



Special Issue in Honour of Michel Che: Preface and Recollections of his International Influence on Catalysis both Fundamental and Industrial



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ABSTRACT

This special Issue of the *Journal of Catalysis* pays tribute to Professor Michel Che. In addition to the Editorial Preface, colleagues share their recollections of the vigorous endeavour he displayed throughout his scientific life to promote efficient international collaborations, as well as to bridge fundamental science and its applications. His human qualities are unanimously valued, which has left a trail marked with friendship.

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1. Editorial Preface by Jacques Védrine, Catherine Louis, Hervé Toulhoat, and Graham Hutchings

This special issue of *Journal of Catalysis* is devoted to Professor Michel Che, who unfortunately passed away on 7th August 2019. We have invited his main collaborators and scientific friends to contribute to their recollections concerning the scientific domain he has pioneered: a molecular approach to heterogeneous catalysis, based on transition elements taken as probes, specific isotopes and physical techniques. His work has led to the emergence of interfacial coordination chemistry at the junction of colloidal, electro-, supramolecular, geo- and solid-state chemistries. His studies have largely contributed to improving the understanding of the elementary processes involved in laboratory/industrial catalysis, and particularly water-mediated assemblies in catalyst preparation.

Michel was born in Lyon in December 1941. After a chemical engineering degree delivered by the « Ecole Supérieure de Chimie Industrielle de Lyon (ESCIL, now CPELyon) » Michel Che joined the « Institut de Recherches sur la Catalyse », CNRS laboratory in Villeurbanne, suburb of Lyon. He has obtained there a PhD degree from the University of Lyon under the supervision of Dr. Claude Naccache in 1968. Then, he went to the USA at Princeton University, in the Chemistry department, where he worked under the supervision of Prof John Turkevich for two years. 1969–1971. Between 1972 and 1982, when employed by the CNRS, he collaborated with Antony Tench of the atomic energy research establishment at Harwell, UK. In 1975, he was promoted a Professor at the Université P. & M. Curie-Paris-6 in Paris, where he created the « Laboratoire de Réactivité de Surface » as director. In 1995, he became senior member of the « Institut Universitaire de France ».

His researches covered the reactivity of solid surfaces investigated from a molecular standpoint based on the combined use of transition metal complexes, specific isotopes and physical techniques. His work, which led to more than 450 publications, a two volumes book (*Characterization of Solid Materials and Heterogeneous Catalysts: From Structure to Surface Reactivity*, 2012, Wiley) and 5 patents, has contributed to improve the understanding of the elementary steps developing at the solid–liquid (gas) interfaces during the preparation of supported catalysts and to bridge the gap between homogeneous and heterogeneous catalysis.

Michel Che was very involved in promoting catalysis in France. Michel Che was the president of the « catalysis division » of the « Société Chimique de France (SCF) » then vice-president of this society (2007–2009). He was the president founder of the European Federation of Catalysis Societies (EFCATS) in 1993–1995, creating the biennial EuropaCat congress and later on, the president of the International Association of Catalysis Societies (IACS) in 2000–2004.

He received many awards in France (A. Joannides & P. Sue), the French–Chinese award of SCF–Chinese Chemical Society, in Europe (Germany, Italy, Netherlands, Poland, UK) and overseas (China, Japan, USA). He was invited to deliver many lectures in Europe (François Gault EFCATS lectureship, RSC Centenary Lectureship and the RSC Faraday Lectureship Prize, Georg Wittig – Victor Grignard prize from the Gesellschaft Deutscher Chemiker and in USA (Frontiers in Chemical research). He earned several honorary doctorates and fellowships. Michel Che was also a member of the scientific committee of the “Institut Français du Pétrole” (IFP, now IFPEN) for more than 30 years, of the “State Key Laboratory of Catalysis” (SKLC) in Dalian, China, of the Cardiff laboratory on Catalysis and of “the Eco-efficient Products and Processes Laboratory” (E2P2L) in Shanghai.

Michel collaborated with many scientists all over the world: this is why we invited some major scientists among them to bring their recollections of Michel's achievements to foster the catalysis community internationally, provided in the next sections of this introductory article.

In addition to his significant scientific contributions, Michel was greatly appreciated by all for his human qualities. All his students recognized him as an outstanding mentor. As a chairman of many committees, he used his great knowledge of catalysis by defining research strategies, by promoting international collaborations and by fostering and educating generations of young scientists to become active and leading scientists across the globe.

We shall always remember Michel's contribution to catalysis and his friendship with great affection. His spirit and soul will remain in our hearts forever.

This special issue to honor Michel Che's scientific contributions to Catalysis includes an introductory chapter that pays tribute to Michel's impact on academic and industrial science in Catalysis via recollections by close collaborators and friends, two short reviews by colleagues and previous students as well as 26 original research articles.

The first review by **Marceau, Carrier et al.**, "Interfacial coordination chemistry for catalyst preparation" links the scientific contributions of Michel in defining and exemplifying the concept of interfacial coordination chemistry, and shows its influence across current scholarly activities on the molecular design of catalytic materials. <https://doi.org/10.1016/j.jcat.2021.02.002>

The second review, **by Anpo, Lauron-Pernot et al.**: "Characterisation and reactivity of oxygen species at the surface of metal oxides" focusses on the oxygen species, so important in selective and total oxidation reactions and as basic sites for fine chemistry, characterized by EPR and photoluminescence spectroscopies. <https://doi.org/10.1016/j.jcat.2020.10.011>

The other contributions either cover Michel's scientific interests or present recent discoveries and recent works led by close collaborators and friends of Michel who enthusiastically accepted to pay tribute to Michel Che with this special issue. We have made great efforts to highlight the impact of Michel's work to the scientific community via these contributions by promising younger members of his scientific family.

The content of this issue can be grouped into five clusters, which correspond to Michel's research focuses: the insight-guided preparation and characterization of catalysts, the understanding of catalytic mechanisms, and the quest for catalytic solutions to environmental and industrial challenges

A. Innovative preparation of catalysts following an interfacial chemistry approach,

which includes the above mentioned minireview **by Marceau, Carrier et al.**, and the following nine research articles articles by:

- **Lam, Copéret et al.** on CO₂ hydrogenation on Cu-catalysts generated from Zn^{II} single-sites, <https://doi.org/10.1016/j.jcat.2020.04.028>
- **Ren, Anpo et al.** on optimized electron transfer and molecular oxygen activation by conjugated polymer photocatalysts, <https://doi.org/10.1016/j.jcat.2020.07.005>
- **Horiuchi, Matsuoka et al.** on linker defect engineering of MIL-125 (Ti) MOF photocatalysts, <https://doi.org/10.1016/j.jcat.2020.09.017>
- **Liu, Corma et al.** on atomic-level understanding of the generation of dense PtSn clusters in zeolites, <https://doi.org/10.1016/j.jcat.2020.07.035>

- **Han, Can Li et al.** on atomically dispersed highly active Ptⁿ⁺ species in Pt/In₂O₃ catalysts for methanol synthesis, <https://doi.org/10.1016/j.jcat.2020.06.018>
- **Dalebout, P. de Jongh et al.** on the promotion of copper catalysts by zinc oxide, <https://doi.org/10.1016/j.jcat.2020.10.006>
- **Ballestas-Barrientos, Mashmeyer et al.** on novel thin-film photoanodes of preferentially oriented high-index rutile TiO₂ facets, <https://doi.org/10.1016/j.jcat.2020.09.028>
- **Noble, Regalbuto et al.** on the mechanism of adsorption of Au bis-ethylenediamine onto oxides and carbons supports, <https://doi.org/10.1016/j.jcat.2020.11.026>
- **Gao, Gianotti, Coluccia et al.** on rational design of bi-functional hierarchical SAPO-5 for the synthesis of tetrahydrofuran derivatives from furfural, <https://doi.org/10.1016/j.jcat.2021.03.003>

B. New insight on catalysts surface structures and catalytic mechanisms from EPR spectroscopy,

which includes the above mentioned minireview **by Anpo, Lauron-Pernot et al.**, and three research articles articles by:

- **Folli, Murphy et al.** on EPR and ENDOR spectroscopies of copper (II)-casiopiteina type coordination complexes [Cu(O-O)(N-N)]⁺, <https://doi.org/10.1016/j.jcat.2020.07.016>
- **Pietrzyk, Sojka et al.** on EPR and IR spectroscopic studies and molecular modeling of the structure of Ni²⁺ –NO adduct in NiZSM-5 catalyst and relevance in model HC SCR reaction, <https://doi.org/10.1016/j.jcat.2020.07.018>
- **Lagostina, Giamello et al.** on EPR study with ¹⁷O isotope labelling of vanadium exchanged H-ZSM5 prepared by vapor reaction of VCl₄, <https://doi.org/10.1016/j.jcat.2020.06.029>

C. New insight on catalysts surface structures and catalytic mechanisms from first principles simulations combined with experiments,

which includes a perspective by:

- **Corral Valero and Raybaud**, perspective on progress and challenges in computational chemistry approaches for the preparation of supported catalysts <https://doi.org/10.1016/j.jcat.2020.09.006>
- and four research articles by:
- **Mihaylov, Hadjivanov et al.** on a revision of the current opinions on surface nitrates based on IR spectra from the case study of ceria, <https://doi.org/10.1016/j.jcat.2020.06.015>
- **Chizallet, Carrier, et al.** on surface orientation dependent interaction of cobalt (II) precursors with alpha-alumina, <https://doi.org/10.1016/j.jcat.2020.10.025>
- **Behraves, Murzin et al.** on kinetic experiments and computational approach to unravel the reaction mechanism of oxidative dehydrogenation of ethanol on gold, <https://doi.org/10.1016/j.jcat.2020.07.022>
- **Berger, Sauer et al.** on a computational assessment of adsorption and cracking of propane catalyzed by acidic zeolites of different pore sizes, <https://doi.org/10.1016/j.jcat.2020.12.008>

D. Innovative catalysts and processes for addressing environmental issues,

which includes five research articles by:

- **AlQahtani, Song et al.** on Plasma-assisted catalytic reduction of SO₂ to elemental sulfur on iron sulfide catalyst, <https://doi.org/10.1016/j.jcat.2020.08.013>

- **Zhou, Prins et al.** on bulk CoP and Co₂P catalysts for hydrodesulfurization of dibenzothiophene, <https://doi.org/10.1016/j.jcat.2020.08.030>
- **Yong, Yongdan Li et al.** on Cu-SSZ-13 for selective catalytic reduction of NO_x by ammonia in the presence of SO₂, <https://doi.org/10.1016/j.jcat.2020.06.041>
- **Yuan, Yi-Jun Xu et al.** on defect-promoted visible light-driven C-C coupling reactions pairing with CO₂ reduction, <https://doi.org/10.1016/j.jcat.2020.07.036>
- **Nguyen, Trong-on Do et al.** on synthesis of cobalt clusters embedded-graphitic carbon nitrides for photocatalytic CO₂ reduction under ambient conditions", <https://doi.org/10.1016/j.jcat.2020.09.038>

E. Innovative catalysts and processes for petrochemistry and chemicals

which includes 4 research articles by:

- **Menghen Wang, Ye Wang et al.** on the synthesis of hierarchical SAPO-34 for syngas-to-olefins reaction, <https://doi.org/10.1016/j.jcat.2020.08.020>
- **Harmel, Krijn P. de Jong et al.** on bifunctional molybdenum oxide/acid catalysts for hydroisomerization of n-heptane, <https://doi.org/10.1016/j.jcat.2020.08.004>
- **Yoshii, Yamashita et al.** on a promotional effect of surface plasmon resonance on direct formation of hydrogen peroxide from H₂ and O₂ over Pd/Graphene-Au catalytic nanorods. <https://doi.org/10.1016/j.jcat.2020.05.028>
- **Nikolopoulos, B. M. Weckhuysen et al.** showing that impurities (Fe, Ca, Mg) in Zeolites ZSM-5 derived from copper mines flotation tailings impart higher ethylene and propylene selectivities in methanol conversion to olefins. <https://doi.org/10.1016/j.jcat.2021.02.015>

2. Michel Che and the International Academic Community of Catalysis

2.1. Introduction by Salvatore Coluccia

The contributions of Michel Che to the promotion of Science, Chemistry and Catalysis are enormous, and are remembered here by some of the Colleagues who, in decades of tight collaboration in different Countries, have become inseparable friends.

Michel has been and will be celebrated in the Meetings of the numberless Societies he founded or promoted all over the world. Indeed, this was a pillar of his life: Science is not only Research, but at the same time it is the organization of the scientists in Communities which allow long term programs and guarantee the stability of relations.

His charming wife Danielle had a role in this, and her guest book should be published as a documentation of the ever-growing scientific network which they built together over the years.

Our mutual friendship, which went well beyond scientific collaboration, has lasted for most of our lives since we met at Harwell both invited by the unforgettable Tony Tench in 1974, and has enriched my existence being the solid reference in my successes and in my difficulties.

It appears from these memories that Michel had such a versatile and rich personality that it is impossible to say: *this is the single aspect that describes him best*.

Nevertheless, I wish to mention one that always impressed me: Michel did so much for the Institutions of Science, but, at the same time and even more, he cared for *each single person* who entered his life.

Science and Research have not only been the duties associated to his many roles in Universities and Academies, but ways of putting people together, of supporting each other, of helping the very many who in different Countries needed his help to realize themselves.

I cannot close this introduction without mentioning the sense of humour of Michel, expression of his contagious joy of living, which enlightened the time spent with him. (See Fig. 1).

2.2. Michel Che: My appreciation of his chemistry and his humanity, by John Meurig Thomas

First, his humanity. I first met Michel in Lyon in the mid-1980s when he convened an international meeting on heterogeneous catalysis when several eminent theoretical chemists, notably Roald Hoffmann and Lionel Salem contributed stimulating papers. He was the perfect host, not only for his exemplary time-keeping of an instructive meeting, but also because of his efficiency and charm in making the event so successful.

After he migrated to Paris, he and Jacques Fraissard invited me to be a Visiting Professor at Pierre et Marie Curie University there, a significant period in my life, as I were able to savour not only the quality of the scientific work that both Michel and Jacques were pursuing with conspicuous success, but also my stay in Paris made me a Francophile.

Proud of his Chinese forebears, and of the achievements of modern China, proud also of the French contribution to the world, it was an education to listen to him expound on innumerable topics. Scientifically, we were also on the same wavelength, as I shall now outline in my next paragraphs.

Michel's scientific contributions to surface science, to heterogeneous catalysis, and especially to the preparation of the latter, were highly significant and elucidating. He was one of the plenary speakers at the 10th International Congress on Catalysis at Budapest in July 1992. The topic of his masterly review on that occasion was "*Interfacial Coordination Chemistry: Concepts and Relevance to Catalysis Phenomena*". This was not only a comprehensive review of the relevant literature, it was also a valuable guide to both novitiates and experts as the way forward in preparing active, oxide-supported transition metal-ion heterogeneous catalysts.

In so far as his significance in the history and culture of heterogeneous catalysis is concerned, perhaps one of his greatest constructive acts was to be the brains behind the initiation of EUROPACAT. The first of these, now regular, highly successful, conferences, was held in Montpellier, in the summer of 1993. He and his fellow organisers did me the honour of inviting me to present the opening plenary talk.

Michel's own scientific work went from strength to strength, and all this led him to be universally recognised, worldwide, as an expert in his field of preparation and characterisation of supported catalysis. His old friend and long-standing collaborator from Harwell days in the UK (with the late Tony Tench), Salvatore Coluccia and he helped greatly through their joint and separate scientific contributions to advance our knowledge of oxide-supported catalysts.

He and Jacques Vedrine, the co-editors of the excellent 2-volume collection of experimental techniques required to characterize solids (including catalysts) and their surfaces.

He also spread his wings as far as Japan, and his collaboration with Masa Anpo, in Osaka, became very significant in photochemical contexts. It was through Michel, that I established contact and became a friend and active collaborator with Professor Anpo and his lively and expert collaborators in Japan.

My final comment on Michel's remarkable qualities entails reference to the very thoughtful and stimulating paper that he gave in Cambridge in December 1997 – later published in a book edited by



Fig. 1. Michel Che, September 1997.

my associates Kenneth Harris and Peter Edwards. The subject of that talk was “*The Mysteries of Water in Catalyst Preparation: Solvent or Much More?*”.

This article, which repays re-reading, reveals another characteristic that Michel possessed, namely his historical perspective. The

cultural depth of Michel Che is well represented by the opening paragraph of this article, which I repeat below:

“A hundred years ago in the single year of 1905, Einstein wrote 5 papers that shook the world and changed the face of physics... They led the French CNRS to publish a special issue in which 10 great enigmas of physics were identified. It is striking that the first one, expressed as ‘the mysteries of water’, could have been ranked also as No. 1 for biology and chemistry, so overwhelming is the role of water in life processes and in the genesis of intelligent materials among which catalytic systems can be included”.

This article was Michel's contribution to the Symposium held to celebrate my 75th birthday. Michel gives a lucid account of the subject that was close to his heart for nearly two decades: interfacial coordination chemistry, to which he made seminal contributions.

Characteristically, and reflective of his warm humanity, he ended that published article with a photograph of he and Danielle, and my late wife, Margaret, and me, dining on the Seine, on the day that the first grandchild of the Che's was born (Fig. 2). Happy days.

2.3. Michel Che and China by Can Li

Michel Che was born in 1941 in Lyon, France, while his ancestral home was Shanxi Province in northern China. Perhaps for this reason, he had especially close ties with China throughout his life. Michel was among the first French scientists who visited China in 1978, when the country first started opening up to the world. Michel was very proud of his Chinese origins and often spoke fondly of it with his friends after his first visit to China. In the following 40 years, he visited China almost annually with great enthusiasm and established strong connections and friendships with the Chinese chemistry community.

Since the early 1980s, he was committed to advancing the cooperation between China and France. He initiated the French-Sino Catalysis Symposium with Chinese chemists in 1985, and many French scientists in the field of catalysis came to Beijing to attend the 1st French-Sino Catalysis Symposium in 1987. It played a sig-



Fig. 2. Celebrating Michel's first grandchild on the Seine River. May 22nd, 1993.

nificant role in promoting China's research in Catalysis to the world. With his hard work and dedication, a Programme International de Coopération Scientifique (PICS) between China and France was successfully launched in 1995, which was regarded as "a model of International Cooperation." He played an essential role in the foundation of the Laboratory of France-China on Catalysis (LFCC) in 2000. This was the first joint laboratory on catalysis between China and France, where CNRS organized its 6 laboratories together with TOTAL Company, and cooperated with a Chinese team including Dalian Institute of Chemical Physics CAS, Peking University and two Institutes (RIPP and SRIPP) of SINOPEC, a truly international catalysis organization incorporating members from both academia and industry. He also contributed to the success of the 16th International Congress on Catalysis held on July 3–8, 2016 in Beijing, China.

Michel provided the Chinese Catalysis Society with valuable suggestions and guidance. He mentored numerous Chinese young scientists in catalysis and other chemical fields—helping them define their research subjects and introducing them to the international stage. Opportunities like these were rare but crucial, especially in the 1980s and 1990s, when China had just opened up to the world. Michel connected Chinese scientists to their international community when they truly needed that platform of exchange. Meanwhile, Michel delivered inspiring lectures on catalysis and coordination chemistry at a number of universities and symposia in China.

Michel collaborated with many scientists in China and was awarded as guest / honorary professorships of many leading universities and institutes in China, such as the Dalian Institute of Chemical Physics, the Institute of Chemistry, Chinese Academy of Sciences, Shanxi University, Tianjin University, Taiyuan University of Technology, Peking University, Fuzhou University, East China University of Science and Technology, etc. In 2006 He was appointed to the Chairmanship of the Academic Committee of the State Key Laboratory of Catalysis (SKLC) in Dalian, China's first

state key laboratory in the field of Catalysis, when I had nice time with him as I was on the directorship of the SKLC.

Due to his great contributions to China's scientific development, particularly in facilitating the international cooperation between China and France, he was awarded the International Scientific and Technological Cooperation Award of the People's Republic of China in 2009—the State's highest honor awarded to foreign scientists (Fig. 3). As Dr. Gilberte Chambaud, the president of the Société Chimique de France, once said, "Michel was the Ambassador of French Chemistry in China."

Michel Che was a kind and charming man, with a great sense of humor. We will forever miss his warm smile, witty remarks, and his genuine care for the people around him. We shall always remember Michel's contributions to the field of catalysis worldwide and his long-lasting friendship with the scientific community in China.

2.4. In tribute to Prof. Michel Che: Scientific contributions & fond memories in Japan by Masakazu Anpo

It is a great honor and pleasure to contribute this short chapter to the Special Issue of the *Journal of Catalysis* dedicated to the late Professor Michel Che.

Long before I first met Prof. Michel Che early in my career, I had heard his name because of his important contributions to the study of heterogeneous catalysis, especially in active oxygen species and coordination chemistry. Prof. Michel Che, whom we all affectionately called Michel, was born in Lyon, France. His father emigrated from China to France as a young engineer. Michel's mother was French, and he was educated in France. Thus, although completely French in manner and speech, these Asian roots made the Japanese and Chinese feel a close familiarity with Michel, as I'm sure he also felt towards us.

Michel visited Japan for the first time to attend the 7th International Congress on Catalysis which was held in Tokyo in July 1980



Fig. 3. Michel Che meeting with Jingtao Hu, the president of People's Republic of China, at the ceremony for the International Scientific and Technological Cooperation Award, 2009.

but, as soon as he met the chemistry community of Japan, he was invited here almost every year after that. He received the Japan Society for the Promotion of Science Lectureship Award in 1986. He was often invited to lecture as an Honorary Professor at Osaka Prefecture University (OPU) and many other universities since 1987 and was also selected as one of the few to be awarded the Special Honorary Professorship of OPU in 2009 (Fig. 4). His inspiring lecture, “Beauty in Chemistry”, conveyed the attraction of chemistry to over 1000 students and staff. He was also an international judge for the selection committee of Newly Recrutable Scientists at OPU from 2010 to 2018, encouraging and nurturing many young scientists who have since become outstanding scientists in their own right. Not only in France or around the world, but also here in Japan, we owe much to Michel.

Michel was also invited to give plenary lectures at the 40th Anniversary of the Catalysis Society of Japan in Osaka (1993) as well as being selected for the Taniguchi International Conference on Catalysis in Kobe in both 1987 and 1996. He has given countless lectures around Japan including several lectures at OPU and Osaka University but he always took the time to talk to the faculty and students afterwards with words of advice and encouragement. He often emphasized the need to study English and to always have curiosity about the worlds around us.

Michel was not only well known for his excellent work and great contributions to chemistry but also for his great charm, humour, wit and warm character, always making everyone around him laugh. He was thus, greatly loved and admired by everyone who knew him. Even though very important and well known, I was always impressed by his humility, kindness and warmth.

2.5. Michel Che and Russia by Boris Shelimov

met Michel in the spring of 1972 during his visit to Moscow at the Zelinsky Institute of Organic Chemistry in the framework of

Russian-French cooperation in the field of catalysis (CNRS–Academy of Sciences of the USSR). During the discussion with Michel, it turned out that we had common scientific interests. At that time, in the laboratory headed by prof. V.B. Kazansky where I worked, the structure and properties of oxygen anion radicals on the surface of oxide catalysts containing transition metal ions were studied by electron paramagnetic resonance (EPR) techniques. Michel did a similar study in the laboratory of prof. A. Tench in England and had already published several pioneering works in which substantial progress was made in the EPR identification of oxygen radicals through the use of oxygen enriched with ^{17}O isotope. It became clear that we could unite our efforts and experience in a joint project. During my stay in France at the Institute of catalysis (Villeurbanne) in 1972–73, EPR was used to study oxygen-17 containing species adsorbed on vanadium (V) oxide supported on silica and to explore kinetics of oxygen isotopic exchange involving oxygen species on MgO and $\text{V}_2\text{O}_5/\text{SiO}_2$ catalysts.

After a fairly long pause, our contacts with Michel resumed in 1995. At that time, Russian science was in a difficult position. After the collapse of the USSR, funding for research projects from Russian government sources almost completely stopped. Fortunately, foreign colleges came to our aid. They found various ways to support scientists from the former USSR. Michel was working hard to find funding to help me. Finally, I was invited to come to Paris as a CNRS visiting scientist and could join a project aimed at the study of initial steps of the alumina-supported platinum catalyst preparation at the Université Pierre et Marie Curie.

In order to understand the mechanism of Pt deposition during the synthesis of supported catalysts, the compositions of Pt complexes adsorbed on γ -alumina from acidic H_2PtCl_6 solutions and their transformations upon drying, rewetting, and calcination were studied using ^{195}Pt NMR, UV–Vis diffuse reflectance, EXAFS, and Raman spectroscopy.



Fig. 4. At the award ceremony for the Special Honorary Professorship of OPU in October 2009. From far left, Prof. Masakazu Anpo (Vice President of OPU), Prof. Taketoshi Okuno (President of OPU, white a ribbon), Prof. Masaya Matsuoka (center), Prof. Michel Che (with a red ribbon), and Prof. Tsutomu Minami (ex-President of OPU, far right).

Thanks to the initiative and high scientific authority of Michel, research in Russia was also supported by two international grants in the framework of the European organization INTAS (International Association), specially created to support scientific research in the countries of the former USSR. In the first INTAS project (1998–2001) “A new approach to designing transition metal oxide catalysts for selective catalytic reduction of nitric oxide by ammonia, carbon monoxide and hydrocarbons” the teams from Zelinsky Institute of Organic Chemistry of the Russian Academy of Sciences (Moscow), St. Petersburg State University and University of Turin (Italy) participated. In the second project, “Photochemical reactions on the surface of solid oxide catalysts in reaction to air pollution and purification problems” (2004–2007), in addition to the above-listed teams, a Danish team from the Technical University of Denmark (Lyngby) also participated. Both projects were successful and focused on environmental protection. Both projects were initiated, inspired and coordinated by Michel.

In conclusion, I cannot but say that to a large extent the success in working on joint projects was due to Michel's exceptional human qualities. I always admired his brilliant organizational skills, persistence in achieving the goal, hard work and perseverance, high demands on the quality and reliability of experimental results and their clear presentation in publications.

2.6. Michel Che and Poland by Krystyna Dyrek and Zbigniew Sojka

In August 2019 the international catalytic community has lost Michel Che, Professor of the *Université Pierre et Marie Curie* - Paris 6 and *Institut Universitaire de France*, a distinguished international scholar working in the field of surface chemistry, spectroscopy and heterogeneous catalysis. During his long service for science and society, we could admire not only his charming personality and exceptional intellectual and academic qualifications, but also his great human decency, sense of fairness and concern for the less privileged. He just liked people and people liked him.

Professor Michel Che was, by all accounts, not only an exceptional scientific figure for the Polish chemical community but also our sincere friend and benefactor. Since his first stay in Poland, Michel visited us many times, contributing his time and energy to developing abundant scientific contacts and fruitful research cooperation between research institutions of both countries in many capacities. He was the operating force behind the French-Polish Seminars on Catalysis, organized alternately in France and Poland for several decades. These meetings played a groundbreaking role in establishing numerous long-lasting and tight interpersonal relationships, supporting substantially the catalysis research development in Poland at that time. Particularly, cordial and enduring amity tied Michel Che with Adam Bielański (Jagiellonian University) and Jerzy Haber (Institute of Catalysis and Surface Chemistry of Polish Academy of Sciences, the founders of the Krakow School of Heterogeneous Catalysis. In recognition of his activity in this field in 1997, Professor Michel Che received the Maria Skłodowska-Curie and Pierre Curie Award granted jointly by the Polish and French Chemical Societies.

The abiding cooperation in the field of heterogeneous catalysis with the Inorganic Chemistry Department of the Jagiellonian University and the *Laboratoire de Réactivité de Surface*, headed by him for many decades, for the most part, was particularly strong and productive. The effect of this cooperation includes numerous common projects, publications, book chapters, not to mention the frequent PhD student, postdoctoral and the visiting scientist stays of all kinds in his worldwide recognized laboratory. Many of us will always recollect the moments of marvelous and unending discussions with Michel about catalysis, chemistry, science, arts or history. We all felt then very fortunate to know him and work with him.

At times of need, during the martial law in Poland, Michel was always the first one there, much more a friend than just a colleague. Without any doubt he was an enthusiastic supporter of the movement “Solidarność”, organizing innumerable transports of medicaments, nutrition and care commodities for children and people in necessity.

In appreciation of his outstanding scientific merits, and the activity in the field of the human rights Professor Michel Che received in 2000 the *doctor honoris causa* degree of the Jagiellonian University (Fig. 5). In the year 2010 Professor Michel Che was also elected a foreign member of the Polish Academy of Arts and Sciences in Krakow.

Michel left us much too soon, and he will be greatly missed by the Polish community of friends, colleagues and former postdoctoral fellows.

2.7. Michel Che and Italy by Elio Giamello

There are two things that struck me when I met Michel in the early eighties having the opportunity to spend a period in his laboratory. These were first impressions that, however, have not changed over time. The first one was the systematic approach in the organisation of his professional activity, a true and methodical exercise of self-discipline. The second one was the authentic, intense and not formal attention he had towards people entering his professional and friendly sphere.

I first saw Michel when he gave a talk in Torino in the late seventies, however the first true meeting with him was for organizing a stage in his laboratory in 1983. When I arrived in Paris in 1984 Michel was, though rather young, the undisputed leader of the laboratory, “le patron”. His way to organize the work and his own activity was methodical. He had a natural talent for self-organisation in part inherited, according to him, from the example of his friend Antony Tench who was able to schedule his daily work in a rigid manner, one hour per day to the administration, two hours to bibliographic research and so on and so forth. Michel's physical ability to work hard was proverbial. There was a legend circulating among the lab's members: “whenever Michel has an airplane flight in the early morning from Roissy Charles de Gaulle, the airport located in the north of Paris, he, living in Sceaux south of the capital, he spends the night downtown in the lab working and waiting the time to go to the airport”.

The laboratory in Paris was frequently visited by foreign guests from all over the world. In these cases, an invitation in Che's place was never lacking and his wife Danielle, always available with great dedication and generosity, has reason to say that she has hosted and fed the Gotha of the catalysis world along the years.

Michel's co-workers, in particular post-doc and visiting scientists from abroad, often reached a high degree of familiarity with him becoming the target of his constant attention. Michel used to get informed about personal and family life of people belonging to this group of special colleagues. Also the problems of academic life and career of everyone in this large group gradually become Michel's concerns. In more than one case he has shown his interest in the evolution of a professional position directly contacting and soliciting the members of foreign academies. In short, if one entered Michel's inner circle it was forever.

3. Michel Che, as scientific counselor of applied research in catalysis

This section emphasises an aspect of Michel's professional involvement parallel to his endeavours to promote and maintain international scientific collaborations as recollected above. It covers his activity as scientific counselor to two major R&D organizations developing catalytic processes and catalysts, IFPEN and

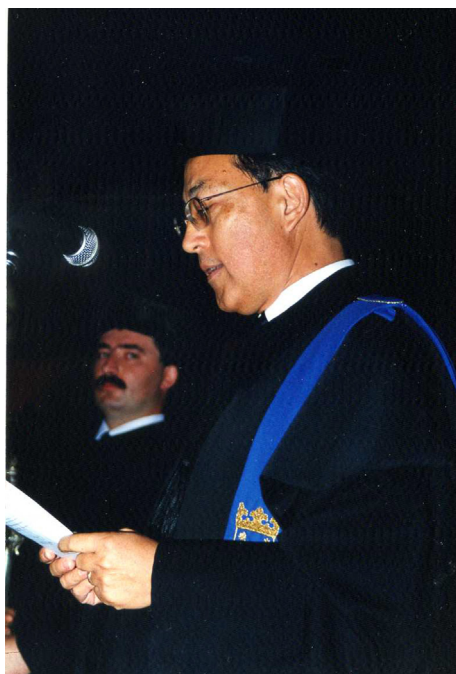


Fig. 5. Professor Michel Che receiving the degree *Doctor Honoris Causa* of the Jagiellonian University in Krakow, Poland, May 2000.

Solvay (formerly, Institut Français du Pétrole, and Rhône-Poulenc, then Rhodia).

Christian Marcilly and Hervé Toulhoat, both retired from IFPEN recall their numerous interactions with Michel over almost 4 decades in the first section. Patrick Maestro, chief Scientific Officer of Solvay Research and Innovation, underlines in the second section the part played by Michel for Solvay, in particular to set up and advise the Solvay research center in Shanghai.

3.1. Michel Che and IFPEN

3.1.1. What is IFPEN, and which are its connections with academic research?

IFP Energies nouvelles (<https://www.ifpenergiesnouvelles.com/>) was founded as Institut Français du Pétrole (IFP) in 1945 by the first post WWII french government, simultaneously with CEA and other applied R&D centers, according to a strategy aiming at the rebirth of and independent french industry, technically as well as financially. IFPEN is therefore a government funded non-for-profit organization, nowadays staffed by circa 1600 professionals on two sites (Rueil-Malmaison near Paris, and Solaize near Lyon). It is however entitled to hold shares of private companies, and the holding IFP Group has interests in upstream as well as downstream businesses of the oil and gas industry, and the advanced automotive transportation sector. Over the years, the aim of IFPEN has been to transfer to industry the technologies developed by its researchers. To reach this objective, fundamental research is essential. IFPEN works with academic partners. Among them Michel Che was very early a major contributor: External Scientific advisor since the early 80's, Director of many PhD thesis, and Mentor for many of its researchers. IFPEN developed a number of significant innovations which provided a basis for the growth of spinoff companies like Technip, Coflexip (now TechnipFMC), or brought to the market by components of IFP group like Axens (<http://www.axens.net>). The latter is a major licensor of process technologies and catalysts manufacturer for the refining and petrochemistry sector worldwide, and therefore of particular interest in the context of

the present contribution. Like the other subsidiaries of IFP Group, Axens is linked to IFPEN by research and licensing agreements, with IFPEN retaining industrial property rights to its results. Agreements set the scope of the collaborative work in compliance with European Union rules. As such, the relationship between IFPEN and its subsidiaries follows business rules, similar to rules governing license agreements with companies that are not part of the Group. Currently, well over 2000 industrial units in the world have been built or revamped under IFPEN license, and use catalysts manufactured on 6 sites (France, Middle East and North America). Worth mentioning is the range of olefin oligomerisation processes catalyzed by transition metal complexes developed over 5 decades by the late Yves Chauvin and his team. Yves Chauvin shared the 2005 Nobel prize in chemistry for having discovered the eponym mechanism of catalytic olefin metathesis. The international action of IFPEN has been very significant since its creation, with for instance the support in terms of staff, know-how and science to create similar organizations in India, Venezuela, Iran, Algeria and Vietnam.

3.1.2. Recollections by Christian Marcilly

I met Michel in the mid 1970s, as a member of several thesis defense committees he was chairing, and which most often took place in the thesis room of the Jussieu campus central tower. I liked very soon this lively and convivial man. Our interactions strengthened at the end of 70's and in early 80's on the occasions of meetings of the zeolites working group, founded by Denise Barthomeuf, then of the Catalysis Division (DivCat) of the Société Chimique de France, co-founded by Michel. All these meetings took place at University Pierre et Marie Curie (UPMC), in the meeting room of the Laboratoire de Réactivité de Surface, the lab of which Michel was then the Director. They were run in a climate of good mood, but very efficiently, following agendas always carefully prepared by Michel.

In 1986, Michel welcomed me in his lab as an Associate Research Director, sent on part-time secondment by IFPEN. During 3 years, until 1989, I shared his office and could appreciate Michel's intense but quiet activity: he led his research teams with competence and a great humaneness. He invited me to attend the weekly presentations of his coworkers, to which were also regularly attending Denise Barthomeuf and Professor Boris Imelik. He also asked me during this period to prepare a postgraduate level lecture on the preparation of catalysts, which I taught for several years at UPMC.

In 1989, I was appointed by IFPEN at the head of a second big project and therefore had to stop my activities of Associate Research Director and my direct collaboration with Michel. It did not prevent me to organize in 1990, at his request, the French-Chinese colloquium of Catalysis in IFPEN premises at Rueil-Malmaison. Between us a strong friendship had developed, actualized by several encounter with our families and regular phone calls. We saw each other again also on the occasions of the periodic meetings of IFPEN Scientific Council, of which both of us were members, as well as catalysis congresses and DivCat workshops. We have spent several days together for the French-Chinese Catalysis Colloquium organized in 1994 in China by Professors Min Enze from RIPP and Li of Beijing University.

After my retirement in 2002, and my move to the Lorraine province, our relations became less frequent, but we stayed in touch each year through season's greetings. Our last encounter took place in 2011 in Lisbon, for the homage to Professor Fernando Ramoa Ribeiro, Rector of the Technical University of Lisbon and Director of the Instituto Superior Técnico (IST). Fernando had passed away a few months earlier: he had prepared his thesis under my supervision in IFP Laboratories in Rueil-Malmaison, with Professor Michel Guisnet from Poitiers University as academic thesis director.

The last news I had from Michel date back to end January 2019 after he returned from a long journey in Asia (Japan and China in particular). I will keep from Michel the memory of a competent and fecund scientist who has left a strong mark on French catalysis. Lately, he developed a passion for the history of sciences, and looked after original publications of great scientists of the past. But this most passionate and demanding scientist was also a cheerful and very generous man, caring regularly about family worries each of his close relations could suffer of, and never hesitating to make himself useful in all circumstances.

3.1.3. Recollections by Hervé Toulhoat

I started my career with IFPEN department of heterogeneous catalysis in 1980, after my doctorate in chemical engineering granted by Paris School of Mines. I was embarked in heavy ends hydrorefining projects with rather short-term goals of developing industrial catalysts. Simultaneously, I was involved in fundamental research actions in collaboration with academic groups, working together with, then supervising PhD students. External scientific advisors like Michel Che were, and still are, invaluable helpful at all stages of these PhD projects, with constructive criticisms of the subjects, their feasibility, the strategy proposed, the choice of academic partner, then in selecting candidate by taking part in interviews, appreciating progress made on the occasion of systematic mid-thesis defenses, or if necessary informal meetings with students and IFPEN and academic co-supervisors, and finally often invited as highly qualified defense committee members.

My first encounter with Michel as a young scientist and PhD co-supervisor took place in the early 80s, and was quite vexing as far as I can remember: indeed, my rather naive sufficiency was publicly and straightforwardly challenged by Michel. Like Lieutenant Hornblower facing his Commodores, if I may dare this literary reference, I fortunately managed after some time to take the good part of it, defend my view, accept the lessons. It was the beginning of a mutual esteem which grew with time and closer interactions.

In the course of my career, I left applied and basic research in catalysis for some years, having accepted to start and manage another research group on physical chemistry of interfaces dealing with wettability and lubrication topics, not catalysis. My connections with Michel were looser in this meantime, but revived crucially with my comeback to our common first love catalysis in 1994 with ambitious projects to harness DFT and other molecular modeling techniques to catalysis research in refining and petrochemistry. My first PhD proposal in this area was adjourned under his fire: I was not so good at diplomacy then ... I discussed in advance my second application the next year with him and it passed. Simultaneously I initiated a sizeable collaborative project in the form of a CNRS virtual laboratory, involving IFPEN, TOTAL, with major academic theoretical chemistry groups in France, Austria (Pr Jurgen Hafner, Vienna), and The Netherlands (Pr Rutgers van Santen, TU Delft). I must say that Michel became soon an enthusiast advocate and constructive critic of this 8 years venture, as new results progressively accumulated in the diverse fields of catalysis by sulfides, by metals, by zeolites, and on important industrial carriers like gamma-alumina. This collaboration contributed to help developing and establish the DFT code VASP (Vienna Ab initio Simulation Program) as the worldwide outperforming standard it is currently for chemistry and materials research at large.

Meanwhile, Michel's actions in favor of IFPEN more traditional and of course unavoidable experimental approaches in catalysis and analytical sciences remained vigorous. Having access to the best students in France (graduated from Ecole Normale Supérieure, Ecole Polytechnique, or ENSCP and ESPCI), and with his talent to motivate ardent young spirits, Michel convinced a number of them to join IFPEN, where they contributed or still contribute with outstanding added value.

In the context of changing legislation in France during the 90's, it became crucial for IFPEN to adapt and reconquer the habilitation to deliver Masters of Science and PhDs for its academic arm, IFP School (<https://www.ifp-school.com/en>). This was a longstanding and complex battle, in which Michel proved himself a precious ally, thanks to his prominent academic position with a leading university (Université Pierre et Marie Curie, Paris 6). An important step was to encourage IFPEN scientists holding a PhD to defend an « Habilitation à Diriger des Recherches » (HdR), now compulsory to supervise PhDs. I was particularly targeted for this quest, and Michel offered me to act as mentor: following his precious advices as well as my obstinate views, I defended with his green light my HdR in December 2002.

At that time, while pursuing my projects in computational catalysis and other applications of molecular modeling, I had accepted three years ago the task to manage IFPEN's relatively modest portfolio of exploratory research projects, spanning in principle the full spectrum of interest for the institute, from applied mathematics to geology, but including catalysis. Then, I was asked to take charge and develop the administration of PhDs at IFP School, a function at the frontier of R&D and academy. During the next 12 years, I had therefore a closer than ever interaction with Michel and the other members of IFPEN's Scientific Council. We met several times a year, in numerous meetings I organized to review thesis projects, recruit candidates, examine students at half-way, etc... His vast experience, up-to-date awareness of advances in catalysis, knowledge of laboratories and academic colleagues was constantly helpful.

To come back to the saga of IFPEN School Habilitation to deliver PhDs, Michel and myself were deeply involved as « sherpas » from both sides to define an agreement of co-habilitation with Université Pierre et Marie Curie. The University President asked IFPEN to conclude first a framework agreement on research collaborations: it was the beginning of three years of negotiations between IP and legal departments of both parties, projects shuttling between presidential cabinets, approvals sought from almost all levels of responsibility inside IFPEN's matrix organization, until early 2009 when chilled Champagne could be uncorked over freshly signed agreements by the Presidents. Such battles are ancillary to science but need to be fought and won. Thanks for that too Michel.

On October 5, 2005, late morning, we were together with three other counselors, reviewing PhDs topics proposed by scientists of the Catalysis and Separation Division, and by coincidence concentrating on a proposal in catalysis by organometallics: then I stopped the discussion abruptly, to announce the incredible news that our emeritus colleague Yves Chauvin had been awarded the Nobel prize together with R.H. Grubbs and R.R. Schrock « for the development of the metathesis method in organic synthesis ». I ran outside to warn colleagues of the department of molecular catalysis, who had all been hired and supervised by Yves Chauvin until his retirement 10 years before, and still had with him frequent contacts. Michel also had kept close ties with Yves, a colleague and friend he greatly respected, and also because they had learned chemistry from the same « alma mater », the Ecole Nationale Supérieure de Chimie de Lyon (now CPE), at about 10 years interval. He was particularly joyful for this recognition, and took a very active part in the organization of the subsequent events in honor of Yves Chauvin in France, in particular under the aegis of the « Société Chimique de France » (Fig. 6).

IFPEN had decided in 2002 to create a prize to reward the best IFPEN funded PhD each year, and it was part of my duty to implement the corresponding procedure with help of scientific advisors, including of course Michel. This prize became the « Yves Chauvin Prize » in 2005 (I had of course to persuade Yves to consent) which greatly added to its prestige among our students (50% French and



Fig. 6. Michel Che and Yves Chauvin at IFPEN Lyon. (2005).

50% from overseas). The competition has been tight so far between disciplines, with demanding criteria in terms of number of publications accepted and patents filed, but Catalysis has been often distinguished, reflecting the traditional excellence of the corresponding research division of IFPEN. Michel accepted to be member of the jury each time candidates with topics in his competence were presented, that is almost each year.

I would like to conclude my testimony by mentioning more personal indebtedness to Michel, like advocating my cooptation as a member of the editorial board of *Journal of Catalysis* in 2005, invitations as keynote speaker in international conferences, invitation to join him and Avelino Corma as the three « conveners » of the theme « chemistry for the environment » of the IUPAC 2019 world chemistry congress in Paris. Last but not least, I owe him to have been warmly welcomed after my retirement from IFPEN in January 2017 as an emeritus co-worker by the Laboratoire de Réactivité de Surface of Sorbonne Université (SU), the laboratory he created and brought to international excellence. Warmly concluding a special event organized at SU in June 2018, Michel retraced my career, and unexpectedly, offered me an original copy of the book “La catalyse en chimie organique” by Paul Sabatier. It was our last encounter. A while before, we had planned enthusiastically new scientific ventures together: they will never happen, sadly.

3.2. Michel Che and SOLVAY

3.2.1. Recollections by Patrick Maestro (with support from Philippe Marion and Stéphane Streiff)

I have been lucky to spend all my career in chemistry, starting with Rhône-Poulenc, then Rhodia, and now Solvay, in groups where science is key for innovation, and understanding what happens in our materials in of paramount importance for the

resolution of problems, development of new products, and acceleration of time to market.

Thanks to these fundamentals of the companies, connection with the external world has always been, not only a priority, but completely included in our purpose. It has thus always been part of our work as industrial researchers to look for the best scientific collaborations worldwide. This has been leading my activity over the years, and allowed me wonderful personal meetings with outstanding scientists and personalities.

Michel Che is definitely part of the top of the tops in this assembly of extraordinary people, not only for his scientific qualities, but also for his human character. The first time I met Michel was around 25 years ago, when I tried to put together around the table different competencies to treat our key problems in catalysis.

I wanted to think “out-of-the box” adding different people to the very good, but somewhat classical at the time, catalysis experts. Indeed it was a risk: it was not obvious that putting together people like Michel Pouchard for solid state chemistry, Jacques Livage for inorganic synthesis, and others, and Michel with his new way of seeing catalysis, would bring something different for our projects. The result was above all what I expected! It went very well because there was a unity between all of them: science at its best.

They analyzed our problems, challenged our teams, and made proposals. And these exchanges led to significant progress and acceleration in our projects, with new ideas and new ways of thinking. This applied to automotive catalysis, oxidation of alkanes, acid catalysis, hydrogenation reactions, etc. . .

Michel was impressive by his willingness to contribute, to listen to his colleagues, and the scientific exchanges were at an unbelievable level, putting our research at a level of challenge we could never have accessed internally only. Michel had developed a



Fig. 7. Michel Che and Bao-Lian-Su signing up at the Solvay China Conference 2017: “Effective catalysis, a Key Driver for a Sustainable Chemistry”.

pioneering way of looking at a catalyst. His approach of surface reactivity was original and risky. He developed a molecular approach of metal complexes, to study surface reactivity and interface phenomena at an unprecedented level, developing new characterization techniques as well. Listening to him explaining the evolution of the catalyst surface during the reaction was not only a way of progressing in our projects, but it was also a pure pleasure, as he was able to put very complex concepts in very simple words. Michel's investigations were at the origin of the understanding of the behavior of a series of catalysts, and led to significant improvements of several of them.

Michel was also a great mentor, unanimously recognized by his students and co-workers. Several of them went to industry, in our company and many others, and several others are now leaders in academia. All are very grateful to have been trained by such a great man.

In the last ten years, we were linked by China! Michel had very close ties with China, the land of his family, and he was one of the first foreign scientists visiting China in the late seventies. He was instrumental in building relationships between Europe and China, and particularly the cooperation between France and China, as a matter of fact, he was awarded the International Cooperation Award of China, the highest Chinese honor for foreign scientists.

When we created of our joint laboratory in Shanghai in 2011, I asked him for support and he enthusiastically accepted to do, creating and strengthening the links with our Chinese partners, while keeping a strong attention and active participation to the scientific challenges and discussions. The Laboratory for Eco-efficient Products and Processes (E2P2L), is now a recognized joint team gathering several participants: Solvay, CNRS, Ecole Normale Supérieure de Lyon, Fudan and East China Normal, East China University of Science and Technology, Poitiers and Lille Universities. This laboratory was set up to address the complexity of the scientific challenges to develop eco-efficient solutions, imposing the combination of a large variety of skills. E2P2L is an open innovation collaborative laboratory addressing cutting-edge academic breakthrough concepts in the field of sustainable chemistry for the

design of eco-efficient processes and sustainable products. We decided to implant this laboratory in China because of the very rapidly increasing quality of its researchers and students represent a huge opportunity both for fundamental and applied chemistry. This was where Michel was key, in the very early days of the project: because of his scientific reputation in China, and of his personal connections, he opened all doors, which resulted in an impressive acceleration of the project! But he was also the president of the scientific committee, gathering highly renowned and complementary scientists to evaluate and challenge the project and its perspectives. It was amazing to see how he conducted the debate, with people as influential as Avelino Corma, Guy Bertrand, Gadi Rothenberg, or Can Li. The level was again extremely high, and our researchers were proud to present their work yearly in front of the highest level of jury they could expect! Owing to this challenge, organized with a masters' hand and exigence by Michel, our laboratory made uncredibly fast progress, and is now recognized worldwide (Fig. 7).

Michel was also a key actor in the setting up of the “French-Chinese conference on Green Chemistry”, organised every two years since 2014, by our friends Yves Queneau, Laurent Bonnevot, Mingyuan He, and Buxing Han. This conference gathers top scientists from both countries to discuss cutting edge technologies in the fields of sustainable chemistry, and are highly appreciated for the level of interactions between mentors and young researchers. Again Michel was an outstanding player in the organization of the conferences, and of the connection he made with Chinese teams.

In addition to his scientific qualities, Michel was a delicious friend, respected for his behavior, always direct, but totally fair and honest. I was relying 100% on him. No risk of listening to him saying something and further doing the reverse. Our conversations were often scientific, but also about many other topics of everyday's life, of history, of our respective personal histories as children of immigrants, of nothing and everything sometimes, always privileged moments, with always a lot of respect, and such a sense of humor.

Our last meeting was in December 2018, at the occasion of the last scientific committee he attended. I will remember how elegantly he passed the President position to Guy Bertrand, his intense participation as a member of the committee, and a wonderful closing dinner in Shanghai, where we shared our wonder in front of the technology and innovation of a drone night show, like only Chinese can do!

We all miss him.

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