THE RECONSTRUCTION OF GIUSEPPE OCCHIALINI'S SCIENTIFIC BIBLIOGRAPHY

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Introduction

The aim of this paper is to present the reconstruction of the scientific bibliography by Giuseppe Paolo Stanislao Occhialini (1907-1993) with some historical comments concerning some aspects of his own scientific production. In the very few and short biographies of him[1] there are no specific indications at all of his bibliography. His life as a scientist[2], as well as his scientific bibliography, can be classified following two different, but almost overlapping, schemes: a quite spontaneous division into chronological periods, and a more awkward subject-depending division.

We can consider as a first bibliographical period the years from 1931 (when he published his first paper in Arcetri) to 1942 (when he published his last paper in São Paulo). Occhialini spent these years[3] in Italy (at the Institute of Physics in Arcetri[4],

[1] The main biographical data about Giuseppe Occhialini are obtained from his own short autobiography, biographical articles, commemorations and necrologies: G. Polvani (1969), «Per i venti anni dal ritorno in Italia di Giuseppe Occhialini», Rendiconti del Seminario Matematico e Fisico di Milano 1969, 39: 11-16; G.P.S. Occhialini (1974), «Occhialini, Giuseppe», *Scienziati e Tecnologi Contemporanei*, 1974, 2: 322-324 (Milano: Mondadori, 1974); E. Fiorini (1985), «Giuseppe Occhialini», *Il Nuovo Saggiatore*, 1985, 1: 18; G.F. Bignami (1994a), «G.P.S. Occhialini (1907-93)», *Nature* 1994, 367: 515; G.F. Bignami (1994b), «Giuseppe P.S. Occhialini (1907-1993)», *L'astronomia*, 1994, 143: 12-13; J. Daintith *et alii* (eds.) (1994), *Occhialini, Giuseppe Paolo Stanislao*, in *Biographical Encyclopedia of Scientists*, 1994, 2: 670 (Bristol: Institute of Physics, 1994); G. Tagliaferri (1994), «Giuseppe Occhialini», *Rendiconti dell'Istituto Lombardo Accademia di Scienze e Lettere*, 1997, 128: 231-240; V.L. Telegdi (1995), *Giuseppe Occhialini 5.12.1907 - 30.12.1993*, Talk presented in Florence, September 11, 1995; A. Russo (1996), «Vita di uno sperimentatore», *Sapere*, 1996, 4: 62-69; G.F. Bignami (2001), *La storia nello spazio* (Milano: Mursia, 2001); G.F. Bignami (2002), «Giuseppe Paolo Stanislao Occhialini», *Biographical Memoirs of Fellows of the Royal Society of London*, 2002, 48: 331-340; V.L. Telegdi (2002), «Giuseppe Occhialini», *Proceedings of the American Philosophical Society*, 2002, 146, 2: 218-222.

[2] During his Milan period, Occhialini was more and more involved in an institutional activity, particularly with respect to the space physics research programmes: J. Krige, A. Russo (2000), *A History of the European Space Agency, 1959-1987. Volume 1: The story of ESRO and ELDO 1958-1973* (Noordwijk: European Space Agency, SP-1235, 2000); J. Krige, A. Russo, L. Sebesta (2000), *A History of the European Space Agency, 1959-1987. Volume 2: The Story of ESA 1973-1987* (Noordwijk: European Space Agency, SP-1235, 2000).

[3] L. Gariboldi (in press), *Giuseppe Occhialini. His Training Years (1907-1934)*, in *History of Physics and Astronomy in Italy in the 19th and 20th Centuries: Sources, Themes, and International Context*, COFIN 2001. L. Gariboldi (2003), *Giuseppe Occhialini: How a Scientist's Migration Affected Cosmic Rays Physics*, Workshop on Migrant Scientists in the Twentieth Century, Milan, June 20-22, 2003.

[4] M. Mandò (1986), *Notizie sugli studi di Fisica (1859-1949)*, in *Storia dell'Ateneo Fiorentino. Contributi di studio* (Firenze: Edizioni Parretti, 1986).

Florence), in England (at the Cavendish Laboratory[5] in Cambridge), and in Brazil (at the University of São Paulo[6], and at the Biophysics Laboratory in Rio de Janeiro). His scientific production pertained to the following subjects: the study and improvement of Geiger-Müller counters starting under the supervision of Bruno Rossi[7]; the invention and development of the controlled cloud chamber[8] with Patrick Blackett[9]; the confirmation of the discovery[10] of the positron[11]; the study of the showers of cosmic rays[12] by means of coincidences telescopes; the invention of a new kind of plane counters to detect uni-directional weakly ionising particles.

As a second bibliographical period, we can individuate the years from 1946 (when he published his first paper with the Bristol group) to 1954 (when he pub-

[5] J. Hendry (ed.) (1984) *Cambridge Physics in the Thirties* (Bristol: Adam Hilger Ltd, 1984).

[6] S. Schwartzman (1978a), «Struggling to be Born: The Scientific Community in Brazil», *Minerva*, 1978, 16, 4: 545-580; S. Schwartzman (1978b), «Science and Higher Education in Brazil: an Historical View», Woodrow Wilson International Center of Scholars, Latin American Program, Working Papers, 1979, April, Number 8; S. Schwartzman (1984), «A Árvore da Ciência», *Ciência Hoje*, 1984, 2, 15: 70-84; M.D. De Souza Santos (1998), *Os precursores da física no Brasil*, in S. Crestana *et al.* (eds.) (1998), *Centros e Museus de Ciência visões e experiências* (São Paulo: Editora Saraiva, 1998): 40-49; A.M. Ribeiro de Andrade (1999) *Físicos, Mésons e Política: a dinâmica da ciência na sociedade* (São Paulo – Rio de Janeiro: Hucitec / MAST, 1999).

[7] B.B. Rossi (1981), «Early Days in Cosmic Rays», *Physics Today*, 1981, 34, 10: 34-41; Mandò (1986), *op. cit.*; M.C. Bustamante (1994), «Bruno Rossi au début des années trente: une étape décisive dans la physique des rayons cosmiques», *Archives internationals d'histoire des sciences*, 1994, 44: 92-115; L. Bonolis (2001), *Bruno Rossi (1905-1993), Enrico Fermi e l'Universo della Fisica* (Milano: Le Scienze, 2002).

[8] P.M.S. Blackett (1948a), *Cloud chamber researches in nuclear physics and cosmic radiation. Nobel Lecture, December 13, 1948*, in *Nobel Lectures, Physics 1942-1962*: 97-119 (New York: Elsevier, 1964); P.MS. Blackett (1969) «The Old Days of the Cavendish», *Rivista del Nuovo Cimento*, 1969, numero speciale: XXXII-XXXIX; M.C. Bustamante (1997), «Blackett's experimental researches on the energy of cosmic rays», *Archives internationales d'histoire des sciences*, 1997, 138: 108-141; P.A.M. Dirac (1984), *Blackett and the Positron*, in Hendry (1984) *op. cit.*: 61-62.

[9] B. Lovell (1975), «Patrick Maynard Stuart Blackett, Baron Blackett, of Chelsea», *Biographical Memoirs of Fellows of the Royal Society*, 1975, 21: 1-115; G.P.S. Occhialini (1975), «Memorial Meeting for Lord Blackett, O.M., C.H., F.R.S. at the Royal Society on 31 October 1974», *Notes and Records of the Royal Society of London*, 1975, 29, 2: 144-146; M.J. Nye (2002), «The Most Versatile Physicist of His Generation», *Science*, 2002, 296 (55-65): 49-50.

[10] C.D. Anderson (1932), «The Apparent Existence of Easily Deflectable Positives», *Science*, 1932, 76: 238-239; C.D. Anderson (1933), «The Positive Electron», *The Physical Review*, 1933, 43: 491-494; C.D. Anderson (1936), *The production and properties of positrons. Nobel Lecture, December 12, 1936*, in *Nobel Lectures, Physics 1922-1941*: 320-325 (New York: Elsevier, 1965); N.R. Hanson (1961), «Discovering the Positron (I)», *The British Journal for the Philosophy of Science*, 1961, 12, 47: 194-214; N.R. Hanson (1962), «Discovering the Positron (II)», *The British Journal for the Philosophy of Science*, 1962, 12, 48: 299-313; N.R. Hanson (1963), *The Concept of the Positron. A Philosophical Analysis* (Cambridge: Cambridge University Press, 1963); M. De Maria, A. Russo (1985), «The Discovery of the Positron», *Rivista di Storia della Scienza*, 1985, 2, 2: 237-286; X. Roqué (1997), «The Manufacture of the Positron», *Studies in History and Philosophy of Modern Physics*, 1997, 28, 1: 73-129.

[11] P.A.M. Dirac (1933), *Theory of electrons and positrons. Nobel Lecture, December 12, 1933*, in *Nobel Lectures, Physics 1922-1941*: 320-325 (New York: Elsevier, 1965); H.S. Kragh (1990) *Dirac. A Scientific Biography* (Cambridge: Cambridge University Press, 1990).

[12] L.M. Brown, L. Hoddeson (eds.) (1983), *The birth of particle physics* (Cambridge: Cambridge University Press, 1983); Y. Sekido, H. Elliot (eds.) (1985). *Early History of Cosmic Ray Studies. Personal Reminiscences with Old Photographs* (Dordrecht-Boston-Lancaster: D. Reidel Publishing Company, 1985); B.B. Rossi (1964) *Raggi cosmici* (Torino: Einaudi, 1964); Q. Xu, L.M. Brown (1987), «The Early History of Cosmic Ray Research», *American Journal of Physics*, 1987, 55, 1: 23-33.

lished one of his last little science papers a few months after the conference in Bagnères-de-Bigorre). Occhialini spent these years in England (at the Wills Laboratory in Bristol with Cecil Powell[13]), in Belgium (at the Centre de Physique Nucléaire of the Université Libre de Bruxelles[14]), and in Italy (at the Universities of Genoa and of Milan). Although Occhialini devoted himself again to the study of cosmic rays, we have to notice a deep change in the kind of instrumentation, the nuclear emulsions[15], the Bristol group discovered the charged π-meson[16] with. The first step of this change had its origin in Rio de Janeiro:

> As soon as Italy signed the armistice, Occhialini contacted again the Brazilian research laboratories, and he started to work in the biophysics laboratory directed by C. Chagas. While he waited to come back to Europe, it was on that occasion that he met a French researcher, C. Leblond, who made physiology experiments with brain tissues that had absorbed radioactive compounds. The phenomenon that attracted Occhialini's attention was the track left by the radioactive material there where it was absorbed. It suggested to him a new way to study elementary particles. By the use of photographic plates with sufficiently thick layers of emulsion, it could be possible to fix the track of the particles that, penetrating into the plates, excited the grains of the emulsion, and to study their physical properties.[17]

Lastly, we can identify a third bibliographical period, limited to the years from 1955 to 1961 (when he signed his last paper). While nuclear emulsions[18] went on being the main instrumentation of detection again, we have to notice a change in the kind of research: from a case of little science to one of big science[19]. Occhialini, as well as all other European physicists engaged in cosmic rays research, was «forced» to take part to some European collaborations[20] – such as

[13] C.F. Powell (1950), *The cosmic radiation. Nobel Lecture, December 11, 1950*, in *Nobel Lectures, Physics 1942-1962*: 144-157 (New York: Elsevier, 1964); F.C. Frank, D.H. Perkins (1971), «Cecil Frank Powell, 1903-1969», *Biographical Memoirs of Fellows of the Royal Society*, 1971, 17: 541-555.

[14] Information about Occhialini's work in Brussels from 1948 to 1964 can be found in: U.L.B. Service des Archives. Dossier académique Occhialini 1P 745.

[15] P. Galison (1997), *Image and Logic. A Material Culture of Microphysics* (Chicago: The University of Chicago Press, 1997).

[16] H. Yukawa (1949), *Meson theory in its developments. Nobel Lecture, December 12, 1949*, in *Nobel Lectures, Physics 1942-1962*: 128-134 (New York: Elsevier, 1964); C.M.G. Lattes (1983), *My Work in Meson Physics with Nuclear Emulsions*, in Brown, Hoddeson (1983), *op. cit.*: 307-310; L.M. Brown, M. Dresden, L. Hoddeson (eds.) (1987), *Pions to Quarks: Particle Physics in the 1950s* (Cambridge: Cambridge University Press, 1987); B. Foster, P.H. Fowler (eds.) (1987) *40 Years of Particle Physics: Proceedings of the International Conference to Celebrate the 40th Anniversary of the Discoveries of the p- and V-Particles, held at the University of Bristol, 22-24 July 1987* (Bristol: Adam Hilger Ltd, 1987); M. Nussenzveig, C. Leite Vieira, F. De Souza Barros (1995), «Cesar Lattes. Modéstia, ciência e sabedoria», *Ciência hoje*, 1995, 19, 112: 10-22; L. Owen (1997), «Discovery of the Pion - 1947», *The CERNCourier*, 1997, 5: 2-5; A.M. Ribeiro de Andrade (1997), *The Socio-Historical Construction of p-meson* (Rio de Janeiro: Museo de Astronomia e Ciências Afins, 1997); Ribeiro de Andrade (1999) *op. cit.*

[17] Archivio Occhialini 7, 1, 1, 5.

[18] M. Baldo Ceolin (2002), «The Discreet Charme of the Nuclear Emulsion Era», *Annual Review of Nuclear and Particle Science*, 2002, 52: 1-21.

[19] L. Gariboldi (2003), *Giuseppe Occhialini: la fisica dei raggi cosmici come «little science» (1931-1949)*, Invited Lecture. LXXXIX Congresso Nazionale Società Italiana di Fisica. Parma, 17-22 September 2003.

[20] M. De Maria, M. Grilli, F. Sebastiani (eds.) (1989), *The Restructuring of Physical Sciences in Europe*

the G-Stack Collaboration and the K-Collaboration – and he played a growing institutional role.

Besides classical bibliographical methods – historical references, primary cross-references, and library research – we could gain useful information with an on-line search[21]. A precious source was also an incomplete index of publications[22] attached to one of Occhialini's *curricula vitae* conserved in Occhialini's Archive, with his own indication of the publications he considered to be the most important ones[23]. This index indicates also four papers with a contribution by Occhialini himself, but not signed by him: in the bibliographical list they are the ones numbered as [55], [58], [59], and [60].

The Papers of the First Period (1931-1942): Arcetri, Cambridge, São Paulo

[1] G.P.S. Occhialini (1931). «Uno spettrografo magnetico per raggi β emessi da sostanze debolmente radioattive», *Rendiconti della Reale Accademia dei Lincei*, 1931, 14: 103-107.
[2] P.M.S. Blackett, G.P.S. Occhialini (1932). «Photography of Penetrating Corpuscular Radiation», *Nature*, 1932, 130: 363.
[3] P.M.S. Blackett, G.P.S. Occhialini (1933). «Some Photographs of the Tracks of Penetrating Radiation», *Proceedings of the Royal Society*, 1933, A 139: 699-727.
[4] J. Chadwick, P.M.S. Blackett, G.P.S. Occhialini (1933). «New Evidence for the Positive Electron», *Nature*, 1933, 131: 473.
[5] G.P.S. Occhialini (1933). «Le recenti ricerche intorno all'elettrone positivo» *La Ricerca Scientifica*, 1933, 1: 372-373.
[6] J. Chadwick, P.M.S. Blackett, G.P.S. Occhialini (1934). «Some Experiments on the Production of Positive Electrons», *Proceedings of the Royal Society*, 1934, A 144: 235-249.
[7] G.P.S. Occhialini (1934). «Il Positrone», *Enciclopedia Italiana* (Roma: Istituto Treccani, 1934).
[8] G. Bernardini, G.P.S. Occhialini (1936). «Il Congresso di Fisica Nucleare a Zurigo», *La Ricerca Scientifica*, 1936: 426-434.
[9] G.P.S. Occhialini (1937a). «Diffusion des rayons gamma du thorium C″», *Réunion internationale de Physique-Chimie-Biologie, Paris, octobre 1937* (Paris: Hermann et C. ed., 1937).
[10] G.P.S. Occhialini (1937b). «La radiazione gamma del Polonio-Berillio», *Rendiconti della Reale Accademia dei Lincei*, 1937, 25: 188-194.
[11] G.P.S. Occhialini (1938). «A Simple Type of Non-Ohmic Resistance for Use with Geiger-Müller Counters», *Journal of Scientific Instruments*, 1938, 15, 3: 97-99.
[12] G.P.S. Occhialini, M. Schönberg (1939). «Sobre uma componente ultra molle da radiação cósmica (I)», *Anais da Academia Brasileira de Ciências*, 1939, 11, 4: 351-355.

and the United States 1945-1960 (Singapore: World Scientific, 1989); A. Russo (2000), *Le reti dei fisici. Forme dell'esperimento e modalità della scoperta nella fisica del Novecento* (Pavia: La Goliardica Pavese, 2000).

[21] Particularly, for the Brazilian period, see the Leite Lopes Virtual Library: www4.prossiga.br/lopes/

[22] Archivio Occhialini 7, 1, 1, 5.

[23] They are: Blackett, Occhialini (1933) [3]; Chadwick, Blackett, Occhialini (1934) [6]; Powell, Occhialini, Livesey, Chilton (1946) [24]; Lattes, Muirhead, Occhialini, Powell (1947) [25]; Lattes, Occhialini, Powell (1947a) [27]; Lattes, Occhialini, Powell (1947b) [28]; Dilworth, Occhialini, Payne (1948) [34]; Bhowmik *et al.* (1959a) [56].

[13] Y. Monteux, G.P.S. Occhialini (1940). «Sur un nouveau type de compteurs plans (I)», *Anais da Academia Brasileira de Ciências*, 1940, 12, 2: 125-129.
[14] G.P.S. Occhialini (1940a). «Contributo allo studio dell'effetto di latitudine per gli sciami», *Anais da Academia Brasileira de Ciências*, 1940, 12, 1: 39-44.
[15] G.P.S. Occhialini (1940b). «Sull'effetto di latitudine degli sciami», *La Ricerca Scientifica*, 1940: 231-234.
[16] G.P.S. Occhialini (1940c). «Sur la radioactivité beta du rubidium», *Anais da Academia Brasileira de Ciências*, 1940, 12: 155.
[17] G.P.S. Occhialini, M.D. De Souza Santos (1940). «Effetto dell'eclissi totale di sole del 1° ottobre sull'intensità della radiazione cosmica», *La Ricerca Scientifica*, 1940: 792.
[18] G.P.S. Occhialini, P.A. Pompéia, J.A.R. Saboya (1940). «Nota sobre a estabilização de tensão em corrente alternada», *Anais da Academia Brasileira de Ciências*, 1940, 12, 4: 349-352.
[19] G.P.S. Occhialini, M. Schönberg (1940). «Sobre una componente ultra molle da radiação cósmica (II)», *Anais da Academia Brasileira de Ciências*, 1939, 12, 3: 195-202.
[20] G.P.S. Occhialini (1941). «Contributo allo studio della componente ultramolle della radiazione cosmica», *La Ricerca Scientifica*, 1941: 1193-1195.
[21] G.P.S. Occhialini, M.D. De Souza Santos (1941a). «On a Method of Recording Random Events», *Anais da Academia Brasileira de Ciências*, 1941, 13: 57.
[22] G.P.S. Occhialini, M.D. De Souza Santos (1941b). «Two Useful Gadgets for Controlled Wilson Chambers», *Anais da Academia Brasileira de Ciências*, 1941, August 8.
[23] G.P.S. Occhialini (1942). «Metodo per la stabilizzazione di alte tensioni», *La Ricerca Scientifica*, 1942: 319-321.

These papers can be classified into two groups: most of them concern the study of elementary particles, both cosmic rays and particles ejected from radioactive compounds, while a few of them regard more strictly the technological development of the detection devices following the German and Florentine tradition of Geiger-Müller counters, such as in the study of the stability of the counters with non-ohmic resistances over 10 GΩ. Occhialini decided to develop Cosyn's technique of saturated photocells, instead of his first proposal of thermionic valves.

In any case, they are definitely typical papers of a little science physics, as it was shortly described by Blackett:

> In those days the work in the Cavendish was small science. Experiments were, on the whole, done by one person who built most of his own apparatus himself. There were some 30 research students and about 1 1/2 mechanics.[24]

In this first period, we have to put in evidence Occhialini's fundamental contribution to the invention of the controlled cloud chamber and its application to the study of cosmic rays:

> For it was certainly his arrival in Cambridge which stimulated my embarking on the field of cosmic rays which I have never left. And our work together in 1932-33 was a real collaboration of the happiest kind.[25]

[24] Blackett (1969) *op. cit.*: XXXIII.
[25] Blackett (1948) letter from Patrick Blackett to Augusto Occhialini, 21st November 1948-Archivio Occhialini 1, 1, 3.

One bibliographical problem concerns the paper [22]. It is listed in the above-mentioned attach to Occhialini's *curriculum vitae* with its relative bibliographical indication, but it is not found in the *Anais da Academia Brasileira de Ciências*[26]. In Occhialini's Archive there is only one other mention of that paper, but it cannot help us anyway: it is a letter written by Mary Horder of the University of Bristol to Augusto Occhialini on occasion of the competitive examination for the chair of Superior Physics at the University of Cagliari:

> I have just had a letter from your son, asking me to look through his papers. I send certain papers to you. I have found three of those he asks for, but not the fourth, which is «Two Useful Gadgets for Wilson Chamber». I am sending the other three hoping they are the right ones. There are many people who feel that Bristol is a poorer place now that your son has gone away.[27]

The Papers of the Second Period (1946-1954): Bristol, Brussels, Genoa, Milan

[24] C.F. Powell, G.P.S. Occhialini, D.L. Livesey, L.V. Chilton (1946). «A New Photographic Emulsion for the Detection of Fast Charged Particles», *Journal of Scientific Instruments*, 1946, 23, 5: 102-106.

[25] C.M.G. Lattes, H. Muirhead, G.P.S. Occhialini, C.F. Powell (1947). «Processes Involving Charged Mesons», *Nature*, 1947, 159: 694-697.

[26] C.M.G. Lattes, G.P.S. Occhialini (1947). «Determination of the Energy and Momentum of Fast Neutrons in Cosmic Rays», *Nature*, 1947, 159: 331-332.

[27] C.M.G. Lattes, G.P.S. Occhialini, C.F. Powell (1947a). «Observations on the Tracks of Slow Mesons in Photographic Emulsions. Part 1», *Nature*, 1947, 160: 453-456.

[28] C.M.G. Lattes, G.P.S. Occhialini, C.F. Powell (1947b). «Observations on the Tracks of Slow Mesons in Photographic Emulsions. Part 2», *Nature*, 1947, 160: 486-492.

[29] G.P.S. Occhialini, C.F. Powell (1947a). «Multiple Disintegration Processes Produced by Cosmic Rays», *Nature*, 1947, 159: 93-94.

[30] G.P.S. Occhialini, C.F. Powell (1947b). «Nuclear Disintegrations Produced by Slow Charged Particles of Small Mass», *Nature*, 1947, 159: 186-190.

[31] G.P.S. Occhialini, C.F. Powell (1947c). «The Scattering of Fast Neutrons by Protons», *Philosophical Society of Cambridge Conference Report*, 1947: 150.

[32] G.P.S. Occhialini, C.F. Powell (1947d). *Nuclear Physics in Photographs* (Oxford: Clarendon Press, 1947).

[33] W.J. Bates, G.P.S. Occhialini (1948). «Applications of the Reflecting Microscope to the Nuclear Plates Technique», *Nature*, 1948, 161: 473.

[34] C.C. Dilworth, G.P.S. Occhialini, R.M. Payne (1948). «Processing Thick Emulsions for Nuclear Research», *Nature*, 1948, 162: 102-103.

[35] C.C. Dilworth, G.P.S. Occhialini, E. Samuel (1948). «Eclaircissement des plaques photographiques», *Bulletin du Centre de Physique Nucléaire de Bruxelles*, n° 2, Août 1948.

[36] C.M.G. Lattes, G.P.S. Occhialini, C.F. Powell (1948). «A Determination of the Ratio of the Masses of π- and μ-Mesons by the Method of Grain-counting», *Proceedings of the Physical Society*, 1948, 61, 2: 173-183.

[26] O. Freire Jr. (2003) personal communication.

[27] Horder (1948) letter from Mary Horder to Augusto Occhialini, 27th August 1948 - Archivio Occhialini 1, 1, 3.

[37] G.P.S. Occhialini, C.F. Powell (1948b). «The Artificial Production of Mesons», *Nature*, 1948, 161: 551-552.
[38] G.P.S. Occhialini, C.F. Powell (1948c). «Observations on the Production of Mesons by Cosmic Radiation», *Nature*, 1948, 162: 168-173.
[39] M.G.E. Cosyns, C.C. Dilworth, G.P.S. Occhialini (1949). «Obturateur thermique pour plaques nucléaires», *Bullettin du Centre de Physique Nucléaire de Bruxelles*, n° 6, Janvier 1949.
[40] M.G.E. Cosyns, C.C. Dilworth, G.P.S. Occhialini, M. Schönberg (1949). «Double Stars with Relativistic Particles from Cosmic Rays», *Nature*, 1949, 164: 129-131.
[41] M.G.E. Cosyns, C.C. Dilworth, G.P.S. Occhialini, M. Schoenberg, N. Page (1949). «The Decay and Capture of μ-Mesons in Photographic Emulsions», *Proceedings of the Physical Society*, 1949, 62, 12: 801-805.
[42] G.P.S. Occhialini (1949). «On the Identification of High Energy Particles in Electron Sensitive Plates», *Supplementi al Nuovo Cimento*, 1949, 3: 413-428.
[43] C.C. Dilworth, G.P.S. Occhialini, L. Vermaesen (1950). «On Processing Nuclear Emulsions. Part I. Concerning Temperature Development», *Bullettin du Centre de Physique Nucléaire de Bruxelles*, n° 13a, Février 1950.
[44] A. Bonetti, C.C. Dilworth, G.P.S. Occhialini (1951). «On Processing Nuclear Emulsions. Part II. After Development Techniques», *Bullettin du Centre de Physique Nucléaire de Bruxelles*, n° 13b, Mars 1951.
[45] A. Bonetti, G.P.S. Occhialini (1951). «Cylindrical Emulsions», *Il Nuovo Cimento*, 1951, 8: 725-727.
[46] G. Meulemans, G.P.S. Occhialini, A.M. Vincent (1951). «The Wire Method of Loading Nuclear Emulsions», *Il Nuovo Cimento* 1951, 8: 341-344.
[47] A. Bonetti, C.C. Dilworth, M. Ladu, G.P.S. Occhialini (1954). «Misure in lastre nucleari», *Rendiconti dell'Accademia Nazionale dei Lincei*, 1954, 17: 311-314.
[48] A. Bonetti, G.P.S. Occhialini (1954). «Technique of Nuclear Emulsions», *Supplementi al Nuovo Cimento*, 1954, 2: 222-227.
[49] C.C. Dilworth, G.P.S. Occhialini, L. Scarsi (1954). «Heavy Mesons», *Annual Review of Nuclear Science*, 1954, 4, 40: 271-314.

The papers of the second period are heavily devoted to the study and application of nuclear emulsions. As we noticed before, Occhialini was involved in this detection technique in Rio de Janeiro, but he definitely applied to it when he went to Bristol, where he joined the Powell group connected to the Ilford Ltd[28] and the Kodak. Both his work in the first and the second period lead to fundamental studies on a new elementary particle, in the latter case the charged π-meson. His role was recognised with the award of the Boys Prize by the Physical Society:

> It gives me great pleasure to inform you that at its meeting on 28th April the Council of the Physical Society unanimously agreed that the sixth (1950) Charles Vernon Boys Prize be awarded to you.[29]

[28] Ilford Ltd (1954) *Ilford Nuclear Emulsions* (Ilford: Ilford Ltd, 1954).

[29] Wynne (1950) letter from C.G. Wynne to G. Occhialini, 1st May 1950 – Archivio Occhialini 1, 1, 5. Unfortunately, no documents about this award are still kept in the Archives of the Physical Society, now at the Institute of Physics in London.

Dr. Occhialini is distinguished by his close association with two major developments in the physics of fundamental particles, namely, the counter-controlled cloud chamber and its application to the study of pair production, and the nuclear emulsion technique leading to the identification of π- and μ-mesons [...]. The remarkable achievements of this work are well known and represent the most outstanding discovery in the physics of fundamental particles in the post-war period; it was largely due to Occhialini's enthusiasm and drive that the preliminary technique was so quickly and effectively developed.[30]

Although we can consider this second period still a little science time, we have to stress some aspects that lead cosmic rays physics towards a big science structure:

- the growing number of researchers and assistants involved;
- the internationalisation of the various groups of research;
- the faster technological development;
- the shift from a university laboratory to groups of laboratories;
- a functional communication network among the researchers;
- the abandonment of the model of a world made of simple elementary particles interacting only by electromagnetic forces, with the establishment of a new sub-discipline, «particle physics»[31].

This peculiar change suggests a shift in the research paradigms from a post third scientific revolution one to a fourth scientific revolution one[32].

The growing collaboration among the researchers was at the origin of a new kind of bibliographical problem, typical of a science evolving to a big science practice:

As for the collaboration they can criticise, but you cannot do physics now if not in collaboration.[33]

The task of film exposure, observation, and interpretation was distributed over many individuals (and groups). Who would count as an author?[34]

The Papers of the Third Period (1955-1961): Milan

[50] G-Stack Collaboration (1955). «On the Composition of the K-Particle Decay Spectrum», *XLI Congresso Nazionale SIF*, Pisa giugno 1955, 235.

[51] J.H. Davies, D. Evans, P.E. Francois, M.W. Friedlander, R. Hillier, P. Iredale, D. Keefe, M.G.K. Menon, D.H. Perkins, C.F. Powell, J. Bøggild, N. Brene, P.H. Fowler, J. Hooper, W.C.G. Ortel, M. Scharff, L. Crane, R.H.W. Johnston, C. O'Ceallaigh, F. Anderson, G. Lawlor, T.E. Nevin, G. Alvial, A. Bonetti, M. Di Corato, C. Dilworth, R. Levi Setti, A.

[30] Nature (1950) pre-print to G. Occhialini, 15th July 1950 - Archivio Occhialini 5, 2, 6.

[31] Galison (1997) *op. cit.*: 230.

[32] See: I.B. Cohen (1985) *Revolution in Science* (Cambridge: Harvard University Press, 1985).

[33] Occhialini (1948) letter from Giuseppe Occhialini to Augusto Occhialini, 28th April 1948 - Archivio Occhialini 1, 1, 2.

[34] Galison (1997) *op. cit.*: 232.

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[53] G-Stack Collaboration (1956). «Observations on Heavy Mesons Secondaries», *Supplementi al Nuovo Cimento*, 1956, 1: 398.

[54] G.P.S. Occhialini (1957). «Possible Ways to Improve the Nuclear Emulsion Situation», *Premier Colloque de Photographie Corpusculaire*, Strassbourg, 1957.

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[57] B. Bhomwik, D. Evans, D. Falla, F. Hassan, A.A. Kamal, K.K. Nagpaul, D.J.J. Prowse, M. René, G. Alexander, R.H.W. Johnston, C. O'Ceallaigh, D. Keefe, E.H.P. Burhop, D.H. Davis, R.C. Kumar, W.B. Lasich, M.A. Shaukat, F.R. Stannard, M. Bacchella, A. Bonetti, C.C. Dilworth, G.P.S. Occhialini, L. Scarsi, M. Grilli, L. Guerriero, L. Von Lindern, M. Merlin, A. Salandin (1959b). «The Interaction of K^- Mesons with Photographic Emulsion Nuclei. Part II. The Emission of Hyperons from K^- Interactions at Rest», *Il Nuovo Cimento*, 1959, 14, 2: 315-364.

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In this third period, the evolution of cosmic rays physics to big science was closed:

In Europe, the idea to realise large international collaborations to check large quantities of plates of nuclear emulsions exposed to cosmic rays prevailed. The scientific collaboration and the strong solidarity ties among the «cosmiciens» played for the community of the European physicists an analogous role to the one that the Manhattan Project played for the American physicists.[35]

The early fifties were also the time when accelerating machines more and more took the place of cosmic rays as the main source of elementary particles whose properties were to be investigated:

> The G-stack project represented the extreme tentative of the European *cosmiciens* to defeat the large machines across the Atlantic Ocean, an extraordinary collective enterprise that marked the most important moment of the scientific season that began in the difficult post-war years.[36]

While, after the mid-fifties, most of the European *cosmiciens* adapted themselves to the new situation and studied the elementary particles with the accelerating machines, mainly at the CERN[37], Occhialini, instead, became a leader in the new astrophysical studies in cosmic rays physics, playing a fundamental role in the birth of the European space physics scientific organisations.

[35] Russo (2000) *op. cit.*: 261.

[36] Russo (2000) *op. cit.*: 299.

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