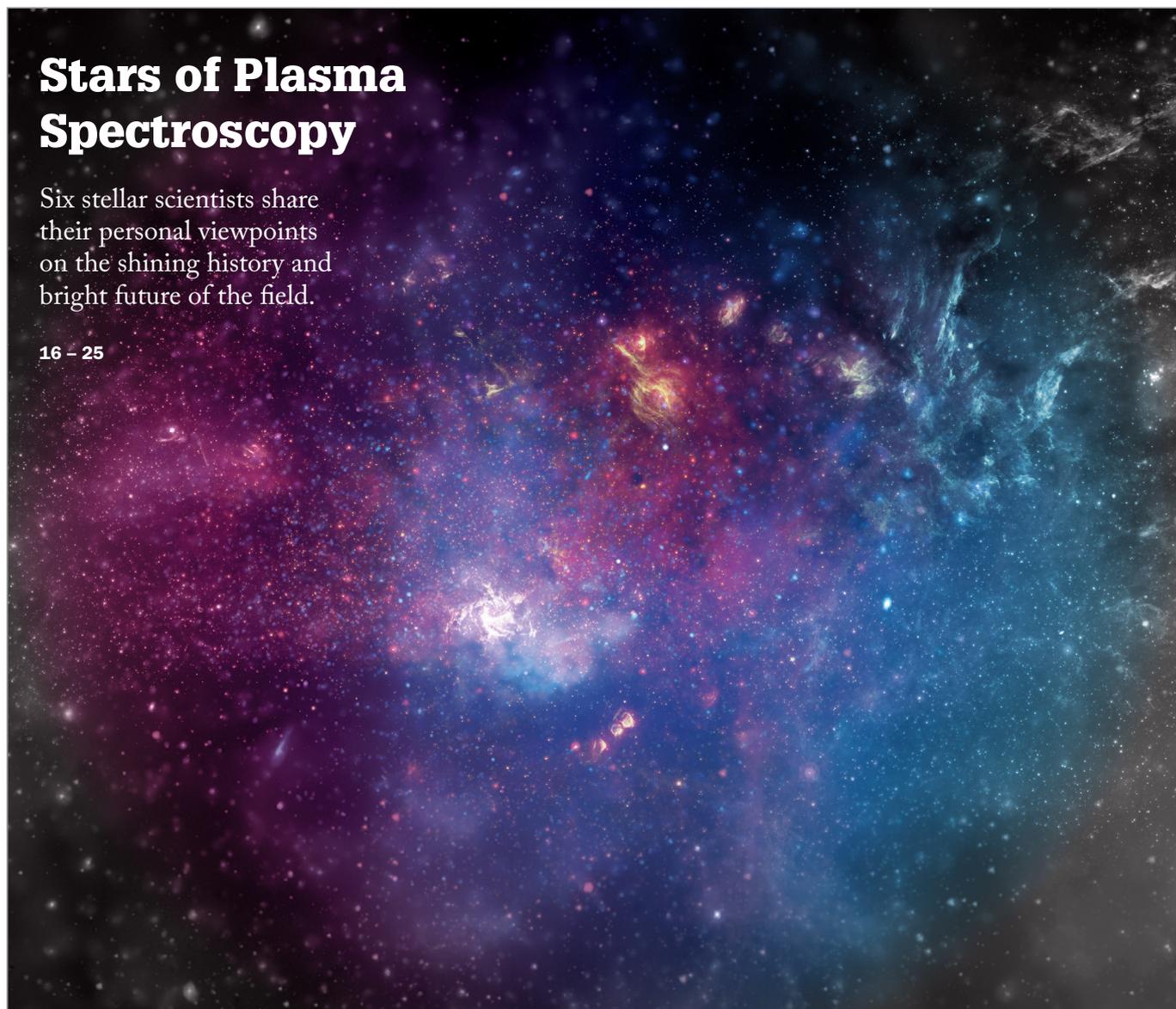
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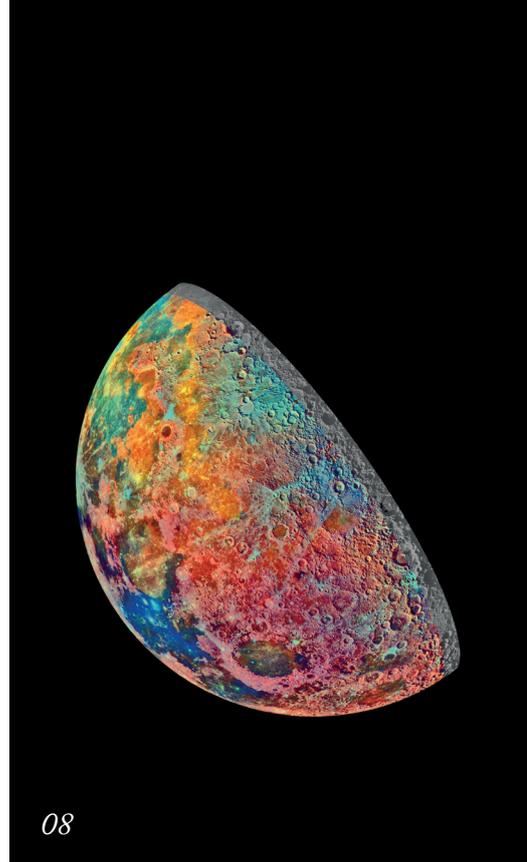
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Six stellar spectroscopists give a personal view on the past, present and future of the field.

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The Future of the Fourth State

Plasma spectrochemistry's significant impact on science, medicine, commerce, engineering, and technology over the past 50 years is impressive. But where to next?

Editorial



Of all the invention, development and rapid application of lasers and atmospheric pressure electrical discharges, the inductively coupled plasma (ICP) discharge has been the most commercially successful, with mature applications from medicine to commercial products, geochemistry to sclerochronology, nanomaterials to metallomics and ionomics.

Commercially available instrumentation is critical to the success of a spectrochemical source, and Fassel and Greenfield's advocative ground work in the 1960s later resulted in the relatively rapid commercialization of ICP-MS. The development of solid-state detector arrays for emission spectroscopy and recently, mass spectrometry, revolutionized and promoted user-friendly plasma spectrochemical instrumentation. The quest for lower limits of detection and matrix-free determinations has driven numerous other instrument developments, including multiple quadrupole MS arrangements and collision/reaction cells, as well computational correction techniques and even chemistry. The applied result? Breakthroughs in earth sciences, forensics, nutrition, toxicology, and medicine.

The power of modern computers and information processing systems has reduced the workload in processing, correcting, and reporting the substantial data flow found in modern spectrochemical analysis, and provided us with automated calibration, diagnostic, and maintenance protocols. Computational capabilities have also led to detailed modeling and simulations of the plasma, interface, and spectrometer among others, which (when coupled with appropriate experiments) can be characterized and improved in research laboratories, leading to new plasma system designs. But instrumentation comes and goes – usually because of business decisions rather than fundamental limitations.

The recent upwelling of laser-induced breakdown spectroscopy (LIBS) with modern lasers and spectrometers offers novel applications reaching far beyond those possible with DC arc technology, especially for solid samples – even on Mars.

Clearly, the modern arsenal of plasma spectrochemistry is the largest it has been in the history of science. Such developments are the substance of the Winter Conference on Plasma Spectrochemistry, next scheduled for Amelia Island, Florida in January 2018.

What's left? Do we need more? As outlined in this special issue, innovation and development are fostered by basic and applied research, quality education, and the quest for improved analytical performance. And we should encourage – no, urge – young investigators to continue carrying the torch of plasma spectrochemistry.

Ramon M Barnes

Guest Editor

Upfront

Reporting on research, personalities, policies and partnerships that are shaping analytical science.

We welcome information on interesting collaborations or research that has really caught your eye, in a good or bad way. Email: charlotte.barker@texerepublishing.com

Mercury Rising?

Double-pulse LIBS semiquantitatively determines mercury levels in landfill leachate

Landfill leachate results from the decomposition of urban waste and contains several organic and inorganic contaminants. Mercury, which can infiltrate soil and bodies of water, is one hazardous and toxic example that must be monitored to protect the environment and agriculture. Debora Milori from Embrapa Instrumentation tells us more about her team's application of laser-induced breakdown spectroscopy (LIBS) for the analysis of mercury – and why she believes the potential of the technique must be more fully exploited.

How did you come to assess landfill contaminants?

In the treatment processes for landfill leachate, it is very important to determine the various types of contaminants present to ensure that pollution levels are below the values determined by law, before being deposited back into the environment. Carlos Menegatti, from the University of Sao Paulo, studies techniques to evaluate landfill leachate, and contacted my research group in Embrapa proposing the use of double-pulse LIBS for this kind of analysis. This is the first time LIBS has been used solely to determine mercury in landfill leachate.

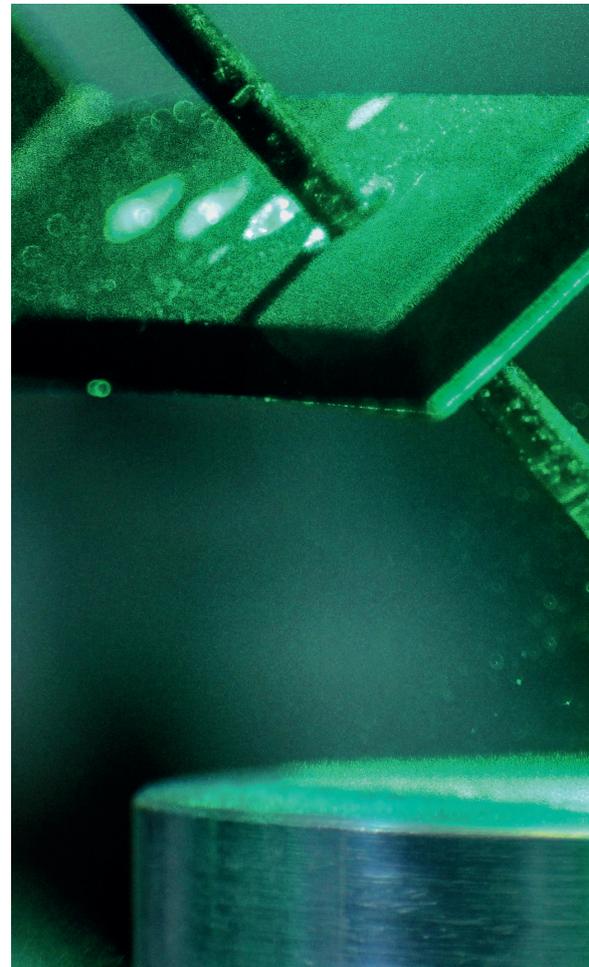
What other techniques do you use in your research?

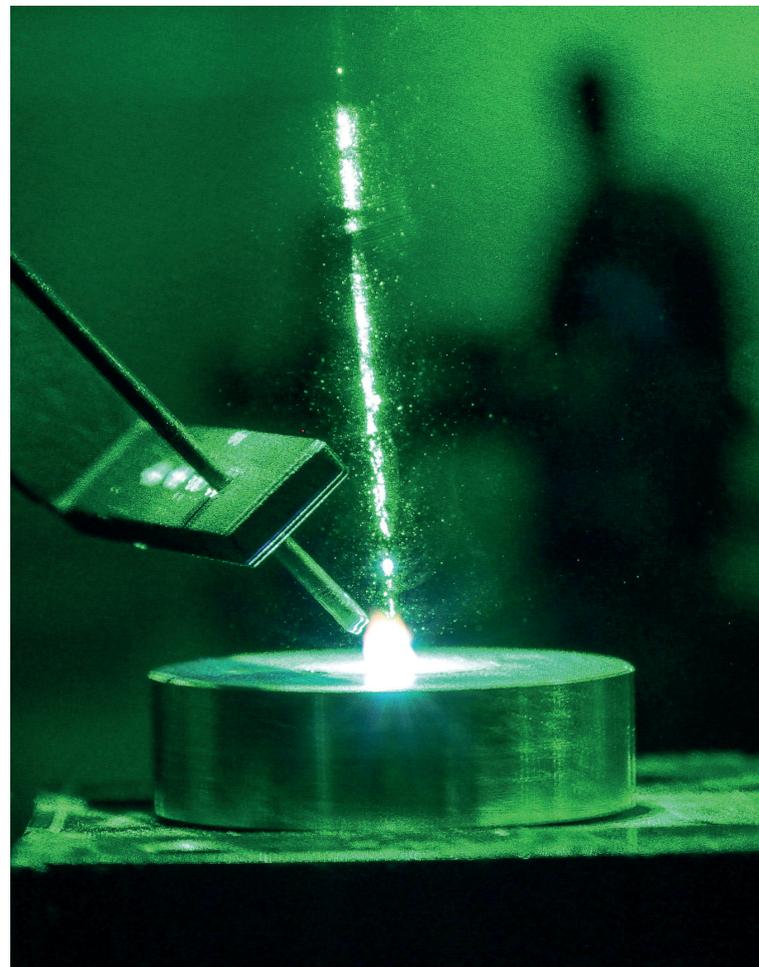
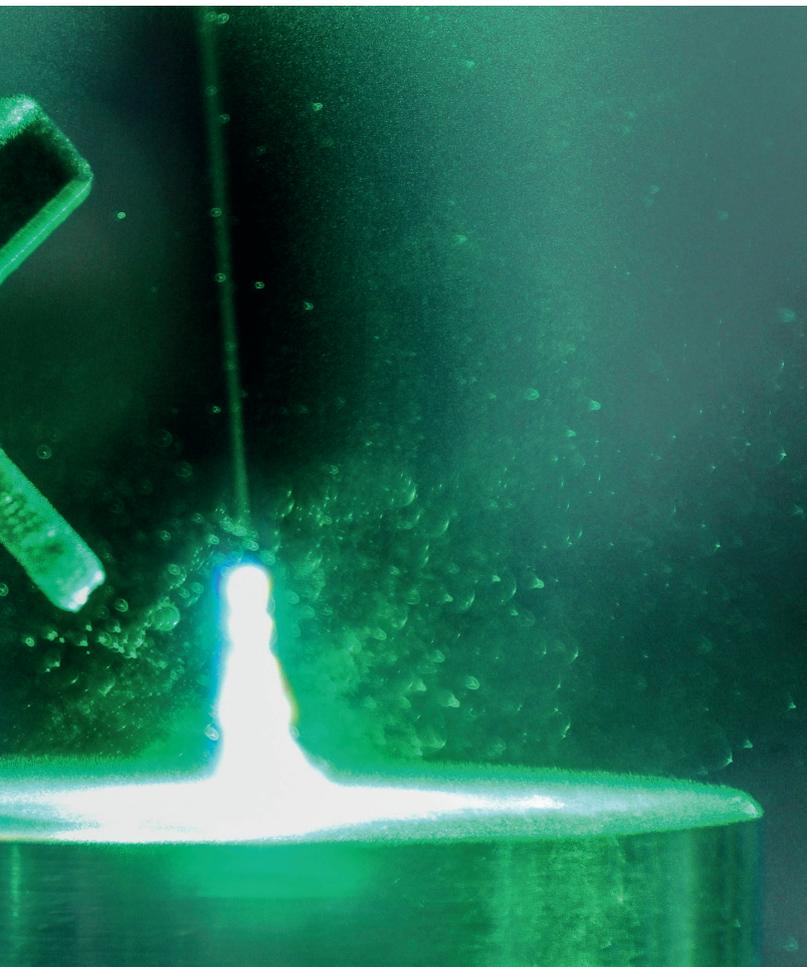
We focus on the development of systems for both precision agriculture and environmental monitoring. Spectroscopy is a valuable tool for applications in these fields, and we use several spectroscopic techniques essential for

material characterization; for example, nuclear magnetic resonance (NMR), electron paramagnetic resonance (EPR), infrared, ultraviolet-visible absorption, fluorescence, and lifetime fluorescence in addition to LIBS. All these techniques deliver relevant information, both to producers and agricultural companies. Moreover, particularly in our laboratory, we develop methods that allow rapid and large-scale analysis without the production of chemical residues (so almost no sample preparation).

What are the limitations of current contaminant detection methods?

The concentration of mercury in





municipal waste landfill leachates was evaluated in the range from 0.05 to 160 $\mu\text{g/l}$, and currently, several analytical techniques are available to determine its concentration in these samples: atomic absorption spectroscopy (AAS), inductively coupled plasma atomic emission spectroscopy (ICP-AES), and inductively coupled plasma mass spectrometry (ICP-MS). Although these techniques are precise and have good limits of detection (LOD), they are relatively time-consuming and generate more chemical waste. Moreover, the use of these technologies requires accurate sample preparation, which can make the whole process expensive and laborious.

Thus, it is impossible to apply them to monitoring mercury in the leachate in real-time and in-situ.

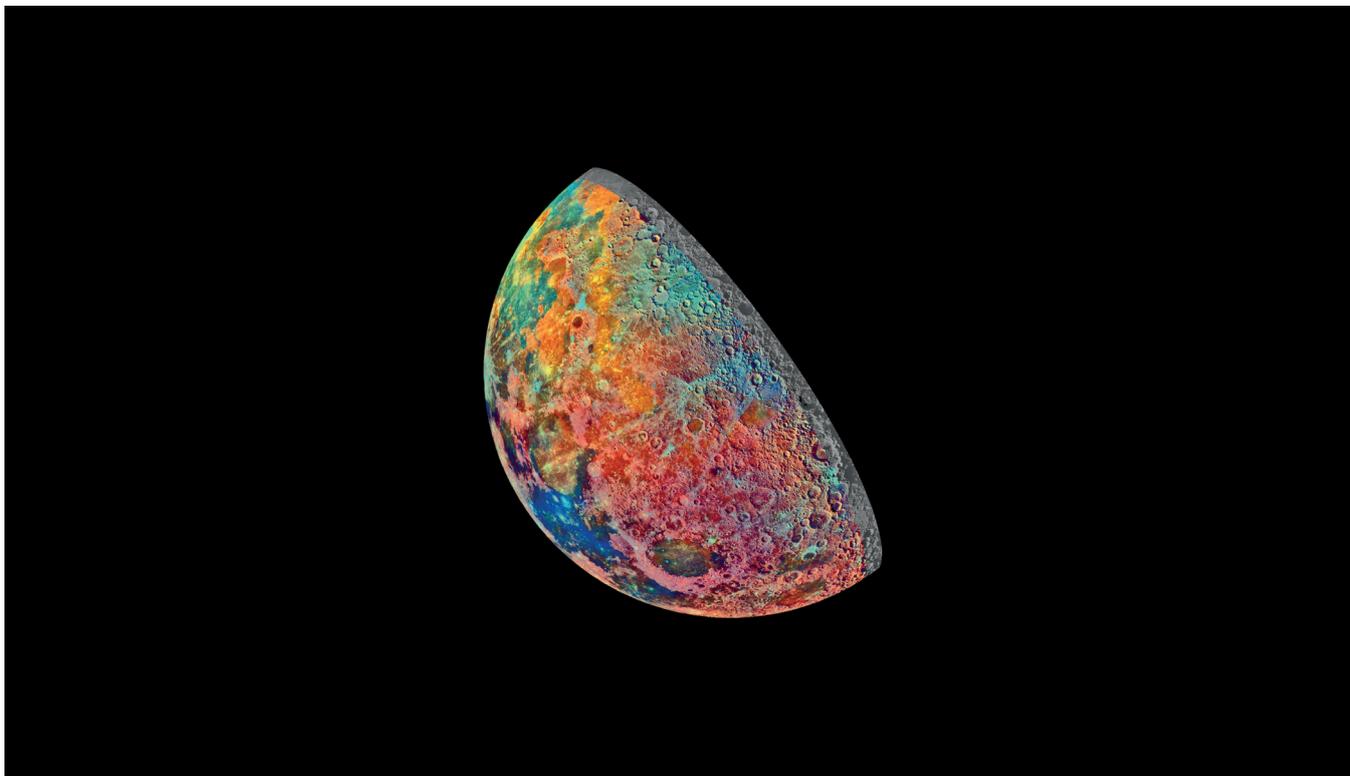
On the other hand, LIBS is an environmentally clean technique, it is fast and it does not require pre-preparation of the samples. I consider it ideal for environmental monitoring; we have previously published papers on the quantification of nutrients and contaminants in food, plants, and soils, and have worked on more complex LIBS evaluations, such as soil pH and texture, or diagnoses of diseases in plants.

What limit of detection could you achieve with double-pulse LIBS?

The limit of detection (LOD) we obtained for mercury analysis was 76 mgKg^{-1} – still high compared with the environmental standards established by law. However, we believe that it is possible to improve this LOD using other experimental LIBS configurations. We are working hard to achieve new levels of LOD for mercury, and intend to evaluate the applicability of LIBS to quantify other contaminants in landfill leachates.

Reference

1. CR Menegatti et al., "Semiquantitative analysis of mercury in landfill leachates using double-pulse laser-induced breakdown spectroscopy", *Appl Opt*, 56, 3730 (2017).



Blue Moon

Orbital spectroscopy supports the theory that water is widespread on the moon

For many years, the moon was thought to be bone-dry. However, in 2008, analyses of samples from the Apollo 15 and 17 missions found traces of water in glass beads formed by volcanic eruptions, suggesting that the moon's interior does indeed contain water. Further analysis in 2011 confirmed the finding, with similar levels of water detected in the lunar samples as in some Earth basalts.

So scientists knew there was water in the moon's mantle, but not how much – or where. Are the samples from a water-rich pocket, while the rest of the mantle is dry? Or is water found throughout the interior?

A recent study funded by the

NASA Lunar Advanced Science and Exploration Research Program added another piece to the puzzle, by measuring water in several large volcanic deposits scattered across the moon's surface, using the Moon Mineralogy Mapper, an imaging spectrometer aboard India's Chandrayaan-1 lunar orbiter.

However, orbital spectroscopy comes with some special challenges. The moon's surface is heated by the sun, especially in the areas where the pyroclastic deposits are found. The resulting thermally emitted radiation is at the same wavelengths as those needed to measure water, obscuring the analysis. Scientists from Brown University were able to correct for the thermally emitted component by conducting laboratory experiments with the Apollo samples, and developed detailed temperature profiles of the relevant areas of the lunar surface.

Using thermal correction, scientists

measured absorption spectra consistent with enhanced OH⁻ and/or H₂O-bearing materials; as the deposits are formed by volcanic activity, the finding suggests that the mantle also contains significant amounts of indigenous water, which raises questions about how it got there.

The volcanic beads are only 0.05 percent water by weight, but the deposits are large so the overall amount of water could be substantial. Forward-thinking Shuai Li, a postdoctoral researcher at the University of Hawaii and co-author of the research, said (1), “Anything that helps save future lunar explorers from having to bring lots of water from home is a big step forward, and our results suggest a new alternative.” *CB*

Reference

1. <https://news.brown.edu/articles/2017/07/moonwater>

Taking the Road to Reno

The keynote speaker of SciX on why you should take a gamble on 2017's "Great Scientific Exchange"

SciX, being held in Reno this year, is known for its strong selection of cutting-edge presentations and its excellent networking opportunities. Janie Dubois (Chair of the Laboratory Capacity Working Group at the World Bank's Global Food Safety Partnership), tells us what we can expect from her as this year's keynote speaker – and why SciX is of such vital importance to the food safety field.

How do you feel about being this year's keynote speaker?

It is very exciting. I have been coming to this conference for years and I've always enjoyed the quality of the information and the atmosphere of friendly exchange that is so characteristic of this conference. My keynote speech will be as much about trying to attract more people to develop technologies for the food safety field, as about discussing what's been done already in terms of scientific development, technical applications and how it affects both health and the economy. In the technology sector, food safety has been just another application for technology that was typically developed for "more lucrative businesses" such as pharmaceuticals. This needs to change, as food safety has become a national priority in most developed countries and a commercial necessity for developing countries. What we need now, as we're trying to make more measurements to demonstrate the safety of food, is tailored technologies and applications

of technologies that further align with our purpose.

Which other presentations are you looking forward to?

I'm always interested in seminars on agriculture/food applications and about tools that detect very small quantities of contaminants – that's one of our biggest challenges in food safety. The forensics and even the process analytical for pharmaceuticals, have tools that adapt quite easily to food analysis, if they can deal with its extremely complicated composition; we're not looking for a needle in a haystack – we're looking for one particular kind of hay within the haystack! The focus on technologies and applications is really what makes SciX a good conference for us because even though there may not be a lot of sessions dedicated to our topic, we can learn about a lot of new applications – it is then our job to draw the links between what we need and what is being presented. Because of my past work in spectroscopy with the pharmaceutical industry, I am particularly interested in seeing IR, NIR and Raman spectroscopies and imaging play a bigger role in food safety measurements.

Are you running any other sessions?

I am also chairing a session where Admiral Palmer Orlandi (Chief Scientist from the Office of Foods and Veterinary Medicine at the FDA) and DeAnn Benesh (the President of the AOAC) will discuss the current needs and the requirements for validation of methods

in the food field (Wednesday, Oct 11). It is a unique opportunity to talk to leaders in the field, both on the regulatory side and in terms of method acceptance. I hope that this networking opportunity will provide the proverbial conversation that saves months of work!

SciX 2016 will be held October 8–13, 2017 at the Grand Sierra Resort in Reno, Nevada. www.SciXconference.org Catch Janie Dubois' lecture, "The analytical and economic challenges of maintaining food safety in a global supply chain" at 6:15pm on Sunday, October 10 in the Tahoe Ballroom.





NMR vs GHB

Could nuclear magnetic resonance spectroscopy improve tests for detecting elusive “predator drug”?

Gamma hydroxybutyric acid (GHB) is a naturally occurring metabolite perhaps best known as a “date-rape drug”. When administered, its concentration in urine and blood increases but rapidly drops to endogenous levels after only 3–4 hours – making proof of consumption extremely difficult, if not impossible. But now researchers believe that NMR spectroscopy could be a suitably

robust technique for the fast and direct monitoring of exogenous GHB (1).

“We are interested in the metabolism of drugs, and wanted to study GHB in particular because of its challenging nature in forensic cases,” says Cristina Legido-Quigley (King’s College London). “Yaoyao Wang, my PhD student, thought of looking at the metabolomics of a GHB trial that Alan Brailsford and I were working on in the Drug Control Centre. Nuclear magnetic resonance (NMR) metabolomics experts Miriam Perez-Trujillo, Teodor Parella and Martina Palomino-Schatzlein later joined the team.”

Though analytical methods such as LC-MS or GC-MS allow accurate

detection and quantification of GHB at low concentrations, the rapid metabolism of the drug makes the provision of longer-term evidence of consumption a complicated process. The team chose to address this problem with a top-down metabolomic approach (1). “Our aim was to find potential surrogate biomarkers of GHB with a slower metabolism, and we chose NMR spectroscopy (Bruker AVANCE II 600) as the analytical platform – a technique quite unexplored in this area,” says Miriam Perez-Trujillo, NMR Spectroscopist, Universitat Autònoma de Barcelona.

“NMR has great power for molecule identification and, using this technique,

we were able to analyze biofluid matrices with minimal sample manipulation – which is to say, with no separation or derivatization steps,” says Perez-Trujillo. “The high reproducibility and the non-destructive nature of the technique are also important advantages – chiefly because other complementary analysis could be performed afterwards, very important in these kinds of forensics cases.”

In the clinical trial, 12 people were administered 25 mg/kg of GHB, with urine and samples collected 10 minutes before and at several time points thereafter (up to 13 hours and 30 hours for blood and urine, respectively). Glycolate – a GHB metabolite – was still detected in urine up to 20 hours later.

Next, the team hope to include a

targeted NMR metabolomic study in urine and serum to more deeply explore the behavior of glycolate and its suitability as surrogate biological marker, ideally applying it to a larger-scale clinical trial. “It would also be interesting to confirm our metabolomics results with other, more sensitive analytical techniques, perhaps to detect altered glycolate concentrations in an even longer timescale,” says Perez-Trujillo. “We would also like to perform a broader study dedicated to GHB quantification by 1D ¹H qNMR in different biofluids, determining exact quantification limits and reproducibility.”

Perez-Trujillo believes that this NMR-based screening method could be a valuable tool throughout the forensics field and beyond. “Although

NMR cannot offer the same sensitivity as other techniques, its minimal sample preparation, comprehensive structural information, and high reproducibility could make it a valuable tool,” she says. “For example, NMR may help provide valuable information in the detection of new psychoactive substances or the presence of unexpected compounds in food matrices that may be harmful to public health. An optimal approach would be combined analysis using NMR and mass spectrometry, to benefit from the advantages of both methodologies.” *JC*

Reference

1. *M Palomino-Schatzlein et al., “Direct monitoring of exogenous γ -hydroxybutyric acid in body fluids by NMR spectroscopy”, *Anal Chem*, 89, 8343–8350 (2017)*

Raman Gamification

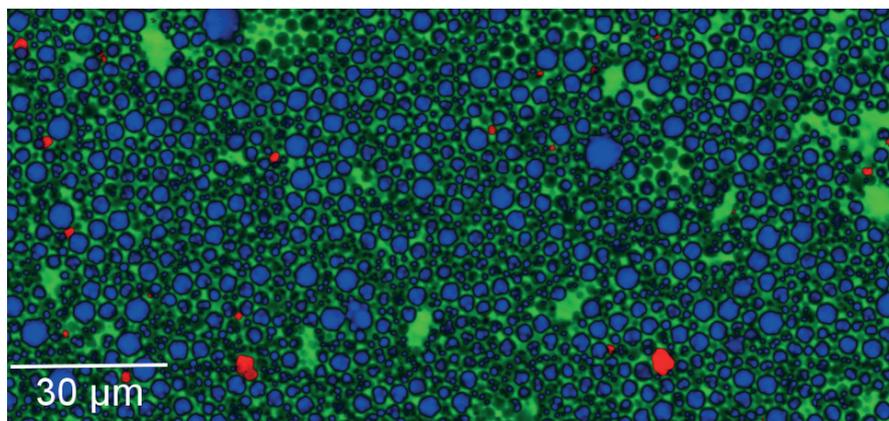
A software/hardware combo – controlled with a game controller – aims to simplify and speed up data acquisition and processing

What?

Suite FIVE is a soft- and hardware suite offering control of measurements and data acquisition for imaging techniques such as Raman and Raman-SEM. It includes a motorized turret, a Software Wizard to guide users through data acquisition, evaluation and post-processing – all accessed using the games console-style Easylink Controller (1).

Why?

With its ability to power through



large datasets, Control FIVE aims to speed up data processing and increase workflow. And the handheld controller makes it easier, more intuitive – and, dare we say, fun – for users (especially video game fans) to direct the motorized stages, laser, and objective selection.

Who?

The suite has been developed by WITec, a manufacturer of confocal

and scanning-probe microscopes, based in Ulm, Germany. WITec took the number two spot in The Analytical Scientist Innovation Awards in 2014 with its RISE Microscopy platform, which combined Raman imaging with SEM.

Reference

1. <http://www.witec.de/products/accessories/software-witec-suite/>

In My View

In this opinion section, experts from across the world share a single strongly-held view or key idea.

Submissions are welcome. Articles should be short, focused, personal and passionate, and may deal with any aspect of analytical science.

They can be up to 600 words in length and written in the first person.

Contact the editors at edit@texerepublishing.com

Rethinking Research

The current economic and political environment is contributing to the decline of science. It's time to hit the 'reset' button.



By Kay Niemax, Wilhelm-Ostwald-Fellow at Department I (Analytical Chemistry and Reference Materials) of the Federal Institute for Materials Research, Germany.

After 42 years of active research in natural science and six years as a close follower, I am becoming increasingly pessimistic about the fate of today's scientific research. Public and private sponsors worldwide are feeding more financial resources into the science system than ever before, but the efficiency of the total system is degrading. What are the reasons for this unfortunate development? Can it be stopped or even turned around?

There are several reasons, which cannot all be listed properly here. It is not only politics and society that are having an increasingly debilitating influence on science; scientists themselves are also responsible for the overall efficiency. Progress in science is being detrimentally affected.

First of all, there is the entropy-like growth of administration in research, which is thwarting the current system. Nobody believes me when I say that even in the 1970s, our national science foundation, DFG, transferred the money

for my first funded research project directly to my private bank account; while every month, my bank transferred my PhD student's salary to his account and his income tax and benefits for social security to the respective offices, all free of charge. Instruments and consumables directly ordered by me were also paid for via my bank. The idea behind this practice was efficiency, and the firm conviction that a funded scientist would spend the limited amount of money in the best way for the success of the project.

“The entropy-like growth of administration in research is thwarting the current system.”

Today, administration, funded partly or even fully by scientific projects, is adding to the expense. Furthermore, it is having increasing influence on the selection process of co-workers, the ordering system, and the implementation of research. Expanding administration has the tendency to develop new and often useless regulations and forms that keep scientists busy and cost them precious time. (Such activities are not only typical for research administration – as we know, for example, from our experience with the 55,000 euro administrators in Brussels. How could life continue in Europe without essential regulations for bananas, cucumbers and, very recently, French-fried potatoes?)

Bureaucracy represents a “black hole”

“It is a mystery why respectable national science organizations worldwide ignore objective experimental data.”

for tax payers’ money. It is interesting that the overhead costs for research projects, which include the costs of administrators, have recently surpassed the 300 percent mark in at least one of

the US National Laboratories. Such developments are not particularly encouraging for researchers elsewhere.

A scientific publication is proof of successful research. Because of increasing financial support and a rapidly growing number of scientists worldwide, the number of publications is also increasing. However, the percentage rejection rate of manuscripts by scientific journals has never been so high. The major reasons are underdeveloped research, and the unintentional repetition of research. In any case, it is an unnecessary waste, both of resources and of precious time.

Ideologically guided influence by political and social groups is another reason why scientific progress in general has slowed down. For example, areas such as gender studies, the economy, or politics are increasingly funded at the expense of objective and unbiased

fields of research. A highly topical example is global warming caused by CO₂ production. Taking into account the serious and convincing arguments presented by the 1973 Nobel Laureate in physics, Ivar Giaever (available on YouTube), for example, it is a mystery why respectable national science organizations worldwide ignore objective experimental data. There are even research institutes founded purely to address the CO₂ problem. Scientists who disavow facts are also responsible for the decline of science.

The high level of present debt in the world will require an economic “reset” in the near future. Science should use this as an opportunity to focus again on efficiency, and on areas that are required for the further development of mankind and progress in understanding the world around us.

Protecting Cross-Border Science

Science symposia only emphasize the need to push beyond discrimination and fight for the exchange of scientific ideas.



By Vincenzo Palleschi, Applied and Laser Spectroscopy Laboratory, CNR, Pisa, Italy.

On June 16 2017, one of the largest analytical spectroscopy events in recent years drew to a close. In just one week, we had more than 500 people attending the ninth iteration of the Euro-Mediterranean Symposium on Laser-Induced Breakdown Spectroscopy (EMSLIBS) and the 40th Colloquium Spectroscopicum Internationale (CSI). The two conferences were jointly organized at the Congress Center of Pisa, Italy, where we had more than 250 oral presentations in five parallel sessions and more than 200 posters.

The EMSLIBS/CSI participants gathered in Pisa came from 45 countries, covering all five continents. When addressing colleagues in my closing speech, I stressed that participation of such a large and variegated group would have been very difficult to accomplish in other parts of the world. In the months preceding the conference, I had to write literally hundreds of letters

of invitation to colleagues from outside Europe. Through them, I witnessed the excruciating difficulties they faced in obtaining the Visa required for their participation in the conference. However, I can state that the only people who did not succeed in getting their Visa were the ones who applied too late; our bureaucracy was at least democratic – annoying for everyone – with no distinctions because of country, race or religion.

I have to admit that before the organization of the Pisa event, I was not as sensitive to the problem of scientific traveling and exchange. And now? I can’t help thinking that many people attending the conference would have had problems in participating if it had been in the USA; take, for example, the four Iranians who attended. Nor is it just a matter of Trump’s travel ban against Muslim countries. The borders have been closed to science and to scientists

at other times in the past.

Several years ago, in Erice, Sicily, I had the privilege of meeting the Nobel Laureate Charles Townes. It was at an event celebrating the 50-year anniversary of the Nobel Prize being awarded for the discovery of the laser. Townes was a great man, 90 years old when I met him, but still in possession of the brilliant mind and enthusiasm of his best years. While describing the path leading to the discovery of the laser, he mentioned that, at the peak of the Cold War, the collaboration between American and Russian scientists was

not seen favorably by the corresponding institutions. Nevertheless, both scientific communities acted together to ensure the continued exchange of scientific ideas and information (read more about analytical science behind the Iron Curtain at tas.txp.to/0817/Separation). The result was the discovery of the main instrument of my research, the laser – and, in 1964, the Nobel Prize was awarded to Townes and the two Russian researchers, Nikolay Basov and Alexander Prokhorov.

Today, admittedly, the situation is quite different, but the prejudices have

not changed that much. Our role as scientists is probably less recognized by politicians than in the past, but I believe we can still do our part to remove obstacles to the free circulation of scientists and scientific ideas.

Here in Europe, we need to do the right thing and keep the scientific borders open, despite the xenophobic sentiments creeping into political debate. In other countries, we need to try and overturn discriminatory acts that are not justified from any point of view, and that are even more unsustainable when blindly applied to the world of science.

Bridging the LIBS Gap

Why it's the right time for the first Latin American symposium on laser-induced breakdown spectroscopy.



By Citlali Sánchez-Aké, Laboratory of Photophysics, Center for Applied Sciences and Technological Development, National Autonomous University of Mexico, Mexico.

In June 2019, for the first time, two important scientific conferences in

spectroscopy will be held in parallel in Mexico City: the 41st Colloquium Spectroscopicum Internationale (CSI) and the first Latin-American Symposium on Laser Induced Breakdown Spectroscopy (LASLIBS).

“Participation in conferences is still limited...but not because of lack of interest.”

Why a Latin-American symposium on LIBS? LIBS is a chemical analysis technique that has unique advantages and relatively simple instrumentation, allowing its use in the laboratory and in the field, and in very difficult conditions, such as underwater and even on Mars. It's not surprising that the scientific community is keen to exploit LIBS and extend its application.

The interest helped facilitate the organization of the biennial International Conference in LIBS (ICLIBS), which started in Italy in 2000 and has a growing number of participants. ICLIBS has been hosted mainly in Europe and the United States, but also in Asia and Africa. In addition to this international conference there are other “local” meetings on LIBS; The Euro-Mediterranean, Asian and North American symposia. But although there are regular attendees from Latin America to these conferences, our participation is still limited and none of these events have been hosted in our region. But it's not because of a lack of interest.

In fact, we want to contribute to the continuous international effort in expanding the knowledge and application of spectroscopy. Some groups in Brazil started working on LIBS as early as the 1990s, but it was not until 2000 that more researchers became involved, and currently there are groups working on LIBS from at least a dozen Latin American countries. Some focus on the fundamentals of LIBS and general applications, but others work on solving specific problems and challenges within

“As a researcher whose education has been paid for with public resources, I consider it my duty to give back to society.”

the region, such as the monitoring of polluted water, characterization of pre-Hispanic archeological pieces, and the removal of the spines of the prickly pear

(which is consumed as food in Mexico), among others.

I believe that the limited financial support of the science provided by the Latin American governments and private industries is the reason for limited participation of our scientists in international conferences. Organizing the LASLIBS will allow us to invite sponsors to research, encourage young researchers and students to work in this field, and bring together the largest possible number of LIBS groups from Latin America.

The organization of such a conference requires extra work, but as a Latin-American researcher whose entire education has been paid for with public resources, I consider it my duty to use this opportunity to give back to society. The previous attempts made by other

groups to organize this kind of meeting suggest that the call for involvement will be successful. Moreover, to hold this meeting in parallel with the 41st CSI, sharing the plenary lectures and social events, will promote the collaboration of scientists within the region and with other groups around the world.

Both conferences will be hosted in Mexico City, at the central campus of the National Autonomous University in Mexico (UNAM). Founded 450 years ago, and with 300,000 students, it is the most important university in the country. To have the first LASLIBS at UNAM aligns perfectly with its spirit; the coat of arms of the UNAM shows a Mexican eagle and an Andean condor protecting a Latin American map – a representation of the unification of Latin American people.



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Stars of Plasma Spectroscopy

From supergiants to bright young sparks, six stellar spectroscopists reflect on personal highlights, review crucial milestones, and predict where the field is – or should be – heading.

An Inquiring Mind

By Alfredo Sanz Medel, Emeritus Professor of Analytical Chemistry, University of Oviedo, Spain.



As a boy, my imagination was caught by the fundamental questions of chemistry – What is this? What is it made of? An excellent chemistry teacher taught me that those basic and intriguing questions could be elegantly answered by “irritating”

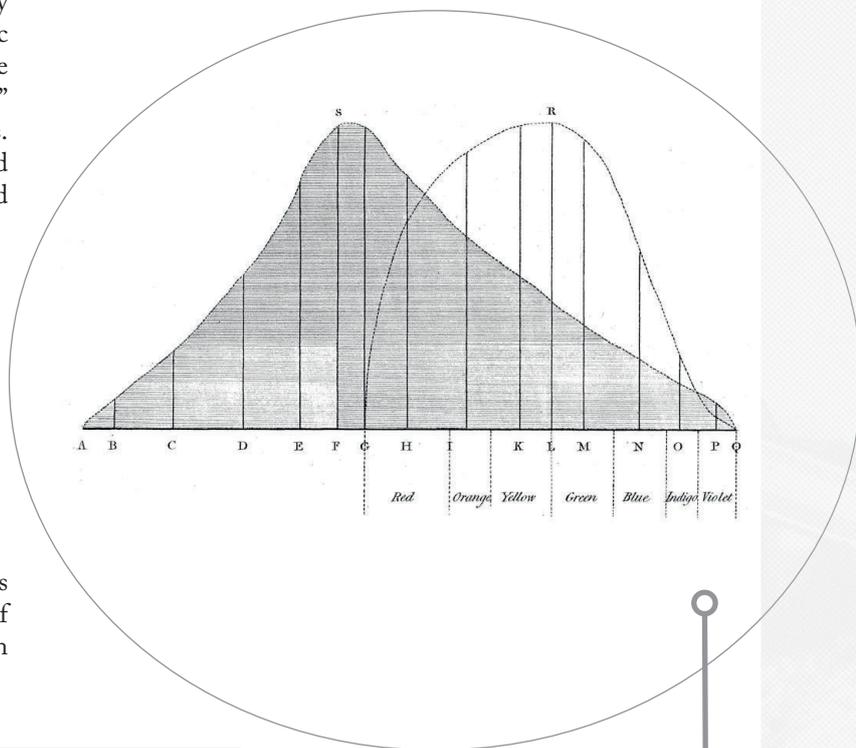
that unknown material with light and measuring the effects. The resulting frequencies of light could then be easily separated and measured with a spectrometer, the scientific device behind any type of spectroscopy.

The interaction between the matter to be studied and the photons of light used to study it was so powerful and so “clean” that I was instantly fascinated by spectroscopy, and eventually made it my career.

In 1980, I was delighted to be able (despite many funding hurdles) to buy my first ICP-OES instrument for Oviedo University – the first one in any Spanish university! It’s amazing to think how far we have come since then. A year ago, my group decided to celebrate my “official” retirement, after almost 50 years devoted to academic and scientific research activities. To see the group’s 35 members – all devoted to advancing spectroscopy by the clever use of spectrochemistry – gathered together in my honor was an extraordinary and touching experience.

All change

To me, the biggest advance during my time in analytical plasma spectroscopy/spectrochemistry was the shift from light (photons) to mass (ions) detection in analytical plasmas. In 1973, J. Alkemade first suggested using a plasma for elemental analysis with mass spectrometry for detection. The UK’s A. Gray pioneered the coupling of a wall-stabilized DC plasma with a mass analyzer over the next few years, and soon afterwards worked with the Fassel and Houk groups to combine inductively-coupled plasma with a quadrupole mass spectrometer. The result of this collaborative effort was published in 1980, setting the scene for modern ICP-MS.

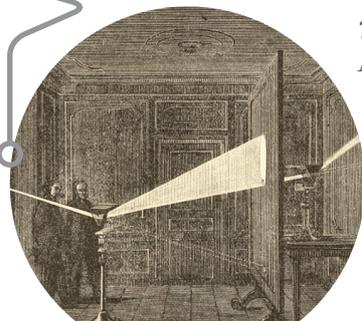


A Timeline of Analytical Spectroscopy

1671

Newton’s paper on the nature of light in

which he coins the word “spectrum” and presents his “experimentum crucis.”



1752

Thomas Melvill examines colored flames with a prism, the first “flame test.”

1762

Andreas Marggraf applies a flame test to distinguish Na and K.

1800

William Herschel discovers infrared radiation and publishes the first spectra drawn as a plot of intensity vs. wavelength, in which he compares visual intensity (R) with thermometric intensity (S).

Since then, the history of ICP-MS development has been one of huge success, and its impact continues to grow in environmental studies, material science, bio- and nano-applications, and many more.

Another milestone that I can't pass by, considering its present relevance, is the explosive growth of chemical speciation of trace elements; that is, the investigation of the nature, structure and quantification of their chemical species. Though the "speciation community" was born many years ago, the rise of elemental mass spectrometry (ICP-MS) gave it a significant boost. The powerful ICP (at 7000 K) destroys virtually all molecules in the sample, making ICP-MS an ideal detector for element speciation work. If molecular information about an element is needed, the atomic detector needs to be coupled to a powerful separation technique (generally gas chromatography, high performance liquid chromatography or electrophoresis methods). Even flow fractionation methods (for example, AF4) may be needed for adequate separation in the case of nanoparticle analysis, before the final element-specific detection with ICP-MS. The observed retention time of the element-containing species (molecules) gives you some molecular information. However, today an integrated or complementary speciation is desirable, which may mean resorting to MS molecular techniques such as MALDI- and ESI-MS to reveal the actual molecular structure of the analyte species.

What's next?

The value of spectroscopy today is overwhelming, both in chemical (molecules and element species) and primary elemental aspects.

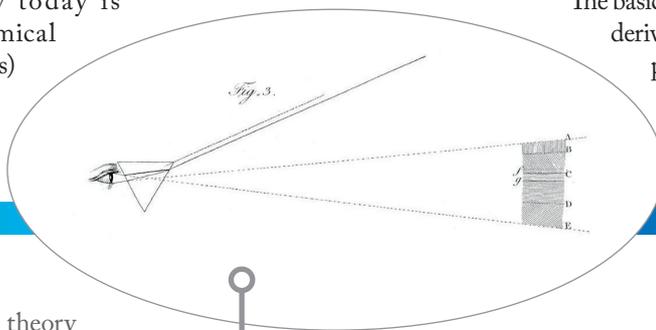
"The value of spectroscopy today is overwhelming, both in chemical (molecules and element species) and primary elemental aspects."

Chemical analysis is the backbone of chemistry and we need innovative advances and applications in several strategic fields. Molecular and cell biology, systems biology, bio-inspired materials, nano- and bionano-applications are booming, as is research into harnessing alternative energies.

Complex molecular problems (for example, in life sciences) can be simplified by using atomic (elemental) spectroscopy and novel hybridizations (for example, HPLC-ICP-MS, LA-ICP-MS...). Many problems that remain in toxicology, environmental contamination, biomedicine, bioscience, elemental imaging, and more will benefit from innovative insights from chemical speciation strategies that modulate or reduce the complexity of the sample.

The introduction of new mass analyzers with resolving power sufficient to get rid of polyatomic interferences, particularly for P and S elements (for example, ICP-QQQ-MS) will substantially expand both targeted and non-targeted element speciation analyses in future. Such capability will be of special relevance for studying the role and function of trace elements in biological systems (where P and S have such a prominent presence).

The basic ideas, knowledge and technologies derived from spectroscopy are already in place, and the scene is set for many breakthroughs to come.



1801

Johann Ritter discovers ultraviolet radiation.

1802

Thomas Young calculates the wavelengths and frequencies of the various colors and presents them in his Bakerian Lecture: "On the

theory of light and colours."

1802

William Wollaston publishes the first sketch of the solar spectrum, using a "1/20 inch crevice" as a slit.

He observed, and drew, several of the dark Fraunhofer lines assuming them to be the boundaries of the colors. He also observed the yellow sodium line in a candle flame.

1814-1817

Joseph Fraunhofer invents the modern spectroscope and observes solar and stellar absorption spectra. His published solar spectrum included about 350 observed lines.

A Field in Flux

By Gary Hieftje, Distinguished Professor and Robert & Marjorie Mann Chair, Indiana University, Bloomington, Indiana, USA.



My career path has not been a directed or planned one. I simply followed opportunities and interests as they appeared, and was influenced by the many great scientists I came into contact with. I began chemistry

research in the area of synthetic organic chemistry (chosen largely due to the prominence of Hope College's Gerrit Van Zyl), had a one-year position as a physical chemist (under Josephus Thomas, Jr. of the Illinois State Geological Survey), and started graduate school as an inorganic major, before moving to analytical spectroscopy with Howard Malmstadt.

A seminal moment for me was touring the laboratories of James Winefordner at the University of Florida, while I was still in graduate school. Like me, Winefordner had been

a student of Howard Malmstadt, though about 10 years before me. When I visited the lab, he was already famous for establishing atomic fluorescence spectrometry as a viable method for elemental analysis,

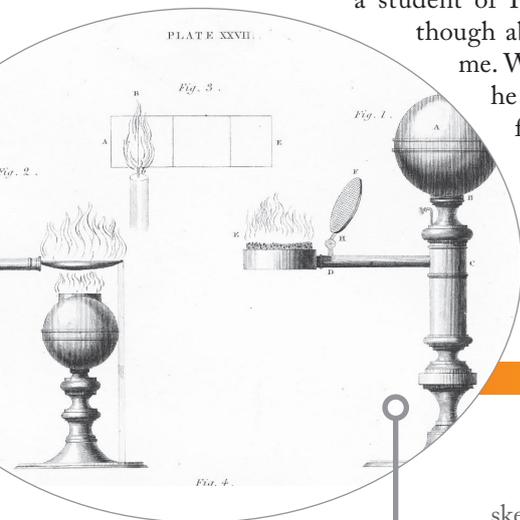
and was a world leader in signal-to-noise enhancement and characterization, something in which I was very interested. Indeed, it was his influence that directed my later research along similar paths.

I was astonished that one of my scientific heroes was so generous with his time and advice. During my brief (and unannounced) visit, he loaded me up with a pile of reprints of his recent publications, took me on a tour of his labs and gave me sound advice – to follow my research instincts, be thorough and objective, and stick by my convictions.

Progress on many fronts

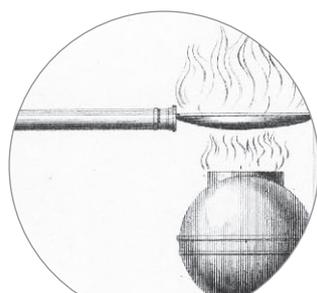
There have been many great achievements in spectroscopy over the past half-century. My original list included 18 entries; here are my top eight:

- Development, application, and characterization of a useful analytical ICP for emission and mass spectrometry (Kees Alkemade, Alan Gray, Velmer Fassel, Stanley Greenfield, R.S. Houk).
- Characterizing and reducing matrix interferences in ICP-emission spectrometry and ICP-MS (Jean-Michel Mermet, Gary Horlick, Ramon Barnes, Sam Houk, George Chan, and others).
- Introduction, improvement, and application of array detectors in plasma atomic-emission and mass spectrometry (M. Bonner Denton, Gary Horlick, James T. Barnes IV, Dave Koppenal, and others).
- Use of ion-reaction chemistry to reduce isobaric interferences in ICP-MS (David Koppenaal and others).
- Fundamental and practical studies in dc and rf glow-discharge spectroscopy (Willard Harrison, R. Kenneth Marcus, Arne Bengtson, Volker Hoffmann, Annemie Bogaerts, and others).



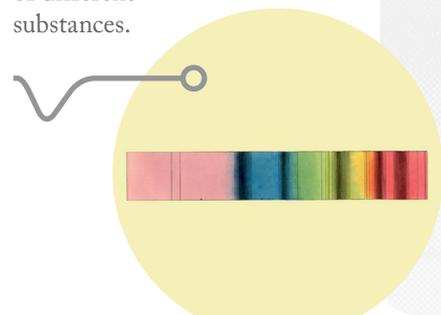
1822
David Brewster, publishes colored emission spectra from flames and absorption caused by glass filters.

1822
John Herschel, first sketched flame emission spectra for different substances.



1834
David Brewster publishes the first molecular absorption spectra, chlorophyll. The five bands resulting from a mixture of chlorophyll a and chlorophyll b, extracted from laurel leaves, are clearly visible. Fraunhofer's solar lines appear in the background.

1834
Henry Talbot proposes flame emission as technique to detect "minute portions" of different substances.



- Introduction and application of plasma-based sources for ambient desorption/ionization mass spectrometry (Chip Cody, Francisco Andrade, Jake Shelley, and others).
- Development and application of laser-induced breakdown spectroscopy (LIBS; Fred Brech, Lee Radziemski, Dave Cremers, Rick Russo, Nico Omenetto, the Mars Rover team, and others).
- Turning laser-ablation ICP-MS into a truly useful analytical tool (Rick Russo, Detlef Günther, and others).

“If plasma spectroscopy is to resume a position of prominence among scientists and funding agencies, we need to see new breakthroughs in technology.”

Breaking free of the herd

Plasma spectroscopy, like many fields, is facing real challenges. Disruptive changes in science communication have occurred over the last 20 years, driven by the Internet and open-sourced literature. The resulting information glut has discouraged scientists and students from consulting any but the most recent publications, resulting in earlier work being needlessly repeated. In addition, citation metrics, slavishly pursued by both scientists and journals, have distorted the perceived value of most work, and given rise to a herd mentality, in which only the ‘trendiest’ areas are pursued and funded.

Conventional plasma spectroscopy (for example, with ICP and glow-discharge sources) is perceived by many as a “solved problem.” As a consequence, potentially path-breaking or disruptive science is not being funded. As funding dries up, many plasma spectroscopists are leaving the field to join more popular (and better funded) areas. Few in the herd are willing to take the big steps needed for a breakthrough, as such adventurous research is rarely rewarded with tenure or

promotion. As Richard Feynman once said, “In a less crowded field, he would not only have seemed (better), he would have been (better).”

If plasma spectroscopy is to resume a position of prominence among scientists and funding agencies, we need to see new breakthroughs in technology. I believe the key priorities are:

- A better ICP or its equivalent – one that consumes less (or no) argon, operates at modest power levels, suffers no or minimal matrix interferences, and uses sample material more efficiently
- A plasma-based source for ambient desorption/ionization MS that is less susceptible to mechanical-positioning variations and is less prone to competitive ionization
- A glow-discharge source that provides three-dimensional spatial information, with either optical or mass spectrometric detection
- A “fieldable” plasma-source mass spectrometer that can provide elemental or molecular information in a continuous, unattended fashion
- A LIBS method that is free from matrix interferences.
- A plasma-source mass spectrometer that can detect and collect super-heavy elements from ore samples.

1835

Charles Wheatstone observes the first spectra of electric sparks and plots spectra of six metals and a flame containing soda.

1842

Edmond Becquerel records a photograph, a

daguerreotype, of the solar spectrum and shows that the spectral lines extend into the ultraviolet. The first published photographic solar spectrum.

1842

John W. Draper records multiple daguerreotypes of

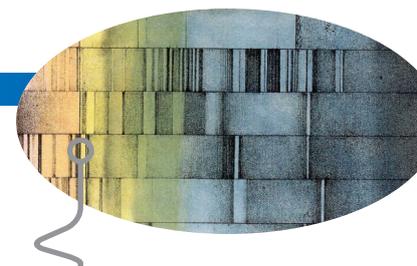
the solar spectrum. This is the only surviving example.

1843

Edmond Becquerel publishes phosphorescence spectra.

1845

William Miller publishes colored flame emission



spectra for various elements, top to bottom: solar spectrum, flame emission spectra of copper chloride, boric acid, strontium nitrate, calcium chloride and barium chloride.

Improving ICP

By Frank Vanhaecke, Professor, Department of Analytical Chemistry, Ghent University, Belgium.



ICP-MS has evolved from a delicate research tool to a well-established and robust analytical technique, with many thousands of instruments in use worldwide. It provides the lowest limits of detection in elemental analysis and is of huge importance

for industry and society. For example, only ICP-MS combines extreme detection power with the multi-element capabilities required for the screening of the highly pure chemical reagents needed to make computer chips, so one could say that the rapid evolution in electronics (smartphones, tablets, and so on) would not have been realized without ICP-MS.

I did not always appreciate the power and potential of chemical analysis. In my undergraduate days, my practical experiences were largely limited to gravimetry and titrations. When a former teacher asked what field of chemistry I would like to continue in, I replied that I didn't know yet, but that it definitely would not be analytical chemistry! However, once I was introduced to instrumental analytical chemistry I soon changed my mind. At this time (the late 1980s), the first ICP-mass spectrometer in Belgium (a first-generation VG PlasmaQuad) was installed at the Department of Analytical Chemistry at our university and I was the first Master's student to use it for my thesis research. I continued working with ICP-MS during my PhD

research, studying fundamental topics, such as the formation of oxide and doubly charged ions. I also participated in several certification campaigns organized by the EU. It was satisfying to think that by demonstrating that ICP-MS produced reliable results (provided spectral and non-spectral interferences were avoided) we contributed to the acceptance of what was then a novel technique. After my PhD, I first explored a career in the chemical industries, but ultimately realized that the academic world was a better habitat for me and I am now a professor in analytical chemistry.

A personal highlight for me was coming up with a zone model to clarify how the signal intensities of atomic, doubly charged and oxide ions respond to changes in instrument settings and matrix composition in ICP-MS. Another satisfying moment was when the results from an HPLC-ICP-MS method that we had developed for quantitative metabolite profiling of a new anti-tuberculosis drug were accepted by the US FDA. More recently, my group has been investigating the use of high-precision isotopic analysis of essential mineral elements in blood/serum as a novel method for medical diagnosis – it's very exciting to see a robust method for assessing iron status (Fe isotopic analysis) and a promising marker for liver disease (Cu isotopic analysis).

As a field, we have made great progress, but it is clear to me that there are still many challenges to be tackled in ICP-MS. Novel application types continue to pop up and challenge instrument manufacturers, like single-particle ICP-MS and bio-imaging LA-ICP-MS. We need improved sensitivity to reduce the size limit of detection in single particle ICP-MS and to further improve spatial resolution in LA-ICP-MS. In addition, multi-collector ICP-MS would benefit from enhanced sensitivity to realize high isotope ratio precision at lower element concentrations, especially as there is an emerging trend in isotopic analysis to not only carry out bulk but also species-specific analysis.

Will we succeed in our efforts? I believe so. Lately, we have

1851

Antoine Masson devises the first complete spark emission spectrometer and publishes spectra of various metals.

1852

George Stokes coins the word "fluorescence" and observes spectra of various substances

including quinine sulfate.

1854

David Alter publishes charts of flame lines of 12 elements.

1857

James Gladstone publishes on molecular absorption spectra for qualitative analysis.

1857

William Swan publishes the spectrum of carbon, C_2 .

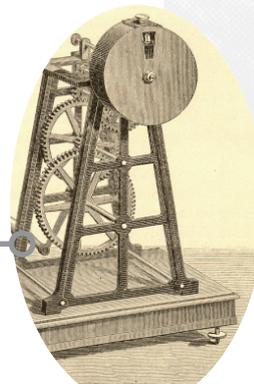
1857

Gustav Kirchhoff explains the relationship of emission and absorption in regard to the solar spectrum confirming the link between absorption and

emission related to individual elements.

1859

Edmond Becquerel uses a chopper to observe phosphorescence spectra.



seen manufacturers further extend the application range of instruments; for example, tandem ICP-MS/MS has proven a very attractive approach to overcome spectral overlap. Personally, I have also been charmed by the new generation of time-of-flight ICP-MS instruments. The semi-simultaneous detection approach they offer is crucial for multi-element LA-ICP-MS bio-imaging applications and single-particle ICP-MS for nanoparticles consisting of more than one element. Moreover, this capability has recently been combined with enhanced mass resolution. Of course, as instruments evolve, expectations become increasingly high, inspiring academics and companies to push even further.

Space to Collaborate

By Steven J. Ray, Winkler Assistant Professor of Chemistry, State University of New York at Buffalo, NY, USA.



I am addicted to research. There is something incredibly appealing in the act of trying something new and untested for the first time, and that's what keeps my motor running. Seeing something that began as a concept being put into practice is incredibly rewarding.

I'm also motivated by training the next generation of scientists. I have been fortunate to work in a community that takes that job seriously, and I have always been impressed by the care that I see colleagues put into teaching and helping to develop our future spectroscopists.

And where will the spectroscopists of the future focus their energies? Prognostication is always tricky, but I expect to see the

continuation of current trends:

- An insatiable need for bioinorganic analyses and chemical insight
- Increasing application of ultra-precise stable isotope measurement across a wide variety of applications
- Far-reaching chemical imaging applications (for example, x-ray spectroscopies, laser-ablation ICP-MS)
- Increased analyses of nanostructured materials in material development and environmental applications
- Increasing need for ultra-trace analysis of non-traditional elements and speciation (for example, fluorine) that may employ new modes of ion chemistry developed for ICP-MS.

As instrumental and analytical capabilities improve, traditional tasks will be shifted to lower-cost solutions that include advanced computer systems, robotic and unsupervised sample analysis, and portable, lower-cost instrumental platforms. We may even see the emergence of new and more advanced instrumentation, as atomic fluorescence and bench-top X-ray systems evolve. Finally, multidimensional analysis strategies will become widespread, in large part because solutions to more sophisticated chemical problems will require a multi-technique approach. The chemical insights provided through data fusion and new chemometric approaches will be critical to this effort.

We have a deep knowledge base, and enormous opportunities before us. In my view, collaborations are crucial to the progress of the field, especially those that lie at the interface between different fields. In many instances, scientists outside analytical chemistry are unaware of the capabilities of modern plasma spectrochemistry. By teaming up we form a virtuous circle, where challenges posed by an application induce new developments in plasma spectrochemistry, which further strengthen the technique.



1860

Bunsen and Kirchhoff propose chemical analysis with spectroscopy, discovering cesium and rubidium.

1868

Anders Ångström publishes his extensive solar atlas assigning thousands of lines

to specific elements.

1874

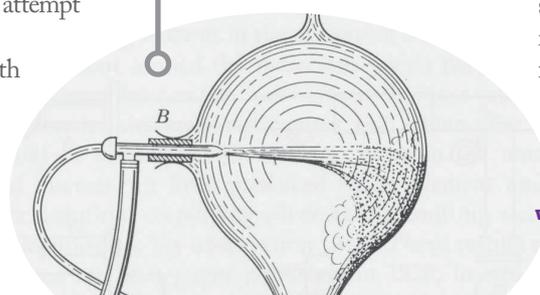
Norman Lockyer and Chandler Roberts publish the first attempt at quantitative spectroscopy with spark emission of metal alloys.

1879

G. L. Gouy invents the pneumatic nebulizer for introducing solutions into flames.

1884

Walter Hartley applies photographic detection for quantitative analysis using spark spectroscopy. He is largely responsible for initiating the field of quantitative spark and arc spectrochemical analysis.



Shine On

By Joanna Szpunar, Professor, French National Centre for Scientific Research, Pau, France.



My career in spectroscopy is the result of a series of coincidences, which led my first working with MIP-AES in the 1990s before moving on to ICP-MS, as my speciation work evolved from volatile to non-volatile species.

I was very lucky to be involved in the early days of HPLC-ICP-MS coupling and share in the excitement it brought to biochemical speciation analysis.

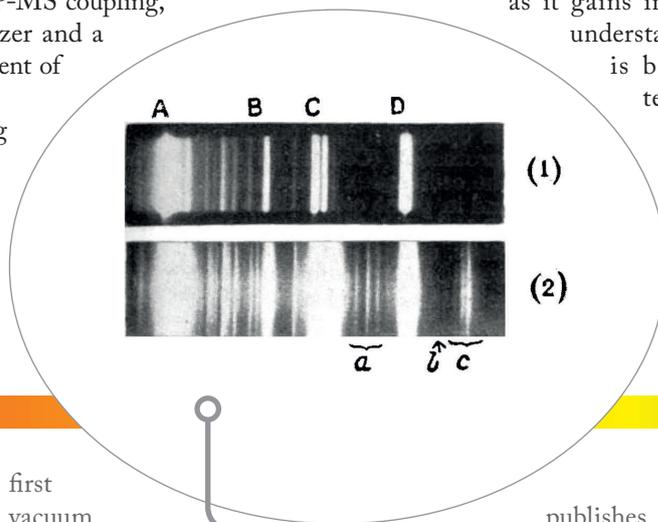
The most rewarding moments for me are those when a difficult experiment proves successful; I have been lucky enough to have had many such moments – and hope to have more in the future. One example from my very early career was the first successful reversed-phase HPLC and ICP-MS coupling, using a direct injection nebulizer and a challenging (at that time) gradient of organic eluent.

I believe that the increasing specialization of different plasma spectroscopy fields will continue. Sub-fields, such as isotopic analysis or imaging, with their dedicated journals

and meetings, will become new scientific communities. The use of specific instruments, such as the HR multicollector or triple quadrupole, will further compartmentalize the plasma spectroscopy family. Therefore, I think that future developments will run in several directions, including improved resolution, quantitative elemental imaging, more precise isotopic ratio measurements, miniaturization of chromatographic couplings and high-throughput routine applications in a variety of fields.

With the field evolving rapidly, clear communication will be important. I am very concerned about the evolution of analytical chemistry publishing and, in particular, the quality of peer-reviewing. I receive a lot of requests for reviews, many of them completely beyond my area of expertise, and I often have an uncomfortable feeling that some people accept such tasks without reservation. Also, some of the papers appearing in – theoretically – peer-reviewed journals seem to have slipped through the net. I think that the days of reviewing on a voluntary basis are numbered, and a new system should be put in place to assure that the best (rather than the most available) experts are used for this task.

There is no doubt that plasma spectroscopy is a well-established technique with great potential. However, as it gains in popularity, I am afraid that understanding of its operating principles is being lost, and spectroscopic techniques are starting to be considered “push-button” tools. Therefore, if I had to choose just one ingredient essential for facing the challenges ahead I would say: quality of education.



1900
The firm of Adam Hilger offers the first commercial quartz prism spectroscope.

1909
Adam Hilger introduces the first photographic quartz spectrograph.

1920
Adam Hilger introduces the

first vacuum spectrograph.

1928
C. V. Raman observes the molecular scattering process now called Raman Spectroscopy.

1929
Henrik Lundegårdh

publishes “Quantitative Spectral analysis of the Elements,” establishing flame emission as a routine analytical method.

1949
Beckman introduces the flame emission attachment for the DU spectrophotometer.

1957
Alan Walsh publishes his first paper on atomic absorption spectroscopy.

1957
Boris L’vov publishes on atomic absorption with a graphite furnace atomizer.

1960
Hilger and Watts

“Plasma spectroscopy in chemical analysis still has untapped potential.”

Shooting Star

By Jorge Pisonero, Associate Professor,
University of Oviedo, Spain.



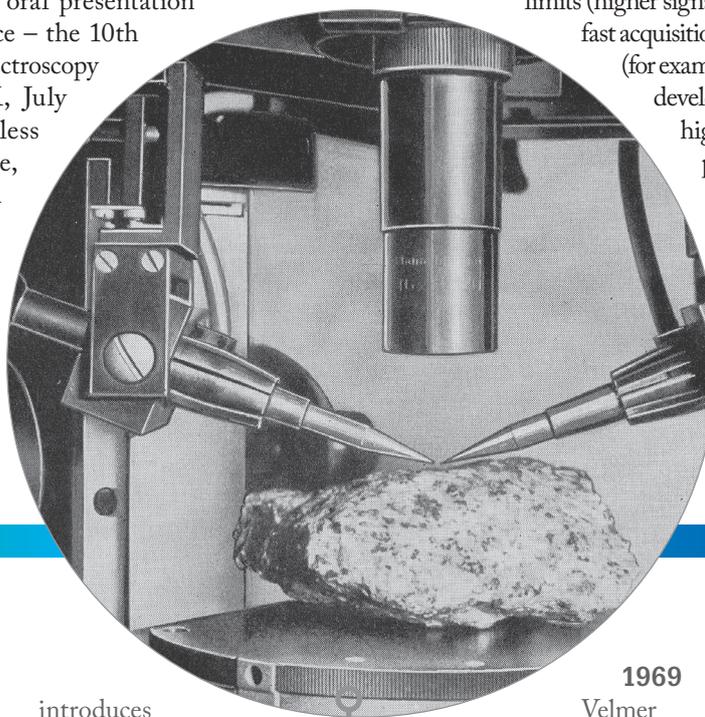
During my undergraduate lectures on atomic physics, I became fascinated by the emission spectra from hollow cathode lamps, which can be interpreted as fingerprints of the discharge gas elemental composition. After graduation, I joined an analytical chemistry group, where I came to fully realize the great potential of spectroscopy to obtain elemental and molecular information from a variety of samples.

I still remember my first oral presentation at an international conference – the 10th Biennial National Atomic Spectroscopy Symposium (Sheffield, UK, July 2000). I had a few sleepless nights beforehand! Of course, I now present regularly, both at specialized workshops and broader spectroscopy conferences.

Plasma spectroscopy in chemical analysis still has untapped potential. For instance, laser-induced

as well as industrial applications here on Earth. Similarly, discharge plasma spectroscopy will have an important impact on several fields, including ambient mass spectrometry (for example, DART, FAPA, LSGD), fast screen analysis at industrial sites (for example, ELCAD/SCGD), and fast depth profile analysis of innovative coated materials (for example, GD-TOF-MS/OES). LA-ICP-MS and MALDI-MS are also becoming more popular approaches in geological and clinical applications to determine elemental and molecular distributions on biological and geological samples.

The major challenges we face are improving absolute detection limits (higher signals with less sample), getting ultra-fast acquisition rates to measure transient signals (for example, in single nanoparticle analysis), developing compact spectrometers with high performance, and using robust plasma generated in nitrogen or air. The development of plasma alternatives to ICP, improving the potential current limitations on matrix effects and elemental/isotopic fractionation, are other potential hurdles to be overcome.



announces the first commercial atomic absorption instrument.

1961
Willard Boyle at Bell Labs forms the first laser induced plasma with a 1 J ruby laser on graphite.

1961
PerkinElmer Corp.

introduces their first atomic absorption instrument at the Pittsburgh Conference.

1964
Jarrell Ash introduces the Laser Microprobe.

1969
Velmer Fassel and George Dickinson publish the first analytical application of inductively coupled plasma emission spectroscopy.

1980
Sam Houk et al. publish

first results using ICP-MS.

1983
Sciex introduces the first commercial ICP-MS.

1983
Radziemski et al. publish on laser-induced breakdown spectroscopy re-invigorating laser plasma spectroscopy and sampling.



In Spectroscopy and in Health

Sitting Down With... Maria Montes-Bayón, Associate Professor in Analytical Chemistry,
Department of Physical and Analytical Chemistry, University of Oviedo, Spain

Tell us about your current role...

In addition to my role as Associate Professor in analytical chemistry, I have recently taken on a new administrative position within the faculty, which takes up a good deal of my time. It's a busy life, but I believe administration is something you should try, at least once. Not everything runs like chemistry, so it widens your horizons. Plus, you never know what interesting new connections you might gain as a result.

What was your route into this field?

My PhD was diverse, involving microwave-induced plasma with atomic emission spectroscopy, gas chromatography-inductively coupled plasma-mass spectrometry (GC-ICP-MS) for small molecules and high performance liquid chromatography coupled with ICP-MS for large proteins. During my postdoc with the Joe Caruso group at the University of Cincinnati, I realized I had a real interest in clinical and biomedical science. When I returned from the US, the Spanish government had opened some positions at the university, offering good salaries, five-year contracts and the possibility of a tenure track. I got one of these prestigious positions, and decided to focus on biomedical and clinical analysis, specifically biomarkers.

Why focus on these areas?

Health is clearly an important topic, and developing analytical strategies to improve early detection of disease is something that can really help communities. When I came back to Spain it was the time of quantitative mass spectrometry, and so we decided to focus our ICP-MS research on quantitative aspects. Here, isotopes are a basic – but interesting – tool.

What are you working on now?

After coming from the US I joined the Analytical Spectrometry group led by Alfredo Sanz Medel, who retired about a year ago. Alfredo is a leader, not only in this university, but also in the spectroscopy

community. After his retirement, the group split into different fractions and our group is now named Mass Spectrometry and Biomedical Analysis. Within this field, I've been conducting research on two defined topics. One is iron-related proteins and iron homeostasis; essentially, developing methods for the determination of transferrin, a protein with a role in anemia. Transferrin is measured in many hospitals, but the various spectrophotometric methods used often lack precision and accuracy. My other focus is on oxidative stress parameters, proteins and metalloproteins. We develop quantitative strategies for analysis of proteins related to oxidative stress, such as superoxide dismutase or glutathione peroxidase, and use ICP-MS as an elemental detector to determine the concentration of metals or metalloids in these proteins. Another part of my research is looking at how metalldrugs, such as cisplatinum- or ruthenium-based drugs, interact with DNA. We are working on a method to detect how effective these drugs are and whether they cause cell damage, which is the aim of chemotherapy.

What drives you?

When something that I've predicted turns out to be true, particularly in areas that have relevance for human health, it gives me a real boost. Right now, we're dealing with new treatments for iron deficiency. Using nanoparticles to overcome iron deficiency is a hot topic (so nanoscience really is everywhere, including the clinical field). Recently, we ran a typical iron speciation experiment with HPLC-ICP-MS, and made some predictions. My student corroborated our result using transmission electron microscopy. We found that cells uptake and manage these nanoparticles without apparent cell toxicity. So, this would mean more efficient treatments for Fe-anemia with reduced secondary effects. In the end, helping people is what matters. I wouldn't want to just run organic or inorganic synthesis of compounds without knowing what applicability they're going to

“When something that I've predicted turns out to be true, particularly in areas that have relevance for human health, it gives me a real boost.”

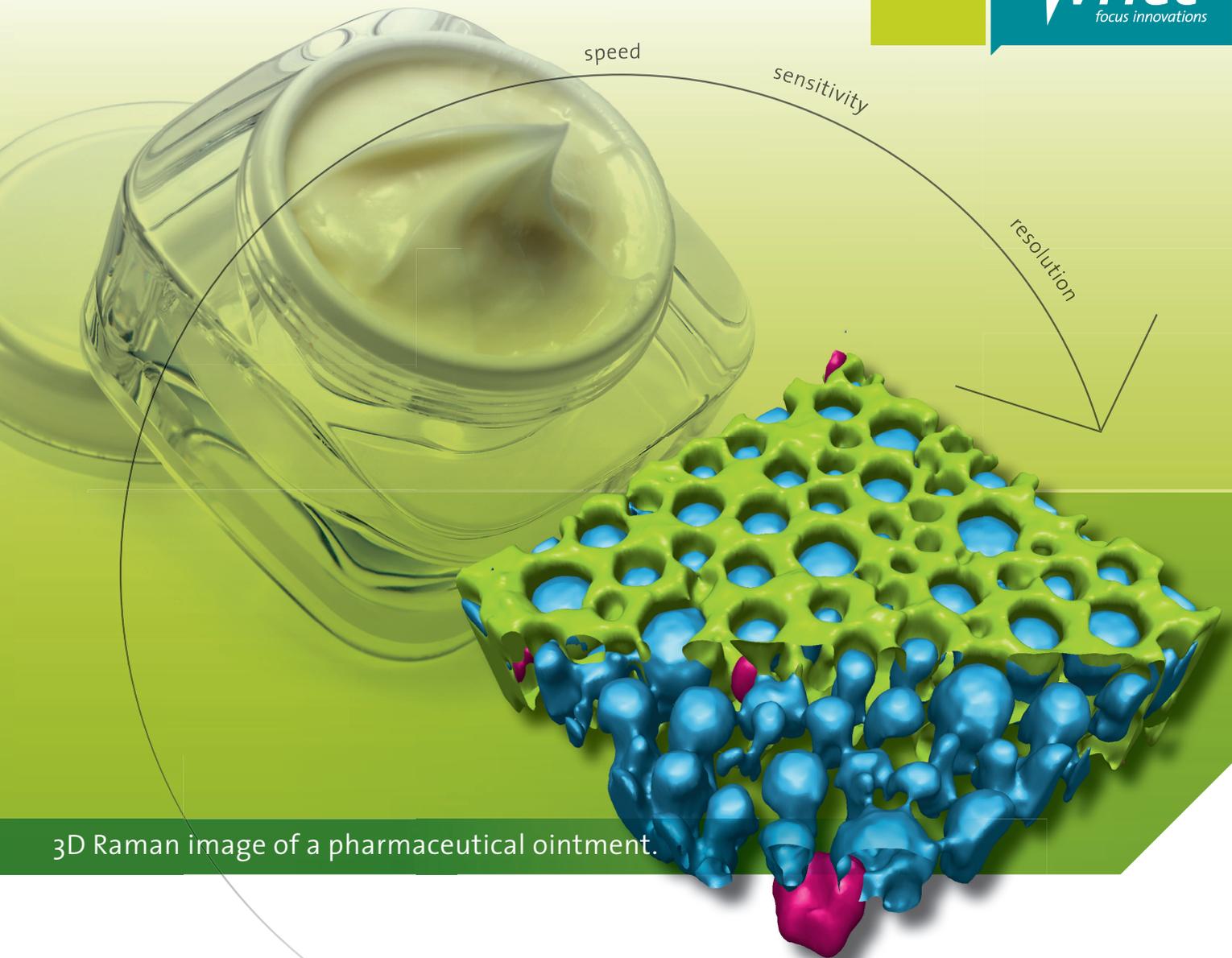
have in ten years. I am an impatient person and like to see immediate results!

What was your best moment in science?

When I received the Bunsen-Kircher award from the German Society of Spectroscopy in 2013. The members of the society are knowledgeable and are at a very high level, and the fact they thought I was eligible for this prize made me feel that all the effort I put into my work was worth it.

How do you see your research developing in future?

Analytical chemistry develops methods, but if these methods are not known, or not used by other communities, they are a waste of time. I think the most exciting part of this job is when the things we have developed are acknowledged by other people – particularly, those from other fields, such as biology or biochemistry. For instance, about two months ago, a call came from an institute in Catalonia related to genomics research. They want to measure specific mutations in DNA but they don't want to deal with the analytical chemistry. Of course, that is our favorite part, so I foresee a successful collaboration. Multidisciplinary approaches are the fastest way to advance in science.



3D Raman image of a pharmaceutical ointment.

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