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Giuseppe (Beppo) Occhialini was born in Fossombrone (Umbria) on 5 December 1907. He spent his childhood and adolescence following his father, Raffaele Augusto, around Italy from one university appointment to the next. Together with (Lord) Patrick Blackett, F.R.S. (P.R.S. 1965–70), his father was to be one of the people who most influenced Occhialini's life and way of thinking. Between 1911 and 1917 the family lived in Pisa; then Beppo (who was at that time still called Peppino) moved to Florence, where he lived with his mother, Etra, until he graduated from university in 1929. In the years that followed he worked at the Institute of Physics of the University of Florence, first as a temporary research assistant and later in a permanent appointment. The seat of the institute was then in Arcetri, very near the observatory and the 'Gioiello', the villa of Galileo's last years. The physics course had been established in Florence only a short time before, thanks to the influence of Antonio Garbasso and Enrico Persico, two charismatic figures in the incredible scientific ferment that was running through the Italy of the 1920s and 1930s. Years later, Beppo's romantic temperament was to recall, of the Physics Institute, that 'the view from those windows made one forget the scantiness of the equipment, the lack of functionality of the convent-like structure and the difficulty of access'. To get to Arcetri, of course, he had to pedal up the hill on his bicycle from Florence.

The Arcetri school of physics was founded in the years during which Occhialini was studying for his degree. Besides the senior professors, it consisted of a group of young researchers, including G. Bernardini, A. Colacevich, L. Emo, G. Racah and Daria Bocciarelli. The influence of Bruno Rossi, who arrived from Bologna in 1928 fresh from university, was especially important for Beppo: in a school made up of enthusiastic and competitive young people, two years could be a sufficient age difference to give rise to a master–pupil relationship. Rossi had just read (and asked his pupil to read) a paper on the origin and nature of cosmic rays. Later, Occhialini was to show him an article written by the already illustrious R. Millikan, the

American physicist who measured the charge on the electron and was an acknowledged opinion-maker in matters of physics the world over. Millikan maintained that cosmic radiation (as he had named what its Austrian discoverer Viktor Hess had simply called *Höhenstrahlung*, radiation from above) consisted of γ-rays. This was a logical hypothesis in the 1920s, because γ-rays from natural radioactivity were the most penetrating radiation known at the time. Forty years later, Occhialini was to initiate γ-ray astronomy in Italy and in Europe. One wonders whether the germ of that idea could be traced back to Millikan's article that he read with Rossi.

As often happens in physics and astronomy, theoretical advances are determined by experimental developments. This was especially true for particle detectors. In addition, the Arcetri school, thanks to the presence of both Rossi and Occhialini, had a strong potential for producing something really new in this field. In those years, starting with Geiger–Müller tubes to detect and count ionizing radiation, Rossi devised an ingenious mechanism for the logical connection of a series of detectors. With the use of this device, a penetrating particle could be followed through various detectors whose signals were selected to coincide in time. The Rossi coincidence circuit, originally invented with valve electronics, soon became a fundamental instrument in all electronic circuits, its scope going well beyond the study of particles or cosmic rays.

Besides working with Rossi on counter-coincidence circuits, Occhialini was already interested in imaging particle detectors. These generate a photograph (or its electronic equivalent) of the particle's physical reality, rendered visible for the first time. At the end of the 1920s the most important instrument in this field was the Wilson chamber, in which tracks left by particles moving in a special gaseous medium could somehow (with a degree of luck) be revealed. Emilio Segrè, a physics Nobel Prize winner, vividly remembers meeting Occhialini for the first time, perhaps in 1929, in Rome: '…two things worried him: how to avoid military service and how to make a one-metre diameter Wilson chamber … an idea which was then considered megalomaniac and rather ridiculous…'.

The first real turning point in Occhialini's life (and coincidentally in physics worldwide) was a trip to England suggested by Bruno Rossi, who was well acquainted with Blackett's work in Cambridge. With a letter of presentation by Rossi and a grant from CNR (Italy's National Research Council), Occhialini left for Blackett's Cavendish Laboratory in Cambridge in 1931. Here he discovered a whole new world, obviously very different from Fascist Italy, already waxing autarchic. The Cavendish Laboratory was one of the cradles of the worldwide revolution that shook physics between 1931 and 1934, with a speed and a depth that is difficult to imagine today. In that short lapse of time, let us not forget, antimatter was predicted and discovered, and the neutron itself was discovered, immediately bringing about a better understanding of the structure of the atomic nucleus and of how it could decay radioactively. Furthermore, the nature of primary cosmic rays was ascertained (thanks to Rossi): this had enormous implications in astrophysics, to be interpreted by Fermi years later. Finally Fermi himself, in Rome, discovered the property of neutrons to induce 'radioactivity' in natural elements; as we now know, this was the first step towards nuclear fission.

In those years of intense and feverish activity, Occhialini worked with passion, knowing that, although not yet 30 years old, he was already one of the leading figures in the scientific scene. He was also conscious of his special gift for developing experimental methods, and also of using and interpreting their results. Soon after his arrival in Blackett's laboratory, he suggested an important modification to the Wilson chamber, which was then used at the Cavendish to detect cosmic rays. The modification consisted of triggering the chamber's expansion to register the passage of a particle no longer at random but only when the two Geiger counters, positioned above and below the chamber, received a 'Rossi style' coincidence signal. This meant making the chamber work only when a particle capable of leaving a track had actually just passed. Thus useful images could be obtained with every expansion of the chamber. Occhialini's modification greatly improved, by a factor of about 1000, the efficiency of Blackett's machine in observing cosmic rays and their interactions.

Blackett immediately understood the importance of the 'controlled' chamber, and in a short time the instrument started collecting useful data. However, the circuitry associated with the Geiger counters still presented difficulties: Blackett recalled that 'to make them work you had to spit on them on a Lent Friday night…'. Finally, they managed to make everything work. Legends abound on what happened then in calm and placid Cambridge. Apparently, Blackett, who was a very serious Navy officer, emerged from the dark room where the photographs from the instrument were developed, shouting, 'One on each, Beppo!': each exposure carried a track that would be useful for physics! Beppo himself, it seems, rushed to the house of Lord Rutherford, who had recently (from 1925 to 1930) been President of The Royal Society and was one of the world's leading physicists, in such a state of exaltation that he hugged the maid who came to answer the door. Notwithstanding his proverbial carefulness in matters financial, Rutherford was so carried away by his enthusiasm for the photos that Beppo showed him that he wrote him a cheque for £50 on the spot…. Who knows whether this is literally true? There are also some negative anecdotes: it seems that Blackett reproached the young Italian for a certain lack of constancy in his work (which later became typical). It seems that Blackett once said, 'Had Occhialini not taken a long holiday, we would have discovered the positron (the positive electron) before Anderson'…. Who knows? In fact, this was the ultimate goal: to be the first group to publish photographic evidence of the positron. C.D. Anderson, in America, beat the Cambridge group by a few months and so earned the Nobel Prize in 1936. Blackett and Occhialini, however, had the satisfaction of being the first to point out the relation between the particle they had also observed (the positive electron) and the antimatter predicted by P.A.M. Dirac's relativistic theory of the electron, which at the time was recent news.

Although he had left for England with the intention of staying for three months, Beppo ended up living in Cambridge for three years. In 1934 he returned to Arcetri, but the political climate was difficult and the institute had changed. Rossi, for instance, was no longer there, having been appointed a professor at Padua. Fascism was becoming more and more important in Italy and was increasing its intolerance with impunity. So Beppo left for Brazil, the great new country that had asked the Italian school for help in developing their physics research. He stayed in Brazil during the difficult war years, from 1937 to 1944. In São Paulo he founded a new school of physics, and also in Rio de Janeiro, where for a year he was a guest in the biophysics laboratory of the great C. Chagas (who won the Nobel Prize in Medicine in 1921).

At the end of 1944, Beppo returned from Brazil to England, where he expected to find employment in war research and was surprised to be refused. (It is easy to imagine the diffidence of the English, tried by a very long war: what does this Italian want, they may well have asked, with his Communist background, and coming from Brazil?) Thanks again to Blackett, he then met and started to collaborate with Cecil Powell (F.R.S. 1949) at the Wills Laboratory in Bristol. Powell was another key figure in Occhialini's life (together with his father, Rossi and Blackett), in the sense that he influenced and shaped Occhialini's way of working in science. Perhaps generations of Beppo's students in Italy absorbed, unknowingly, something of

Powell's (and Blackett's) style. Even in his collaboration with Powell, Beppo managed to leave his mark, with the development of a new experimental technique.

The Bristol group under Powell had launched a new particle detection method: the photographic emulsion, in which charged particles leave a track, as in a photosensitive film. However, the emulsions then available were not sensitive enough for serious physics. With his stubbornness and his intuition, Beppo started again from basics, working with the technicians from the Ilford photographic laboratories. He transformed their emulsion plates into a formidable instrument for detecting and studying elementary particles, about which almost everything remained to be understood. Occhialini immediately thought of cosmic rays, his first love in Arcetri when he worked with Rossi, as the ideal source of high-energy particles. Here he needed to put to some good use some of his adventurous spirit. The war had ended just a year earlier and it was not easy to travel; however, a good exposure to cosmic rays could be obtained only on high mountain tops, higher than could be found in England. So Beppo took advantage of another passion of his, mountaineering, and of an expedition in the Pyrenees, to transport a stack of the new 'Ilford C2' plates to Pic du Midi, more than 3000 metres above sea level. The plates were few, only two dozen, and ridiculously small (2 cm × 1 cm), but they proved sufficient. In Powell's words, 'it was immediately apparent that a whole new world had been revealed …. it was as if, suddenly, an entry had been gained into a walled orchard, where protected trees had flourished and all kinds of exotic fruits had ripened undisturbed in great profusion'.

Apart from Powell's poetic images, it was obvious that the possibility of a whole new physics had opened. Indeed, a few years later, in 1947, the work on the discovery of the π meson and its decay appeared in print. Once again, the discovery of a new particle of great importance for basic physics (Dirac's positron in 1932 and now Yukawa's meson in 1947) had been obtained through a conceptual leap in the experimental method.

In those days, Occhialini discovered not only the pion but also Constance Dilworth, soon to become Constance Dilworth Occhialini. She was a physicist who specialized in emulsions, and in 1948 Beppo moved with her from Bristol (where he had in any case planned to stay for only a few months) to the Free University of Brussels. There he founded and later directed a research group on emulsions, which were made even more sensitive thanks to a collaboration with Kodak, as well as one with Ilford. Work in Occhialini's group was still centred on the study of cosmic rays, which at the time were still used as a source of high-energy particles: accelerators were not competitive yet, although the foundation of CERN (the European Organization for Nuclear Research) was approaching.

In the meantime, Beppo's academic career in Italy was advancing, mediated by his father, who was a professor in Genoa. And so it was in Genoa, not surprisingly, that he was offered his first real position in Italy, a physics chair, in 1950. In fact, Raffaele Occhialini had told everyone squarely that he wanted his son at the University of Genoa. And so another research group was immediately formed in Genoa, with Beppo's first generation of Italian students.

In 1950, still quite young, Occhialini was elected a member of the Accademia dei Lincei. Not long afterwards, in 1951, his father died, undoubtedly happy to have seen his dreams come true for his son. Of course Beppo continued to work in Brussels, as well as in Genoa, developing nuclear emulsions for the study of cosmic rays. In 1952 he was offered a professorship in Advanced Physics at the University of Milan, where the study of particles with the Wilson chamber had long been a reality. Part of the Genoa group moved to Milan, and Beppo assembled yet another research group at Milan University, using his capacity for persuasion and his charisma, which was by then very strong (even though he was only 45 years old). Occhialini also made the best use of the enthusiasm and flexibility that were typical of Italian academic research in those years.

In Milan, Occhialini found a good friend and a valid supporter in Giovanni Polvani, at the time Rector of the university, and the group's activities solidified and diversified. Beppo also continued his collaboration with other countries: he still directed the laboratory in Brussels and he was asked, this time by UNESCO, to organize physics research in Brazil. Back in South America, he again took up studying cosmic rays at high altitudes: he participated in the creation of a laboratory in Chacaltaya, more than 5000 metres high in the Bolivian Andes. Those were to be the last years, before the advent of accelerators, in which cosmic rays remained the only source of energetic particles. However, it was precisely in those years that the emulsion method gave its most beautiful results, pushing researchers to organize great international collaborations. Beppo, naturally, started directing one of those from Milan, and kept in continual contact with Powell.

From Milan, in 1954, a stack of plates, prepared with special care, was sent to be exposed at an exceptionally high altitude. They were entrusted to the Italian expedition that was to conquer the summit of K2 (8611 metres) in the Himalayas. Beppo, we think, would have liked to accompany Ardito Desio, the expedition leader. Desio was a colleague of his and Polvani's at the University of Milan. The stack of plates was diligently carried by the climbers up to a very high altitude on the Abruzzi spur, above 7000 metres. However, the climbers, not especially sensitive to the charms of particle physics, were none too keen on the project, which involved lugging useless weight. Somehow, on the way down after the conquest of the summit, the plates were inexplicably 'forgotten' in a high camp where, the K2 climbers said, 'whoever wants to, can go up and get them'. Presumably they are still up there: one wonders how many cosmic rays they will have collected by now.

Back in Europe, the great adventure of CERN was brought about in Geneva at the beginning of the 1950s, and founded officially in 1954. Decades before the Treaty of Maastricht, and only a few years after the end of a devastating war, the physicists of the leading nations had created the basis for the European Union. Starting from science, Europeans demonstrated that they could work and build together. Moreover, they were soon able first to compete with, and then to surpass, their American colleagues, who had become very strong competition as a result of war research. In this historical and cultural period, which was crucial for Europe, Italian physicists, including Edoardo Amaldi and Occhialini himself, played a very important role. The Milan group switched over to using CERN's artificially accelerated particle beams, thus triggering the decline of research into cosmic rays. Cosmic rays remained still largely mysterious from an astrophysical point of view, but they had been surpassed as an instrument of investigation of the subnuclear structure of matter.

Occhialini (and Connie) went back to cosmic physics a few years later because of a new important connection with Rossi, 30 years after Arcetri. Rossi invited the Occhialinis to Massachusetts Institute of Technology (MIT), where he had for a few years been a leading figure in the growing American space research programme. After a year at MIT, in 1960, Beppo was happy to return to the study of rays, of any kind, coming from the sky. And now for the first time, after Sputnik, they could be directly captured or studied *in situ*. Indeed, detection techniques used on board balloons and satellites fascinated Beppo and Connie so much that, with Rossi, they started investigating how to transfer into space the same methods and ideas that they had originally developed for the study of elementary particles.

Rossi was both an authority on the Earth's particle environment (known today as the magnetosphere) and on cosmic X-rays and γ-rays. Beppo started studying precisely these two topics with his group in Milan at the beginning of the 1960s. Less than 10 years after the foundation of CERN, another great adventure was starting that was again destined to unite scientists from all over Europe: the conquest of space. In 1963 the European Space Research Organization (ESRO) was founded by the same great names in European physics that had been responsible for the creation of CERN, plus, of course, the other charismatic leaders of the space adventure. At the same time, the more engineering and industrial-orientated European Launcher Development Organisation (ELDO, the ancestor to today's Arianespace) started its activity.

The University of Milan group, led by Occhialini, was increasing in both the number of its staff and the importance of its research projects. The group gained support from the CNR and was the first in Italy to start designing and building instruments for use in space, first on balloons and later on satellites. It was an exciting time; everything was still to be discovered. Were there, for instance, neutrons reaching the Earth from the Sun and influencing our atmosphere? Although most of the primary cosmic radiation had been found to be made up of protons, were there also electrons among them? What about positrons? And what of the never forgotten γ-rays (of which Millikan wrote in the 1920s)—were there any at all, coming from the Sun, or from our Galaxy, or from deep space, like the X-rays that Rossi and Giacconi had just discovered? The Milan group attacked all these problems, with Beppo's enthusiasm and energy acting as a motor. His charisma was fundamental in creating opportunities for international collaborations. Occhialini established contacts with the French group of his friend Jacques Labeyrie. Labeyrie had learnt how to divert towards astrophysics some of the effort that General de Gaulle's France was making to develop atomic research at the Centre d'Études Atomiques in Saclay, near Paris. With the French, the Milan group obtained the first successes in the measurement of electrons and γ-rays in balloon flights.

Right from the start, Beppo was conscious of the importance of the ESRO venture, and in 1964 he started taking part in its decision-making and advisory bodies. In 1965, the first payload was approved for the European satellite HEOS-A, and it included an Italian instrument. It was, quite naturally, an instrument that measured electrons in cosmic rays, developed jointly by the groups in Milan and Saclay. Almost at the same time, an instrument built to measure γ-rays from the Sun, and wholly developed in Milan, was approved to be carried by the ESRO satellite TD-1, together with a French–Italian–German instrument for γ-rays from the deep sky. It was a great beginning, in which almost everything was new or still waiting to be invented: from the astrophysics of the mission and the physics and technology of the detectors, which were mostly home-made, right down to the production of some of the parts by industry, which was also just starting its work in space.

In 1966, full of eagerness and excitement, I joined Occhialini's group as an undergraduate and was immediately put to work on the instrument for solar γ-rays for the TD-1 satellite. This gave me ample opportunity to see, and try to absorb, Beppo's tremendous capacity for action from scientific, human and political points of view. After the first successes in space, the Milan group became stronger and bigger, and the university structure, always slightly precarious, was no longer adequate. Fortunately, in those years the CNR was starting to build up its own research laboratories, staffing them independently from universities. In 1970 the Laboratory of Cosmic Physics and Related Technologies was founded, with Beppo as a director and about two dozen researchers and technicians.

Those years were also crucial for the development and construction of COS-B, a great new second-generation space instrument that was conceived exclusively for γ-ray astronomy. In 1970 Occhialini started the project in Milan, in a tight European collaboration: the group in Saclay, of course, plus the Max Planck Institute for Extraterrestrial Physics in Munich (headed by R. Lüst, who later became General Director of the European Space Agency (ESA), the successor to ESRO), the University of Leiden (with H. van de Hulst (For.Mem.R.S. 1991)) and the University of Southampton (with George Hutchinson). With COS-B, as well as other ESRO instruments, Beppo showed how he could work constructively on a supranational scale while mantaining his unique Italian character. COS-B was launched in 1975 and soon became the first great European success in high-energy astrophysics.

The ESA was also founded in 1975, as an agency more attentive than ESRO to applications of space technology to industry in a growing European market. In a rapidly changing Europe this represented a step forward, but perhaps Beppo did not find in it room for the pioneering and fiercely independent spirit that had accompanied him through his life. Beppo never actively became part of the ESA. Meanwhile, in Milan the laboratory was going through a difficult period, owing to the changes that had occurred in the Italian academic world in the beginning of the 1970s. After his election as a Foreign Member of The Royal Society in April 1974, Beppo abandoned his post as Director of the laboratory, thus depriving it of a leadership that would have been essential to consolidate Milan and Italy's presence inside the European scientific community. He continued his scientific activity, of course, with Connie and a few others, but he was no longer there to support or indeed spur on Italian researchers in the European arena. However, he had a great personal satisfaction. In 1981 he was awarded a very important and prestigious prize by the Wolf Foundation in Israel. And perhaps it was not by chance that only a few years later, in 1987, Bruno Rossi and Riccardo Giacconi were also awarded the same prize.

In the years 1972–82 Occhialini took part, albeit indirectly (and inevitably more and more so as time went by) in both political and scientific aspects of the management of the COS-B mission. This was the last action of his as a European scientist. The mission was a great success, both for the quality of the technology on board and for the soundness of its simple management. It was the first mission promoted by the ESA, and it was also the first time that Europe ventured to launch an astronomical observatory into a deep orbit. The mission lasted seven years, more than three times longer than had been initially planned. For the first time, moreover, flight technology included sophisticated detectors and intelligent electronics. Beppo had planned it as a European mission and thus he carried it out, with his incomparable skill in management, based on people, efficiency and scientific exactness—including, of course, his group's publications, which he reviewed for precision of content and sobriety of style with almost obsessive care. The results obtained with the COS-B mission created a new school of European γ-ray astronomy. They also gave the field such a boost that for several years Europe remained ahead of the USA.

It is possible that the outcome of the COS-B mission was not as important as the discoveries of the positive electron or the π meson had been, and certainly Beppo's contribution was not as central. Nevertheless, the discovery of the γ-ray sky was a self-standing and lasting result for a new field such as high-energy astrophysics. Moreover, it taught the Milan group (and, indirectly, Italy) how to build second-generation space instruments in collaboration with industry, and how to interpret and exploit their results.

At the beginning of the 1980s the long development of an Italian national scientific satellite began. Beppo spent more and more time in his retreat in Tuscany, but he emerged to support the idea of SAX, the X-ray astronomy satellite that now bears his name. Two proposals for X-ray astronomy reached the final stage, and the choice between them was not easy. Beppo was officially asked to give his opinion as a member of an *ad hoc* review committee. Significantly, Bruno Rossi was also asked to serve on the same committee. It was the last time, almost 60 years after the first, that the two scientists collaborated professionally. And a worthy end it was for two long careers that, although different in many ways, had been equally brilliant and repeatedly entwined. (They were to pass away within weeks of one another, and years before BeppoSAX finally achieved orbit. The Rossi X-Ray Explorer was flown by NASA shortly after BeppoSAX.) In 1993 the European Physical Society elected Beppo as an Honorary Member: his last and most valuable recognition in life. Occhialini died on 30 December 1993. In the same period Bruno Pontecorvo, a great friend and contemporary of Beppo's, also passed away. A toast of Pontecorvo's, which he sent from the Soviet Union in honour of Beppo's 60th birthday, has become famous: 'I toast all of you, Beppo's friends and pupils, and wish you may collaborate with him in some scientific pursuit: it's a practically sure way of winning the Nobel Prize'.

Much has been said about Occhialini and the Nobel Prize: Blackett won it in 1948, and Powell in 1950, both for work in which Occhialini's contribution had proved to be determining. Why was the prize not shared with Occhialini? Was he too young? This might have been true when he worked with Blackett (Beppo was only 25) but certainly not 15 years later, at the time of Powell's pion. Was it because he was a Communist? Certainly he was no more a Communist than Powell himself, who was one of the few English men who continued to declare himself as such throughout the war. Perhaps an answer could be found in the papers, in Stockholm: 50 years have gone by, and all the main characters of the time have gone. Even the Swedish Academy's strict rules would now permit science historians to examine the transcripts of the discussions and all the relevant documentation.

Acknowledgement

The frontispiece photograph was taken in 1933. (Copyright © The Royal Society.)

Bibliography

A selected list of publications appears on the accompanying microfiche. A photocopy is available from The Royal Society's Library at cost.