ENRICO FERMI AND ETTORE MAJORANA: SO STRONG, SO DIFFERENT

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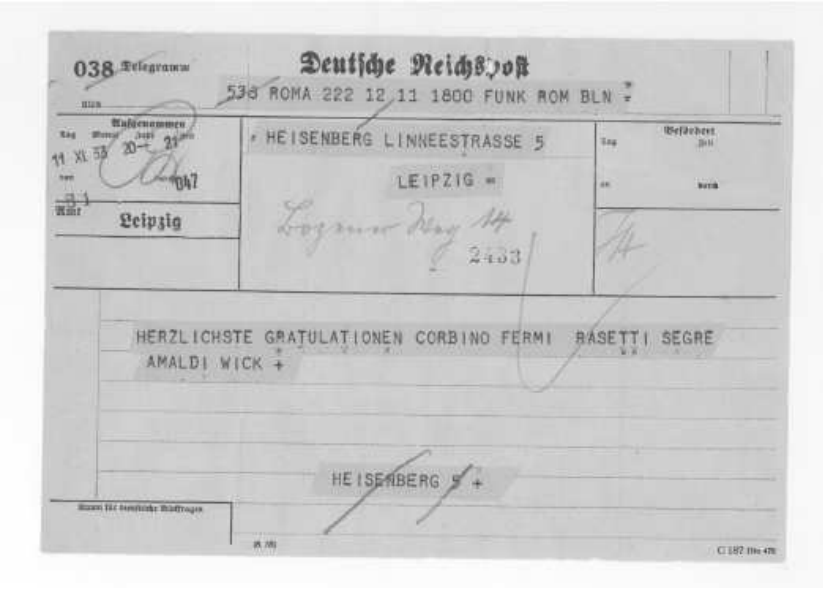
Abstract
By exploiting primary sources we will analyze some of the aspects of the very complex relationship between Enrico Fermi and Ettore Majorana, from 1927 (first contacts of Majorana with the Institute of Physics of Rome, and with Fermi) until 1938 (disappearance of Majorana). The relationship between Fermi and Majorana can not be interpreted in the simple scheme Teacher-Student. Majorana, indeed, played an important role in the development of research in Rome in the field of the statistical model for the atom and in nuclear physics.

Our current research concerns the development of Nuclear Physics in Italy in the Thirties of XXth Century, and is based exclusively on primary sources (archive documents, scientific literature printed on the journals of the time, and so on). In this framework, we will try to outline some aspects of the complex topic concerning the relationship between Enrico Fermi and Ettore Majorana. Of course, this paper will touch only some of the most important issues. For convenience, our exposure will be connected to a periodization of Majorana scientific activity, which we used in previous works.
One of our important results is the reassessment of the role played by Majorana for the decisive orientation of the research in Rome (statistical model of the atom, nuclear physics). This role is obscured in discussions which place emphasis on the (alleged) "genius" of Majorana, usually associated with his (alleged) "lack of common sense". Perhaps we could summarize, in a very concise and expressive manner, the nature of the relationship between Majorana and Fermi, and in general the Physical Institute of Rome, presenting these two important documents stored in the "Archive Heisenberg", at the Max Planck Institute of Munich.
On November 9, 1933, the Sweden Academy of Sciences announced that the Nobel Prize for Physics for the year 1932 was awarded to Werner Heisenberg. Immediately, all the exponents of world culture send their congratulations, in various forms. Heisenberg stored in a folder of his personal archive all received messages. Among them, a telegram by the Deutsche Reichspost, from Rome and dated 11-XI-33 (Fig.1) written in a very cold and formal style, in German: "MOST CORDIAL CONGRATULATIONS CORBINO FERMI RASETTI SEGRE AMALDI WICK"
We note the order of signing according to the close rank of academic seniority at the Institute of Physics in Rome (Orso Mario Corbino, Enrico Fermi, Franco Rasetti, Emilio Segre', Edoardo Amaldi, Gian Carlo Wick).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HERZLICHSTE GRATULATIONEN CORBINO FERMI RASETTI SEGRE AMALDI WICK
HEISENBERG

Fig.1. "Roma" Congratulations (Heisenberg Archive, Max Planck Institut, Munchen)

Ettore Majorana (who is in Rome) is not included in the list, not even at the very last place. But Majorana, who had left Leipzig in early August, sends his "Gratulationen", according to his style. He sends a small personal business card, dated Rome, 11.11.1933 (Fig. 2) with the title "Dr." canceled by hand, written in a poignant Italian. It is a very intense letter.
“Dear Professor, Let me (if you have not forgotten me !) allow to express my greetings on the occasion of the new formal recognition of your prodigious work. With deep admiration
Yours Ettore Majorana”.

Fig.2 Majorana Congratulations (Heisenberg Archive, Max Planck Institut, Munchen)

1.The formation years until the doctoral degree (1929)

The scientific research activities of Ettore Majorana develop immediately at the highest international standard, while it is still a university student at the School of Engineering, in 1928.
His first research concern the applications, the improvement, and the extension of the statistical model for atoms, introduced by Enrico Fermi at the end of 1927, only few months before! (Fermi 1927). This model is now known as the “Thomas-Fermi model”.
As it is well known, Enrico Fermi was called as full Professor in Theoretical Physics in Rome in 1927, through the effort of the Director of the Institute Orso Mario Corbino to develop advanced modern physics in Rome. The main Fermi achievements concern: the so called “Fermi-Dirac statistics”, the statistical model for the atom, the theory of weak interactions, the discovery of the neutron-induced radioactivity, the effect of the slowing down of neutrons, (after the 1938 Nobel Prize and the emigration to the U.S.A.) the atomic pile, the Manhattan project, the elementary particle physics, the computers, and so on).
The first involvement of Majorana on the statistical model subject is a paper in collaboration with his friend Giovanni Gentile jr., published on the Proceedings of the “Accademia dei Lincei”, presented on July 24th, 1928 by Orso Mario Corbino. (Gentile, Majorana 1928).
They calculate the splitting of the spectroscopic energy levels due to the hypothesis of the spinning electrons as recently developed by Dirac. It is a well received paper, developed completely in the frame of Fermi aproach.
Then Majorana continues his research alone, with full autonomy and effectiveness.
He proposes an improvement of the model (he changes the expression of the effective potential acting on the optical electron) and includes also positive ions (it is the first treatment made). Some of the results are communicated to the XXII General Meeting of the Italian Society of Physics (Rome, 28-30 December 1928).

At that time Majorana was still a student, and had recently officially moved from Engineering to Physics. The communication was presented by Majorana in front of an audience of famous Physicists and Mathematicians, as O.M. Corbino, T. Levi Civita, V. Volterra, G. Polvani, Q. Majorana, A. Carrelli, E. Fermi, (he was not a timid person!)
This communication is regularly published on “Il Nuovo Cimento”, the Journal of the Society (Majorana 1929), but it has been never mentioned in any scientific paper, nor by any of the many historians who wrote on the life and activity of Majorana. Historical analysis is in a paper by F.G. and N.R. (Guerra, Robotti 2008). The acknowledgements are very interesting: “The A. thanks Professor Fermi, for the advice and suggestions around new applications of this statistical method that has thrown much light on the atomic physics, and whose fertility, appears far from exhausted, still waiting to be ventured into investigation of fields of larger scope and more full of promise. "
The results contained in Majorana notebooks (at Domus Galiaeana in Pisa) and in the communication show that Majorana reached a fully developed scientific personality, completely independent from Fermi. However, Majorana does not publish the results announced in the communication, nor the other results contained in his notebooks. An enlarged paper on the subject would have given a complete representation of the statistical model, his applications and extensions. As a matter of fact, Majorana does not work anymore on these subjects.
Fermi convinces himself of Majorana improvement only in late 1933 and puts it at the basis of the monumental conclusive paper of the Rome School, co-authored by Fermi and Amaldi in 1934, without any reference to Majorana (Fermi, Amaldi 1934). It is amazing to note that all formulas of the general Fermi-Amaldi paper (1934) coincide with the corresponding formulas of Majorana communication (1929).
Majorana earns his doctoral degree in Physics (July 6th, 1929) with a Thesis on Nuclear Physics (with the title "On the mechanics of radioactive nuclei"). Fermi is the supervisor. Majorana Thesis is the first work on Nuclear Physics in Rome, and also in Italy. Majorana gives a rigorous justification to Gamow model of alpha decay based on the quantum tunnel effect. Anyway, even if original and internationally competitive results are achieved, they are not published.

2. From the doctoral degree to the private professorship (1929-1932)
After graduating a short period of silence: he does not deal at the moment with Nuclear Physics, but maturates new lines of research (Atomic Physics, Molecular Physics and Elementary Particle Physics) in complete autonomy from Fermi (which deals with Quantum Electrodynamics and Hyperfine Structure of Atomic Spectra).
Then follows a very intense activity, oriented toward the “Il Nuovo Cimento”.
Between the end of 1930 and January 1931 there are ready two papers (Majorana 1931 A, B) on the quantum explanation of the chemical bond (formation of Helium molecular ion and Hydrogen molecule). The first is presented by Corbino at Accademia dei Lincei, December 7, 1930: "I warmly thank Professor Enrico Fermi, who gave me precious advice and aid” .
Majorana becomes a pioneer in Theoretical Chemistry (this discipline will develop in Italy only in the 50s of XX Century).
In 1931, other two papers will be published, this time in Spectroscopy. Majorana provides a theoretical interpretation of two new lines of Helium, recently discovered (Majorana 1931 C) and some triplets of calcium (Majorana 1931 D). These two works are appreciated as elegant examples of applications of group theory. In reality they have a direct physical interest: for the first time the role of the phenomenon of self-ionization of atoms is recognized in Spectroscopy.
Follows a very important work (published in 1932): "Atoms oriented in magnetic field" (Majorana 1932 A). In this paper, he proposes an optimal arrangement of the magnetic field to show the sudden flip in the spatial quantization of the spin of atoms, and other related effects. This arrangement is immediately adopted with great success in the laboratory of Otto Stern in Hamburg (where there is temporarily Emilio Segrè). Majorana gives the “Announcement” (never quoted in Literature), in the Journal “Ricerca Scientifica” (Majorana 1932 B), so as to publicize immediately his results and have priority of discovery!
Then the fundamental work: "Theory of relativistic particles with arbitrary intrinsic momentum“ (Majorana 1932 C). He formulates a relativistic generalization of the Schrödinger equation that completely eliminates the existence of negative-energy solutions (provided instead by the Dirac equation) and valid for particles with arbitrary spin (Dirac equation instead is valid only for s = 1/2). It is expanded and systematized by Wigner in 1939, which recognizes the pioneering role of

Majorana. He thanks Fermi: "I especially thank Professor E. Fermi for the discussion of this theory."
The period 1930-1932 is therefore scientifically very intense. The activity is carried out in complete independence. In this period we mark an additional peculiar aspect of Majorana scientific career. After earning the doctoral degree he does not receive any position (all other brilliant young "Panisperna boys" are immediately hired in the University, at the beginning with temporary "assistant" positions). Majorana "frequents freely the Institute, by following the scientific movement". In November 1932 he earns the abilitation to the private professorship ("libera docenza") in Theoretical Physics. Fermi is the Chairman of the Minister examination Committee.
At the end of 1932, the "strict relationship" between Ettore Majorana and the Rome Institute of Physics (in particular Enrico Fermi) come to the end, as he explicitly remarks in his 1937 curriculum presented in the application for the Palermo professorship.

3. The visit to Lipsia (1933)
It is a strategic decision! With the support of Fermi, he applies for a fellowship to be exploited abroad to the National Council for Research (C.N.d.R.). He gets the fellowship: 12.000 Lire for six months (the salary of an industry worker was less than 1000 Lire/month, for a full professor was around 25.000 Lire/year). His program is very advanced: Nuclear Physics and Elementary Particle Theory. Fermi support letter to Majorana project is peculiar (more conservative): he says that Majorana will continue with profit his research on atomic physics, and applications of group theory. He does not seem aware of the advanced Majorana programs: Nuclear Physics and Elementary Particles
To understand the apparent discrepancy between two descriptions of the planned program, it is necessary to recall some crucial aspects of the situation in Rome, in the strategic year 1932. This is addressed in depth in our articles (Guerra, Leone, Robotti 2006; Guerra, Robotti 2008 A, 2009) and in the monograph (Guerra, Robotti 2008 B). Here we are going to some brief schematic remarks. Since the beginning of the Thirties, it was clear to Orso Mario Corbino and Enrico Fermi that the thrust of Atomic Physics, even in its newest quantum aspects, was running low, and that the new open frontier was that of the physical study of the atomic nucleus. Hence the decision to organize in Rome, in October 1931, an International Conference of Nuclear Physics, the first of its kind in the world, which took place with great success with the support of the Academy of Italy and Volta Foundation, with a budget of about 200,000 lire (full original documentation is at the Accademia dei Lincei). But after the Conference the difficulties in starting the actual research in Nuclear Physics were evident. To witness the deep atmosphere of indecision we report about significant passages of the letter, dated September 30, 1932, sent by Fermi, from Arno Mignano, to his collaborator Emilio Segrè, then in Hamburg (the original is at Fermi Archives of Chicago): "About the work programs for the coming year, I have none at all: I do not even know whether I will return to play with the Wilson Chamber, or whether I become again a theoretical physicist. Of course the problem of equipping the Institute to work on the nuclear physics is becoming more urgent, if we do not want to reduce us too much in a state of intellectual slumber".
Moreover, in Rome it is not immediately grasped the significance of the discovery of the neutron by Chadwick, announced in February 1932 (after preliminary results of Bothe and Becker, and Joliot and Irene Curie). The Fermi report on the structure of the nuclei, in an important conference in Paris in July 1932, almost does not mention it. It merely exposes the situation at the end of the Congress in Rome, many months before, including the difficulties in the quantum description of the alleged nuclear electrons (which would have required an alleged new theory radically different from quantum mechanics). On the other hand, Heisenberg in Leipzig, immediately realizes the potentialities of the existence of the neutron for a possible quantum-mechanical description of nuclear structure, as it will be explained later. And Majorana, who "follows the scientific movement", snaps the Heisenberg program. Fermi on the other hand, from the theoretical standpoint, continues with his research, at the highest level, on the hyperfine structures, where the magnetic properties of the nucleus are revealed in the change of the spectral lines at the atomic level. While in Rome, experimental research in the field of nuclear physics is oriented towards the study of energy levels through the nuclear spectroscopy of gamma rays emitted in nuclear decays.
This strategic decision was certainly influenced by previous experience in Spectroscopy in Rome (Franco Rasetti, Professor of Spectroscopy, had obtained, among other things, extremely important results on Raman effect). And it is significant that, in the spring of 1933, the National

Research Council plans the national research in nuclear physics through a rigid division of tasks, so organized: Rome is responsible for the gamma spectroscopy; physics of the neutron is assigned in Florence to Gilberto Bernardini and collaborators; Padua gets cosmic rays for Bruno Rossi and collaborators. In this context, Fermi and Rasetti also make up a bizarre gamma spectrograph with a crystal of bismuth, described in an article in “La Ricerca Scientifica”, but that will never find application in actual research. In some ways, it is really amazing the Majorana physical intuition, that an effective study of the structure of the nucleus was within the practical possibilities of the moment.
In Leipzig Majorana enters into good relations with Heisenberg. Heisenberg, starting from July 1932, after the discovery of the neutron, was developing a model for the nucleus, assuming that it was composed only of protons and neutrons, held together by exchange forces, very similar to those entering the chemical bond. His results were explained in a series of three papers published, since July 1932, in the eminent German Journal “Zeitschrift für Physik”. Majorana in Leipzig gets the chance to see the third paper before publication and makes two fundamental improvements to Heisenberg theory: Majorana exchange forces change only the position of the two interacting proton and neutron, and have a sign opposite to Heisenberg exchange forces. The advantages of Majorana proposal are very deep. In particular the α particle is recognized as the most stable nuclear structure, and the almost uniform density of nuclei is explained. He immediately publishes a paper in the German Review “Zeitschrift für Physik” (Majorana 1933 A), as Heisenberg did, and also an “Announcement” (never quoted in Literature), in the Journal “Ricerca Scientifica” (Majorana 1933 B). Heisenberg realizes immediately the advantages of Majorana scheme, and begins immediately to advertise these results, in particular in his report at the important Solvay Conference in Bruxelles (October 1933). It is an international triumph for the young Majorana.
After the success of Majorana, research in Nuclear Physics in Rome received by Fermi an energic re-orientation. The proton-neutron nuclear model of Heisenberg-Majorana, based on quantum mechanics, opens the way to the Fermi theory of beta decay (December 1933), based on quantum field theory, where the electron and neutrino are created at the time of beta decay. There is no pre-existing electron in the nucleus, in agreement with Heisenberg-Majorana. It is fully recognized the centrality of the neutron, and Fermi discovers neutron-induced radioactivity in March 1934, led by his theory of beta decay. The discovery of the effects produced by the slowing down of neutrons complete the extraordinary results obtained by Fermi in the period December 1933-October 1934, that will be worth of the Nobel Prize in 1938. These successes take place along lines of research that completely subvert the schedule provided above. Rome actually became the world center of the neutron physics (the bismuth crystal gamma spectrograph no longer exists even in the Museum). Some merit to this success should surely be attributed to Majorana.

4. The silence (1933-1937)

After his return from Leipzig (Majorana comes back to Rome at the beginning of August 1933, at the highest level of his scientific prestige) we have total absence of publications.
His abilities displayed as a leader in the research can find no effective realization.
Moreover, he attempts to attend to his duties for the private professorship, by submitting to the Faculty every year very advanced programs (always different) for the proposed courses. His scientific interests can be reconstructed from the most advanced parts of his proposed programs. He never succeeds to give the free course. He never gets a position at the University.

5. Ettore Majorana Full Professor of Theoretical Physics at the University of Naples (1938)

In 1937 Majorana officially reappears in the scientific world, perhaps in connection with the planned national competition for Theoretical Physics (Palermo): he publishes on Nuovo Cimento one of the most important works of his life: “The symmetrical theory of electrons and positrons” (Majorana 1937). It is a remarkable paper, completely up to date even from the experimental point of view, dealing with the quantum theory of interacting fields, so that the “Dirac sea” (fully occupied negative energy states) is avoided. It foresees the existence of an elementary particle of spin ½, which coincides with its anti-particle, "the Majorana neutrino“. If the paper was published in order to make stronger his curriculum, then Majorana is moving along well established academic strategies. Nearly one quarter of the manuscript, dated around 1936, is preserved at the Domus Galilaeana in Pisa

On the relationship with Fermi, we have a reprint of the article with dedication (courtesy of Prof. Giacomo Morpurgo): "To His Excellency Enrico Fermi, with very best regards. Ettore Majorana". Recently we found a reprint with dedication to Gian Carlo Wick: "A Gian Carlo Wick with very best regards. Ettore Majorana". Note the nuance in the dedications: Fermi (His Excellency), expected President of the Evaluating Committee, Wick, a candidate in pole position.
The competition for a full professorship in Theoretical Physics at the University of Palermo (deadline for applications: June 15th, 1937) is a particularly significant example of the academic practice of the time (rich documentation at the Central State Archives in Rome). Ettore diligently submits his application (it is the first occasion for a chance to be officially recognized). Attached to the application are: "Scientific activity" and "List of Publications". Obviously in the list it is missing the communication to Congress in 1928 and the two Announcements on the "Ricerca Scientifica" (not suitable for a Competition).
On July 7, the Committee was appointed directly by the Minister (in a totalitarian regime). Of course Fermi is the President of the Committee, so composed: "Fermi Enrico; Persico Enrico; Lazzarino Orazio; Polvani Giovanni; Carrelli Antonio". In the first meeting (October 25, 1937, Record 1) the Committee decides to propose to the Minister to appoint directly Majorana as full professor in some University of the Kingdom, outside the procedures of the competition. The scientific Report on Majorana is of course very laudatory, albeit with some important omissions. The Minister accepts the proposal immediately, and on November 2, 1937, Majorana is appointed Full Professor in Theoretical Physics at the Royal University of Naples.
Having removed Majorana from the competition, the work of Committee resumes immediately beginning again with the record N°1! (not number 2!). In November 1937 the Committee, according to the rules, selects the winning "triplet" in the following order: "Wick Giancarlo; Racah Giulio; Gentile Giovanni".

6. The disappearence (1938)

Majorana in Naples attends regularly to his course. The contents can be reconstructed from his notes in Pisa and from the testimony of his students, in particular Prof. Gilda Senatore. From the notes at the Domus, the intent of Majorana is clearly to differentiate his course from that of Fermi, in particular by developing in full detail, some of the important topics, that Fermi had just mentioned (as for example the relativistic corrections to the quantum Bohr atom).
He disappeared in circumstances not yet clarified in late March 1938.
After his disappearance, a presumed intervention by Fermi on Mussolini, to intensify the police researches, is not confirmed in the Central Archive in Rome (secretariat of the Duce). In fact, the alleged letter of Fermi to Mussolini (27 July 1938), preserved at the Domus (Fig.3), shows puzzling aspects. It contains a central body written with "unknown" handwriting, in a very rhetoric style, certainly completely unrelated to Fermi, as even Emilio Segrè recognized in a letter addressed to Amaldi, who had sent him a copy of the text of the letter. On the other hand, the first and last lines of the letter are written in the handwriting of Ettore's brother, Salvatore. Significant is the attempt to imitate the signature of Fermi. Notice the incredible addressing of "Fermi" toward Mussolini as "Duce", while the correct addressing would have been "Excellency". This letter is a further step in the complex research theme "Majorana". As a matter of fact, a careful comparison of the handwriting of the central body of the letter with the existing documents, at the Domus Galilaeana in Pisa and the Archive of the Department of Physics in Rome, leads to a surprising conclusion. The letter was in reality written by Giovanni Gentile jr, a close friend of Majorana strictly associated with his Family. The style of the letter is in complete agreement with this discovery. A full analysis of this disconcerting episode is contained in a forthcoming paper.

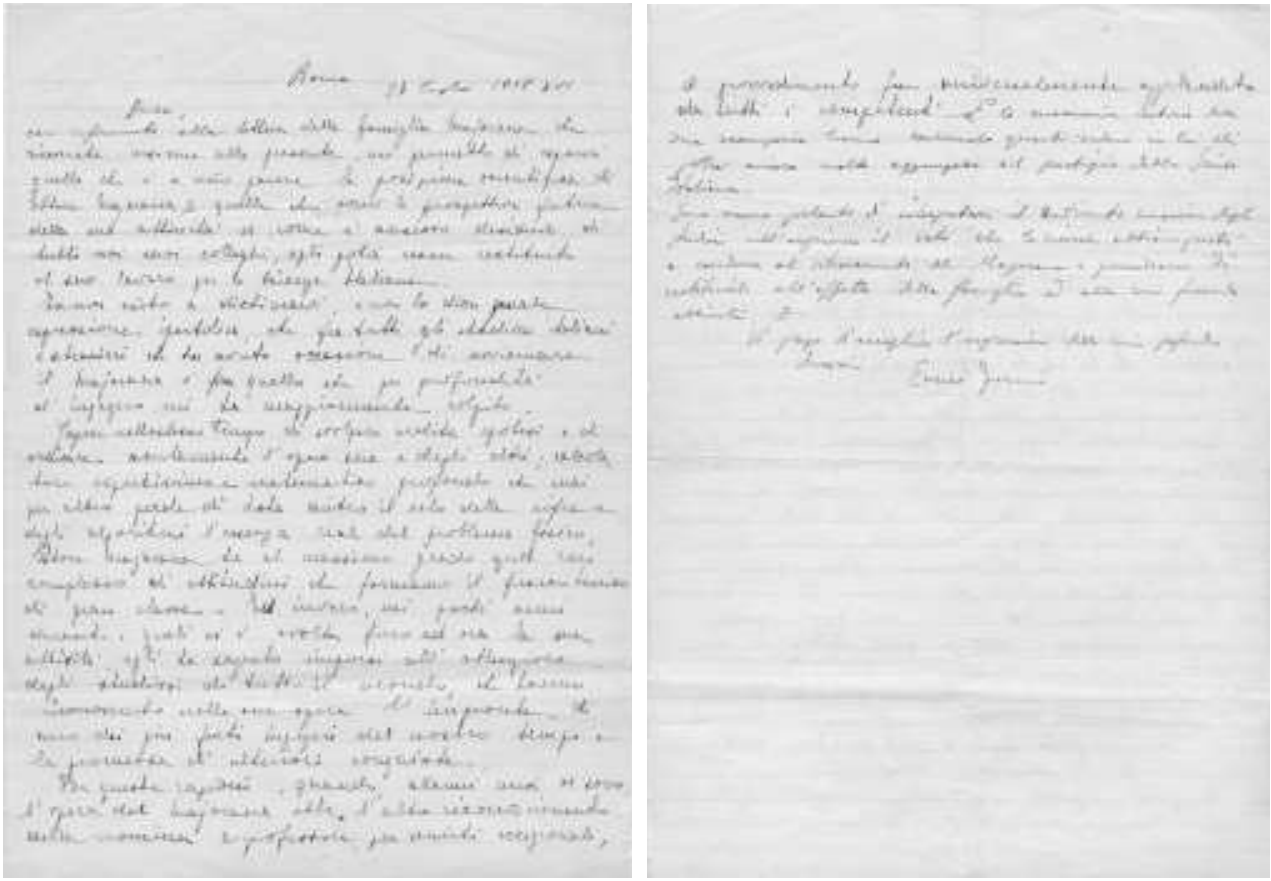

Fig. 3 Presumed "Fermi letter" to Mussolini (Domus Galilaeana, Pisa)

7. Conclusions

In the confirmatory report (1930) for Fermi Professor of Theoretical Physics, the Commission (Chairman Orso Mario Corbino) recognized, among other things, the merits of the "construction of a school of young people vigorously trained in the study of the most advanced problems of modern physics". Ettore Majorana was certainly one of them. However, the complex issue of relations between Majorana and Fermi can not be simplistically interpreted in terms of Teacher-Student. Majorana since the early activity shows a wide autonomy and independence. His ability to "follow the scientific movement" allows him to have a significant influence on the development of research in Rome, mainly on the themes of the statistical model of the atom, first, and the physics of the nucleus, later. The international prestige achieved by the development of nuclear models directed him towards an effective role as leader of the research. The situation of apparent separation from active research, created after his return from Leipzig in August 1933, has prevented the occurrence of this event.

Italy lost in 1938, almost simultaneously but in different circumstances, the two leading figures in the field of research in nuclear physics, Majorana and Fermi.

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