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OBITUARY

Michel Bornens (1938–2022), a visionary scientist

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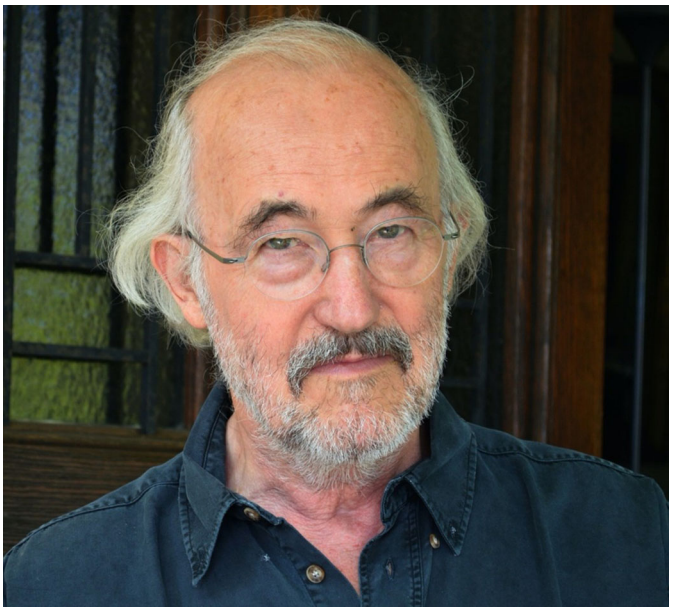
Michel Bornens was born in Paris in 1938 and died there in 2022. After studying at the 'Agro', a thesis at the CNRS in Villejuif and a post-doc in the USA, he worked at the Centre de Cytologie Expérimentale in Ivry sur Seine and then at the Centre de Génétique Moléculaire in Gif-sur-Yvette, before taking part in the setting up of the cell biology department at the Institut Curie in Paris in 1995.

It is 5pm when Michel Bornens returns to the lab. He has gone out to buy Le Monde, which has just arrived at the kiosk next door. He clears off his desk, pulls down the curtains slightly, puts on the music, opens the newspaper wide and starts reading. This image says a lot about Michel. The importance that politics had in his life. His strong commitment to the values of solidarity, sharing and freedom, and to the defence of the common good. And his curiosity about the whole world. It also says that he felt at home in his office.

He did not experience the boundary, so often claimed today, between the private sphere and that of work in the laboratory. Science was an integral part of his life. Above all, he liked to think. He liked to think and imagine the world. Of course, he wanted to understand first and foremost, but his desire to observe and admire was already immense. He was a thinker and a contemplator.

He was curious about everything around him, from the farms of the Jura to the ports of Brittany. He was as enthusiastic about the making of pelardon [a type of cheese] as he was about the building of boats. He was fed by music and painting. And he loved above all to learn the stories. The stories of the craftsmen who make the instruments, of the directors who make the movies or of the farmers who work the land.

His insatiable curiosity led him to be interested in all living organisms. He saw in them, in different forms, the manifestation of the same great principles of life. Michel believed that these principles were at work in every single cell. In the early 1980s, for many researchers, the cell was a bag of enzymes whose targets and function had to be identified. For Michel the cell was a compartmentalised, structured, organised and spatially oriented entity (Fig. 1). The centrosome, by organising the microtubules, had to be somehow linked to the entire intracellular space as well as to its limits, the plasma and nuclear membranes (Fig. 2). The microtubule network could therefore measure and integrate spatial information, concentrate and titrate biochemical information, and then combine all these processes in the regulation of cell behaviour. This is how he contributed to the emergence of cell biology in France.



Michel Bornens

The researchers who worked with him all had fond memories of it. We were both excited to feel that we were part of a team of adventurous explorers and slightly worried that we were quite far from the common frontiers of knowledge. Fortunately, Michel's stature and his ability to share his enthusiasm for the great mysteries of biology were there to reassure us. He encouraged us not only to consider new hypotheses, but also to try out of the ordinary experiments. Thus, Fréderic Tournier injected centrosomes from human lymphocytes into frog oocytes to trigger their parthenogenesis and produce frogs without fathers. Matthieu Piel covered phantoms of enucleated cells with frog egg extracts to study the respective capacities of the two centrioles to organise microtubules. It must be said that Michel guided us by example, having himself had a calf slaughtered by surprise to find out whether the stress of the slaughterhouse was the cause of the alignment of centrioles in the thymus... Fundamental experiments, even if they didn't always look like it. Indeed, from one thing to another, and from unfinished experiments to technological twists and turns, Michel and his team managed to describe nothing less than – the structure and composition of the centrosome as well as a number of key rules on how it regulates the organisation of the microtubule network, the progression of the cell cycle, the orientation of the mitotic spindle, the final stage of daughter cell abscission, the differentiation of the myotubes and the polarisation of the cells in response to the geometry of their adhesive environment.

Michel's thinking went far beyond what could be experimentally tested. He was trying to conceptualise how the cell senses, acts, optimises and progresses in time. As an autonomous entity, an

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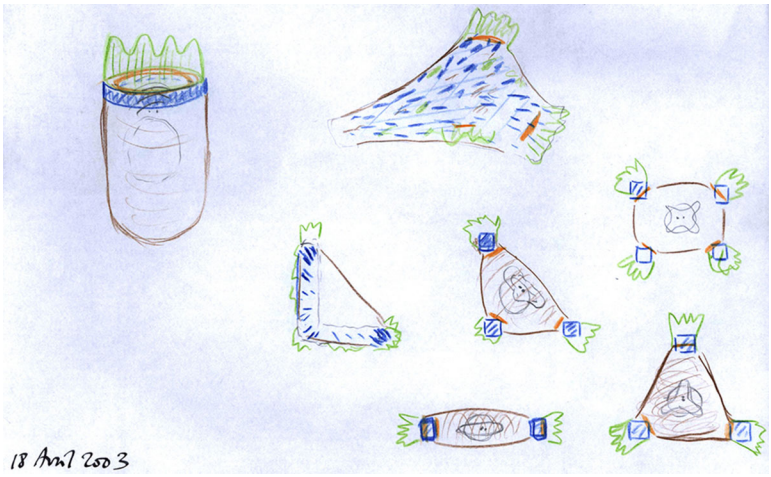

Fig. 1. The cells are structured, compartmentalised and spatially oriented. Cellular adhesions, shown in blue, are the points of mechanical interaction between the cell and its environment. They participate in the establishment of internal borders, represented in orange, which partition the cell. The actin network, drawn in green, is supported by these adhesion points. The centrosome, represented by the doublet of dots, patrols an internal space that is also defined by the position of the adhesion points. Drawn by Michel Bornens in 2003.

organism in its own right, it had to be at all times the product of its history and the preparation of its future in order to function in the present. At any given moment, the structure of the cell and its physiological state – reflected in the expression profiles of proteins and their phosphorylation states – are the consequence of its history. And they predetermine its capacity to react. The adapting cell must be able to take its time and behave differently according to its past experiences. It therefore necessarily has memory and calculation capacities. These functions are key for cells to learn. Little is known about this today. It may seem worrying that there are such gaps in our understanding, and one might be afraid to venture into such obscure areas. But for Michel, it was necessary to confront the limits of our knowledge rather than ignore them – an indispensable condition for setting up the experimental models that would allow us to ask the right questions under the right conditions.

Michel was aware that cellular functions could not be understood by adding up the role of each protein. The number and combinatorial nature of possible interactions quickly became unmanageable. And even if supercomputers made them possible, the classic experiments of gene silencing or overexpression would probably not allow the redundancies and compensation mechanisms that ensure the essential functions of the cell to be taken into account. The problem had to be tackled from another angle. We had to look for another approach that would try to grasp the logic of the functioning rather than the nature of the cogs. It was this strong idea that led him to work with soft-matter physicists who saw adhesion as a form of viscous and dissipative wetting rather than as cooperation between integrins. With Jacques Prost, they proposed support for initiatives that would bring together physicists with biologists from the Institut Curie, and in so doing they developed a concept that later became a standard in international research. Each of these meetings between physicists and biologists was an opportunity to see symmetry breaking, oscillations, and active and dissipative behaviours in cells, and to replace the names of proteins by their role in modulating the corresponding physicochemical parameters, such as adhesion energy, viscosity, resonance frequency or quality factor.

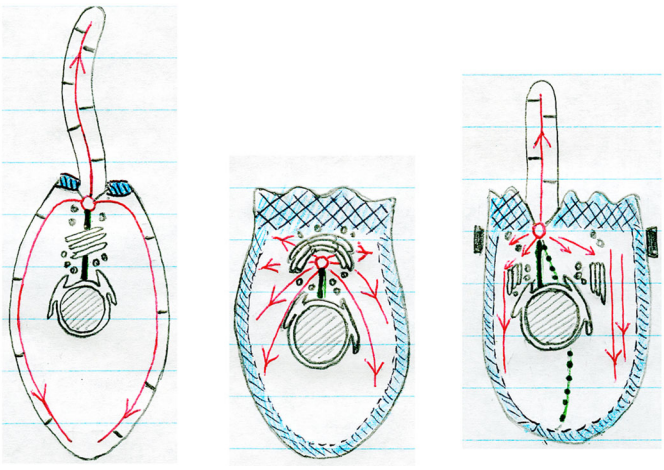

Fig. 2. The rules guiding cell polarity are identical in cells that are swimming (left), crawling (centre) or static and quiescent (right). The actin network is drawn in blue, transport along microtubules is shown in red. The centrosome, at the centre of the microtubule network, integrates spatial and biochemical information throughout the intracellular space. Drawn by Michel Bornens in 2008.

Another of Michel's passions was evolution. For him, it was essential to know the history of our cells in order to understand how they function and interact. Animals, like other multicellular organisms, evolved from single-cell ancestors, and this involved adapting pre-existing mechanisms to new conditions. Michel knew to what extent the study of the mechanisms at work in our unicellular cousins can enlighten us on the functioning of the complex organisms that we are. He had of course given a lot of thought to the joint evolution of the centrosome and the cytoskeleton. He wondered whether the centrosome, as an integration centre capable of organising the sensory perception, locomotion and division of flagellated unicellular organisms, could also regulate the proliferation–differentiation balance and 'individuation' of animal cells.

You won't see any medals or awards in Michel Bornens' curriculum vitae. He didn't need them. He was well aware of who he was and what he was worth, and did not seek reassurance from the recognition of his colleagues. He was self-confident and used the time he saved in seeking awards to explore areas of biology that were still unknown to him. He read widely and attended almost every seminar at the Institute. He took inspiration from all fields of art and science, and his curiosity was boundless. It must also be said that it was a different time. Researchers took more time to look up from their own work. There was less competition between teams for funding, which was provided on a recurring basis by the institutions. Michel fought alongside the researchers who had formed the 'Sauvons la recherche' collective to preserve this way of working

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and for governments to invest in research. For him, knowledge was the best defence against obscurantism and a powerful weapon against inequality.

Michel's personality had a profound effect on the young researchers who met him. He often came to share an anecdote or a comforting personal thought with those who gave their first lectures with emotion. He knew how to find the right and stimulating words to accompany the reflection of the students in thesis juries. He congratulated and encouraged those who came to his office to present their preliminary results. When taken to a microscope or a culture room, he would light up and always find the right word to tell us how satisfied he was, while at the same time asking us the questions that would guide us to the next stage.

Thus, Michel has accompanied biology and biologists with extraordinary enthusiasm. His personal relationship with science has strongly influenced recent developments in cell biology and his imprint will be felt for many years to come.

We thank Didier Job for the helpful discussions when writing this piece. This piece is also posted in French on the website of the French Society for Cell Biology: https://sbcf.fr/en/actualites/.