Fermi and Astrophysics: Selected Papers with Commentaries and Translations

Edited by Remo Ruffini

with translations from Italian to English by

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Preface

A meeting on Enrico Fermi and Astrophysics was held at the University of Rome "La Sapienza" and the ICRANet Center in Pescara in celebration of the hundredth anniversary of the birth of Enrico Fermi (1901–1954). During that anniversary year many events were organized covering the activities of Fermi in particle physics, nuclear physics, statistical mechanics and quantum statistics. Besides these fundamental fields of physics, amply documented in the existing literature, I thought Fermi had also played a key role by pioneering ideas which, directly or indirectly, became crucial for the understanding of some basic conceptual aspects of astrophysics and general relativity. This was the main focus of our meeting in Pescara, where a series of talks was presented dealing mainly with astrophysics, at the end of which I delivered a concluding lecture in the Aula Magna at the University of Rome "La Sapienza": "Fermi, General Relativity, Astrophysics and Beyond." The proceedings of that meeting were published as a special combined issue of *Il Nuovo Cimento B* [1].

I pointed out the paradoxical situation regarding a collaborative work by Fermi and Anthony L. Turkevich at the intersection of general relativity, cosmology and astrophysics: an article summarizing their findings was not published under the authors' own names at the time but only later extensively quoted in a 1950 review written by others together with a declaration of its authenticity by the original authors. This unpublished Fermi-Turkevich article was not included in the collected papers of Fermi published in the West [2].

It has for the most part been ignored in the current scientific literature and in textbooks on cosmology and astrophysics. To the best of my knowledge, it has only been mentioned by Frank Wilczek in the opening talk at the Chicago celebration of Fermi's 100th birthday. In the Russian edition of Fermi's collected papers this article was included, thanks to the forceful request by Bruno Pontecorvo, as Bruno recalled to me many years later. Nevertheless this Fermi and Turkevich paper has indirectly greatly influenced developments in cosmology. It was well known to a small number of scientists and was certainly well known to Bob Dicke at Princeton, as I found out in 1968. Due to the beauty of its scientific approach, the numerical techniques adopted, and the importance of the results obtained, it has to be considered as one

of the fundamental contributions to relativistic cosmology, and since that time I have made a special effort to publicize it and assign it as mandatory reading for all my university students.

I then realized that a number of other articles by Fermi were equally insufficiently well known: a possible reason being that they had not yet been translated from Italian into English, especially those by the young Fermi when he was a student at the Scuola Normale Superiore in Pisa dealing mainly with electrodynamics and the special and general theories of relativity. This led to a lengthy process in which with the help of Emanuele Alesci, Donato Bini, Dino Boccaletti, Andrea Geralico, Robert Jantzen, and Simone Mercuri, we translated from Italian to English a selection of Fermi's papers, including the ones of the Pisa period. In the course of our work we also became aware of scientific results published in a series of six papers written by Fermi in 1922–1923 during his Pisa period while still a student and later in a temporary position at the University of Florence, results which he presented in Göttingen in 1924. This work, which has been overlooked in nearly all textbooks, is his solution of the infamous so-called "4/3 problem" that plagued the classical theory of the electron introduced by Abraham and Lorentz during the first years of the life of special relativity and which was wrongly interpreted by Poincaré as due to unidentified internal stresses holding the electron together. I discussed this topic with Donato Bini, Andrea Geralico and Robert Jantzen over the period of a few years, resulting in our commentary article Appendix (A.1) and a shortened version (A.2) for the journal *General Relativity and Gravitation*.

While examining Fermi's early papers, we came across two important papers which we also translated. The first is a 1930 lecture delivered in Trento in which he clearly motivated his distrust toward approaching the internal constitutions of stars, an attitude which had negative consequences for the Italian development of astrophysics. The second was greatly rewarding: a crucial lecture that Fermi later delivered in Italian at the University of Rome in October 1949, "Theories on the origins of the elements," recorded by Ettore Pancini, which we have also translated into English. Through this I finally became aware of Fermi's deep knowledge of cosmology and derivation of the key equations, which allowed him to perform the computation in his work with Turkevich. There were also some other later papers related to astrophysics which, although they had been published in English, for a variety of reasons, had not yet reached the attention they deserved from the scientific community at large. We started assembling all of this material. Of course many books and even movies already exist which review the glorious achievements of the Fermi group in Rome on neutron physics, nuclear physics and statistical mechanics, but none of these overlap with our specific interest in the matter of general relativity and astrophysics. I first noticed with curiosity Fermi's apparent lack of interest in general relativity and also in astrophysics during the entire Rome period of his life. This was particularly surprising since many fundamental results were obtained in those years in England and in the United States which had great significance for

astrophysics in the following decades. Many of the results were indeed obtained using Fermi's conceptual discoveries.

It became natural to ask why Fermi, one of the first scientists to reach a deep understanding of Einstein's theory of general relativity and to give profound contributions to that theory, already as a student in Pisa, never addressed any issue related to general relativity after transferring to Florence in 1924 and in 1926 to Rome. What could have happened during this Florence transition which inhibited his desire to pursue general relativity further?

While I was mulling over all these issues in the intervening years, I continued my work in relativistic astrophysics and was witnessing on a daily basis the tremendous relevance to the field of relativistic astrophysics of the classic work of three giants: Fermi, Einstein and Heisenberg. The greatest and most fundamental new results have come from the utilization of their ideas not in the isolation that they had created between themselves while alive but in a profound new interaction unhampered by their personal prejudices. From this thinking came the decision to contextualize this material with a companion book [3] dedicated to Einstein, Fermi, Heisenberg and the birth of relativistic astrophysics which took place due to both theoretical and observational advances that came one after the other in the 1960s, seen from my personal perspective as one of the participants in this story from its beginnings to the present time. I purposely avoided there entering into matters already extensively treated elsewhere, including in my own books, and have focused on a historical perspective regarding some particular events in the development of relativistic astrophysics which I have witnessed directly or have reconstructed in Rome, Princeton, Cambridge, Moscow and in locations where relativistic astrophysics after its inception flourished in the following years. I have privileged the indications on some current research which I consider particularly promising.

In this volume the introductory Chapter 1 summarizes the contents of the remaining two chapters and appendices. We have reproduced and where necessary translated the fundamental contributions Fermi made which are relevant to astrophysics, starting from his early student days in Pisa (see Fig. 1) and continuing throughout his life. Chapter 2 contains those relevant papers from his Italian period before moving to America, followed by Chapter 3 which includes papers from his American period, including his paper on theories of element formation in the early universe from his 1949 Rome lecture as recorded by E. Pancini, and the Fermi-Turkevich work reproduced by Alpher and Herman. These are discussed in detail in the companion book. Appendix A contains some commentary articles regarding Fermi's early work in Italy, while Appendix B reproduces a selection of papers from the 2001 Meeting on Fermi and Astrophysics published in Nuovo Cimento in 2002.

In addition to remembering Fermi's contributions to fundamental physics starting from his student days in Pisa, continuing throughout his life, before closing, I recall here the influence Fermi had on science in China. This was commemorated in a special ceremony held in Beijing during the Fourth Galileo-Xu Guangqi Meeting

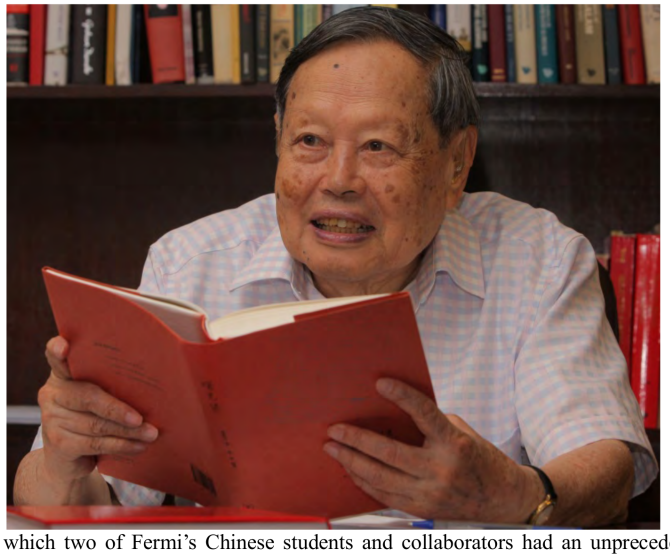
(GX4) in May 2015 (see Fig. 2) just preceding the Fourteenth Marcel Grossmann Meeting in Rome in July 2015. On that occasion both Fermi's former students C.N. Yang and T.D. Lee received Marcel Grossmann Awards (see Figs. 3 and 4). Yang (see Fig. 5) then delivered a talk of his personal recollections of Fermi, including an exchange with Eugene Wigner, indicated by "W", as well as their final meeting in the hospital (accompanied by Murray Gell-Mann) in the last minutes of Fermi's life. As the most unique Fermi reminiscence I have ever read and possibly the most touching words expressed by one human being for another, we reproduce them below.

— *Remo Ruffini*

Fig. 1 The young Enrico Fermi.

Fig. 2 The group photo for the GX4 Meeting (C.N. Yang and his wife at center of first row).

FRANK C.N. YANG
"for deepening Einstein's geometrical approach to physics in the best tradition of Paul Dirac and Hermann Weyl"



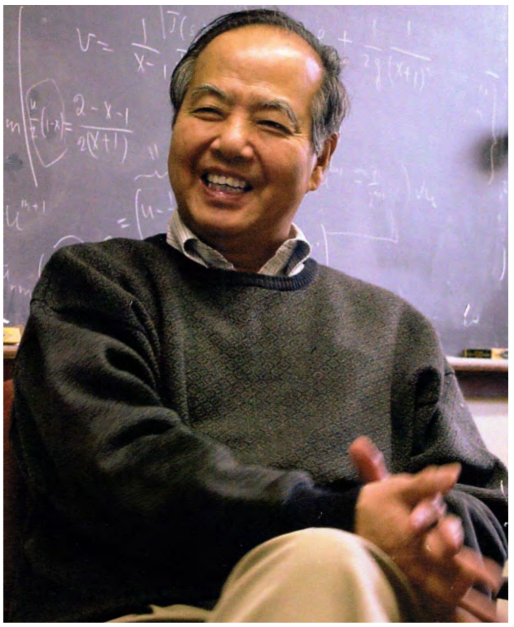
"… I would like to discuss some influence Fermi had in China: this is the case in which two of Fermi's Chinese students and collaborators had an unprecedented impact on science at the international level and triggered the scientific development of the largest nation in the world: China. During my second visit to China in 1979 I went to Kun Ming: it was quite an experience to see this beautiful location on the border of a lake so vividly described by Marco Polo. There was a train line constructed by the French reaching this town from Hanoi. There was also a beautiful university where two young students studied physics during World War II, there the professors from the Bei DA and Qing Hua university of Beijing and their families having escaped from the east of China ahead of the Japanese invasion. Their names were Chen Ning Yang and Tsung Dao Lee. At the end of the war they transferred to the USA: Frank C.N. Yang became Fermi's assistant and T.D. Lee was followed in his Ph.D. thesis by Fermi. The remarkable scientific career of these two young Chinese scientists is well recorded in the history of science. After Nixon's visit to China in 1972, Yang and Lee frequently went back to China to deliver lectures based on the Fermi tradition and today they are spending the greater part of their time in China organizing scientific centers and activities. In 1979 Yang gave a lecture at the second MG meeting in Trieste (see figure on the right: C.N. Yang speaking with a thoughtful Pam Dirac listening). During the Third Galileo-Xu Guangqi Meeting in 2011 I had another pleasant meeting with C.N. Yang. This also gave me the opportunity to see Beijing University again, having originally seen it in 1978 after the cultural revolution with all its libraries burned, now renewed and reaching a new splendor. Next to the Zhou Pei-Yuan Institute are the offices of the C.N. Yang Center. We talked about our common friend Isidor Rabi and his role in collaborating with Eisenhower as President of Columbia University prior to the latter's election as President of the USA. We also talked about Fermi's role in formulating his theory of beta decay, of the adventures of the A-bomb and H-bomb projects and many other topics. This also gave me the chance to introduce him to our ongoing projects with ICRANet in Brazil."

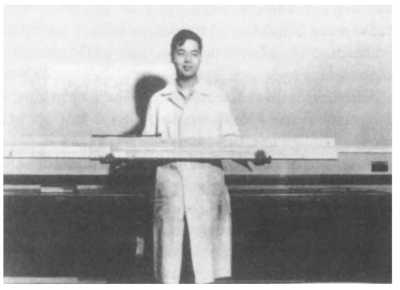
From "Einstein, Fermi, Heisenberg and Relativistic Astrophysics: Personal Reflections by Remo Ruffini" World Scientific Singapore 2015

Fig. 3 MG Awards booklet page [5] for C.N. Yang.

T.D. LEE

"for his work on white dwarfs motivating Enrico Fermi's return to astrophysics and guiding the basic understanding of neutron star matter and fields"





"… Returning to the main topic of Fermi and astrophysics, it is interesting that according to T.D. Lee Fermi's original critical attitude expressed in his Trento lecture on the interior of stars was evolving towards the end of his life. As recalled by T.D. Lee in a talk held at a joint meeting of the APS and AAPT in February, 2010 "Remembering Enrico Fermi," Fermi was beginning to warm up towards astrophysics in his final years: Fermi asked Lee during his Ph.D. thesis the approximate temperature of the Sun at its center. Lee replied, "Ten million degrees." Fermi asked: "How do you know?" Lee told him he had looked it up. Fermi asked if he'd verified the number and Lee replied, "It's really complicated. It's not so easy to integrate these equations." Fermi suggested that Lee build a huge specialized slide rule that would enable the solution of two radiative transfer equations, one that involved the 18th power of the temperature, and the other that involved the reciprocal of temperature to the 6.5th power. Over the next few weeks Lee built a slide rule that was 6.7 feet long and carried out the necessary integration. 'It was great fun'…

In the imperial Chinese tradition of the past, in each town in China there was a palace in which every year the best young astronomers were examined and selected and brought to the imperial palace to perform their study and research. Great credit goes to T.D. Lee for having reactivated this selection process on a large scale and having sent the most qualified young students not to the imperial palace in Beijing but to the leading universities in the USA for many years a similar program has been activated in Tokyo.

These experiences, as well as our more limited effort with ICRA and ICRANet, have been significant components in guaranteeing that most impressive scientific, technological and industrial development that the entire world admires today in China. In some sense this authentic scientific and cultural evolution of modern China was triggered directly and indirectly by the influence of Fermi."

From "Einstein, Fermi, Heisenberg and Relativistic Astrophysics: Personal Reflections by Remo Ruffini" World Scientific Singapore 2015

Fig. 4 MG Awards booklet page [5] for T.D. Lee.

Fig. 5 C.N. Yang receiving the Marcel Grossmann Award in Beijing at the GX4 in 2015.

Yang on Fermi

I remember that it was at the Second Marcel Grossmann Meeting in Trieste in 1979, that I formulated the phrase "symmetry dictates interactions", which describes the principle that governs the structure of interactions. I am happy to receive this award from an organization based in Italy, the country I feel closest to, after China and the USA. Enrico Fermi was one of the great sons of Italy in her long history. Prometheus in Greek mythology, Suiren in Chinese mythology, taught mankind how to use chemical energy. Enrico Fermi in reality, taught mankind how to use nuclear energy.

Enrico Fermi was, of all the great physicists of the 20th century, among the most respected and admired. He was respected and admired because of his contributions to both theoretical and experimental physics, because of his leadership in discovering for mankind a powerful new source of energy, and above all, because of his personal character. He was always reliable and trustworthy. He had both of his feet on the ground all the time. He had great strength, but never threw his weight around. He did not play to the gallery. He did not practise one-up-manship. He exemplified, I always believe, the perfect Confucian gentleman.

Fermi from 1950 to 1951 was a member of the General Advisory Committee (GAC) of the Atomic Energy Committee (AEC) chaired by Oppenheimer. He then resigned with a quote:
"You know, I don't always trust my opinions about these political matters".

> Shakespeare's Sonnets No. 94
> *They that have power to hurt and will do none,*
> *That do not do the thing they most do show,*
> *Who, moving others, are themselves as stone,*
> *Unmoved, cold, and to temptation slow;*
> *They rightly do inherit heaven's graces,*
> *And husband nature's riches from expense;*
> *They are the lords and owners of their faces,*
> *Others but stewards of their excellence.*

In my years in Chicago, Fermi was personally very kind to me. I remember in June 1948, I had problems with the US Immigration Office. Fermi and Professor Allison, the Director of Chicago's Institute, went with me to the Immigration Office in Chicago. The Head of the office was so overwhelmed by the presence of Fermi that all my immigration problems were resolved immediately.

Fermi made many first rate contributions to physics. His contemporaries, including himself, considered his beta decay theory the most important. To bring out the great impact that paper had on physicists in the early 1930s, allow me to tell you a story.

Y (C.N. Yang): What do you think was Fermi's most important contribution to theoretical physics?

W (Eugene Wigner): Beta decay theory.
Y: How could that be? It is being replaced by more fundamental ideas. Of course it was a very important contribution which had sustained the whole field for some forty years: Fermi had characteristically swept what was unknowable at that time under the rug, and focused on what can be calculated. It was beautiful and agreed with experiment. But it was not permanent. In contrast the Fermi distribution is permanent.
W: No, no, you do not understand the impact it produced at the time. Von Neumann and I had been thinking about beta decay for a long time, as did everybody else. We simply did not know how to create an electron in a nucleus.
Y: Fermi knew how to do that by using a second quantized ψ?
W: Yes.
Y: But it was you and Jordan who had first invented the second quantized ψ?
W: Yes, yes. But we never dreamed that it could be used in real physics.

In the fall of 1954 Fermi was critically ill. Murray Gell-Mann and I went to the Billwigs Hospital to see him for a last time. He was thin, but not sad. He was reading a book full of stories about men who had succeeded, through shear will power, to overcome fantastic obstacles and misfortunes. As we bade goodbye and walked towards the door of his room, he said:
"Now I have to leave physics to your generation."
— Chen-Ning Franklin Yang

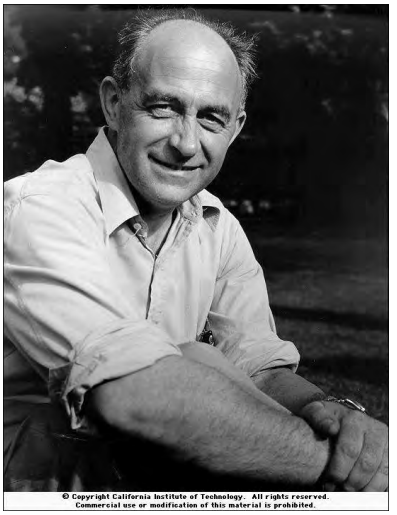


Fig. 6 Enrico Fermi (1901–1954).

Bibliography

[1] *Il Nuovo Cimento B* Vol. 117, Nos. 9–11, 2002; available online at:
`http://en.sif.it/journals/ncb/econtents/2002/117/09-11`,
Proceedings of the Ninth ICRA Network Workshop on Fermi and Astrophysics.

[2] *Enrico Fermi: Note e Memorie (Collected Papers)*, Accademia Nazionale dei Lincei and The University of Chicago Press, Vol. 1, 1961, Vol. 2, 1965; Volume 1 is available on-line at:
`http://www.archive.org/details/collectedpapersn007155mbp`.
Both volumes are available at the Accademia dei Lincei website:
`http://www.lincei.it/modules.php?name=Content&pa=showpage&pid=125`.

[3] *Einstein, Fermi, Heisenberg and the Birth of Relativistic Astrophysics*, Remo Ruffini, World Scientific, 2017.

[4] Rong-Gen Cai, Remo Ruffini, and Yue-Liang Wu, *Int. J. Mod. Phys. A* **30**, 1502005 (2015),
`http://www.worldscientific.com/toc/ijmpa/30/28n29`,
preface to the Proceedings of the 2015 Fourth Galileo-Xu Guangqi Meeting.

[5] The Fourth Marcel Grossmann Meeting Awards booklet
`http://www.icra.it/mg/mg14/mg14_awards.pdf`.

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