IN RICORDO DI

Raul Gatto
(1930-2017)

Raoul Raffaele Gatto: an unforgettable Maestro

Raoul Raffaele Gatto passed away in Geneva on september 30th, 2017, at the age of 87. Gatto was married to Regina Bongardi (deceased in 2005) who gave him three children: Stefano, Riccardo and Raffaella.

Gatto has been a leading figure of theoretical particle physics in the second half of the last century, in Italy and internationally, and one of the important contributors to the present paradigm in Elementary Particle Physics known as the *Standard Theory*.

Emeritus Professor in theoretical physics at the University of Geneva, Gatto, in his long professional life has been full professor at the Universities of Cagliari, Florence, Padua and Rome. Deputy Director of *La Rivista del Nuovo Cimento*, he has also served as Topical Editor for *Il Nuovo Cimento*. From 1969 and for over thirty years, has been Editor of *Physics Letters*.

Always at the leading edge of research, Gatto has attracted and formed young investigators of several generations, many of whom have had important roles in scientific institutions in Italy and abroad. He leaves a school of imposing dimensions.

Raoul Gatto was born in Catania in 1930, studied physics at Scuola Normale Superiore di Pisa and graduated with Marcello Conversi and Bruno Ferretti in 1951. After the Diploma, he went to Rome as assistant to Ferretti. Quite soon, in 1956, he left for the United States, to become a staff member of the Lawrence Radiation Laboratory in Berkley.

The group of Luis Alvarez was then in full production, discovering new hadrons with the hydrogen bubble chamber. Gatto absorbed quickly the exciting atmosphere of the laboratory. He wrote several papers, investigating the symmetries of the weak interactions (Fermi's imprinting on Italian theoretical physics) and the phenomenology of weak decays of hyperons, based on the data collected by the Alvarez group.

On his coming back, Gatto brought to Italy the new ideas flourishing at the time in the U.S., concerning the application of symmetry and group theory to particle physics.

A sharp description of Gatto's research program of the time can be found in a CV that he wrote in 2011: ... *una linea di ricerca basata su idee teoriche innovative pur restando connessa ai programmi dei grandi laboratori internazionali, facendovi partecipare giovani laureati, molti dei quali per il loro valore sono arrivati a posizioni scientificamente prestigiose*[1].

[1] "A research based on innovative theoretical ideas while in touch with the research programs of the big, international laboratories, with the participation of recently graduated investigators, among whom several have later obtained scientifically prestigious positions".

Frascati

Back to Italy, in 1960, Gatto became the director of the newly formed theory group at Frascati Laboratories. He found there, as junior partner, Nicola Cabibbo, freshly graduated with Bruno Touschek and recruited in Frascati by Salvini.

Frascati was busy building an electron-positron collider, a big machine that followed the pioneering work done by Touschek and collaborators with the accumulation ring AdA (Anello di Accumulazione). A larger version of AdA, was called Adone (big AdA, in Italian) and it was the sensation of the moment.

Great expectations were raised about the results to be obtained in what was the first exploration of Electrodynamics at high energy. Raoul Gatto and Nicola Cabibbo wrote a long article that summarised the theoretical situation of the high-energy electron-positron collisions [1]. It was called *The Bible* by people in Frascati and showed very clearly the potential for elementary particle physics of future experiments with Adone. As later recalled by Cabibbo, writing this paper they had *the exhilarating experience of expanding into a vacuum* because for a few years the only theoretical papers on the physics of e^+e^- annihilations were those coming out of Rome and Frascati [2].

The years of Frascati were extraordinarily productive for Gatto and Cabibbo, who worked with young physicists of the area (Giuseppe Da Prato, Gian De Franceschi) and visitors from abroad (Sam Berman, Charles Zemach).

In 1960, independently of Schwinger [3] and Lee and Yang [4], Cabibbo and Gatto formulated the hypothesis that there is a muon neutrino different from the electron neutrinos [5], noting that two massless neutrinos with exact muonic and electronic number conservation would make the amplitude of the decay $\mu \to e\,\gamma$ to vanish exactly, as suggested by data.

In a remarkable paper, Cabibbo and Gatto [6] worked out the properties of the weak currents under the *SU*(3) symmetry, the *Eightfold Way* newly introduced by Murray Gell-Mann and by Yuval Ne'eman, putting into evidence the different normalisation required by data of the strangeness-changing *versus* the strangeness-conserving current. It was a crucial step that later led to Cabibbo's theory of universal semileptonic weak decays [7].

Less known, but equally remarkable, is a paper on the diagonalization of the fermion Lagrangian, in the presence of parity-violating fermion bilinears [8]. The concepts developed here, and in a similar paper by Feinberg, Kabir and Weinberg [9], were to be used fifteen years later to show that the interaction of the Higgs field with fermions is able to produce quark masses and the Cabibbo-Kobayashi-Maskawa mixing matrix.

While in Frascati, two most bright students of the young generation joined Gatto, *i.e.* Guido Altarelli and Franco Buccella, to compute the

cross-section of electrodynamic processes suitable to measure Adone's luminosity. Giovanni Gallavotti, of the same generation, was working on a similar process, under the guidance of Touschek.

Gatto's program of attracting young investigators to particle physics was taking momentum.

Arcetri

Gatto had become full Professor at Cagliari University in 1960, a position he kept commuting from Frascati. The Frascati period came to an end in 1963, when he was called as full Professor in Florence, to replace Giacomo Morpurgo who had moved to Genova. In Florence, Gatto was joined by his former students, Altarelli and Buccella, and by Gallavotti. I joined as well, moving from experimental to theoretical particle physics (I had done a thesis in "Istituto Superiore di Sanità" on silicon detectors), with a fellowship from "Sanità".

In the Physics Institute of Arcetri there were Enrico Celeghini, recruited by Gatto in Cagliari, and elder people who had been working with Morpurgo: Marco Ademollo, Claudio Chiuderi, Giorgio Longhi, Enrico Giusti, Emilio Borchi, Mario Poli.

Gabriele Veneziano was writing his dissertation under the supervision of Gatto. Giuliano Preparata was also making a dissertation with Gatto, in Roma, and joined Firenze by the end of 1964.

Gatto had a very interesting and attractive personality. He masterly led the large group made by the ambitious, young *gattini* (we the romans, the little cats) and the somewhat elder people he had found in Florence.

Gatto's secret was to put you in front of advanced but accessible problems (radiative corrections, *SU*(3), *SU*(6), *U*(12), quark statistics, *CP* violation, weak interactions… you name it). He would discuss your results, send you back if not convinced, or write a draft paper.

In everyday life, Gatto acted as the boss. He would come to your office and say: *Oh, there is this calculation… it could be done, if you like…*

I still remember the afternoon when he assigned me my first calculation, an application of Gell-Mann's *SU*(3) symmetry to neutrino reactions, my first theoretical paper.

Gatto's school participated in the struggle of theoretical physics of those years, towards a theory of strong interactions. The main theme of our research was to go beyond the pure concept of symmetry, *SU*(3), *SU*(6) or higher, and delve deeper into the role of quarks.

We learned that we could compete with other groups, in U.S. and Israel. Sid Meshkov defined us the *Italian mafia*, as opposed to the *Israeli mafia* of Haim Harari and colleagues, who were working on similar subjects. With Gatto our Maestro, we had been recognised as useful interlocutors.

Among the results of the Arcetri school, the electrodynamic calculations concerning electron-positron annihilation have been widely used by the experimental collaborations, in Frascati and elsewhere.

By far the most known result, however, was obtained by the old hands, the so-called *Gatto-Ademollo theorem*, the statement that deviations from exact *SU*(3) symmetry intervene in baryon and meson weak decays only to second order in the symmetry breaking parameter [10]. This result had an important role in the analysis of the experimental results and is today widely accepted to justify the excellent agreement of the Cabibbo theory with baryon and meson weak decays.

An original and important paper with Emilio Borchi contained the proposal, by the time really unorthodox, of the existence of mesons made by a quark and an antiquark with one unit of relative orbital momentum [11]. The idea became soon crucial for the classification of the higher meson resonances that began to be discovered in these years, A_1, A_2, B, ...

By the end of 1966, the Florence experience came to an end. The school disbanded, some coming back to Rome (Giuliano and me), some going to the States (Altarelli and then Giuliano). Chiuderi moved to astrophysics. Veneziano, shortly after graduation went to Israel, to meet later the glory with the Veneziano dual model.

In 1967, Gatto, now famous for his papers and for having grown so many pupils, went one year to Geneva and, in 1968, moved to Padova, where he joined Giovanni Costa, Mario Tonin, Gianfranco Sartori and other younger theorists.

Padua

In 1968, Gatto, Sartori and Tonin [12], addressed the divergent results found in second-order weak interactions of the Cabibbo theory by Boris Ioffe and Evgeny Shabalin [13], and by Francis Low [14]. Gatto, Sartori and Tonin showed that the leading divergent term vanishes for a specific value of the Cabibbo angle, such that $\tan^2\theta = m_u/m_s$. Relating by current algebra the ratio of quark masses to the ratio of meson masses, one finds $\sqrt{m_u/m_s} \sim m_\pi/m_K \sim 0.28$, which gives a good approximation of the Cabibbo angle.

Unfortunately, the cancellation of the divergences was found not to be compelling in the quark model, where the divergent terms can be absorbed in the quark masses (see the discussion of J. Iliopoulos in ref. [15]). The relation they found is of considerable historical importance, however, for the debate it raised among weak-interaction practitioners, that eventually led to the proposal of the charm quark [16, 17], the GIM mechanism and to the successful extension of the Glashow-Weinberg-Salam theory [18, 19, 20] to include the weak interactions of quarks: the beginning of the Standard Theory.

Since then, there have been many attempts to derive the Gatto *et al.* relation, which remains a plausible, impressive regularity, still begging for a rational explanation.

Rome

Gatto was called at University of Rome "La Sapienza" in 1971. It was the time of Bjoerken scaling in deep inelastic electron-nucleon scattering, interpreted by Feynman as the scattering of electrons off essentially free, pointlike partons inside the nucleon. Gatto set up to study the issue in field theory, with a group of young investigators recently hired in Frascati, *i.e.* Aurelio Grillo, Sergio Ferrara and Giorgio Parisi. In a contribution to a Conference organised by Gatto in Frascati, May 1972, Bardeen, Fritzsch and Gell-Mann launched the idea of QCD [21], before the discovery of Asymptotic Freedom, by David Gross and Franck Wilczek [22] and by David Politzer [23].

In the quest to explain why Nature seems to *read, in field theory books, only the chapter on Free Fields* (as Gell-Mann had put it), Gatto and his group investigated Bjorken scaling in the light of Conformal Invariance [24].

In 1973, they formulated the Conformal Bootstrap program [25], using techniques derived from conformal symmetry in conjunction with the Operator Product Expansion, causality and locality.
The Conformal Bootstrap program has been developed later by Alexander Polyakov [26], active at the time in the former URSS, and in two dimensions is deeply related to string theory [27]. It is today an important part of theoretical physics, a recognition of the pioneering role of Gatto and his Frascati group in the seventies.

Soon after the discovery of the J/Ψ, November 1974, Appelquist and Politzer [28] and De Rujula and Glashow [29] identified the new resonance as a charm-anticharm bound state: the narrowness of the observed state was understood as a very characteristic manifestation of QCD in a system made by heavy quarks. This allowed them to compute, in terms of α_s, the ratio between the e^+e^- and the hadronic widths of the J/Ψ and of the η_c, yet unobserved.

Both the J/Ψ and the η_c are *S*-wave bound states. A few months later Gatto, in Rome, Riccardo Barbieri, in Pisa, and coworkers [30] extended this observation to the *P*-waves, predicting the ratios: $\Gamma(\chi_{c0}):\Gamma(\chi_{c2}):\Gamma(\chi_{c1}) = 15:4:1$ up to binding corrections and corrections of order α_s. These corrections were computed in the following years, when Gatto had already moved to Geneva [31]. It took a decade to get relatively precise measurements of these widths. The current PDG numbers, within less than 10% errors, are: $\Gamma(\chi_{c0}):\Gamma(\chi_{c2}):\Gamma(\chi_{c1}) = 12:2.4:1$. There are not many numerical predictions in hadronic systems of comparable success.

Geneva

Gatto moved to the University of Geneva in 1975 on the chair left by Stuckelberg. By that time, the way to the Standard Theory had been traced and word passed to experiments. Gatto, and many others, looked for theoretical ideas to go beyond the new paradigm, not neglecting, however, investigations related to the ongoing experiments, at CERN in particular.

In Geneva, Gatto soon became the center of a vast group of younger people, mostly coming from Italy, that he directed to the new problems. He had visitors from Pisa –Barbieri, Strocchi and Morchio– and from Padua – Sartori and Vendramin. Other collaborators of that period were Savoy, who had a temporary position in Geneva, and Abud who was doing his PhD. Gatto started a collaboration with Caffo and Remiddi from Bologna about radiative corrections in Standard Model processes.

Back in 1966, in Florence, Gatto had recruited few new students, among them Luca Lusanna and Roberto Casalbuoni. Roberto met Gatto again in 1979 while visiting CERN, at a seminar where Haim Harari illustrated his "rishon" model of quark and lepton subconstituents. The search of subconstituents was the initial argument of a long collaboration with Roberto, that lasted until 2006, when Casalbuoni took the direction of the Galileo Galilei Institute in Florence. Their proposal of a composite model of quarks and leptons [32] attracted considerable attention. Work went along up to 1983, with Bordi and Dominici, both from Florence, joining in 1982.

More or less at that time Gatto got interested in chiral symmetry breaking in color gauge theories. The group was enlarged to Andrea Barducci and Stefania De Curtis from Florence. These works ended with a theoretical determination of the quark masses [33].

The perturbative realisation of the electroweak symmetry breaking [34] raised many doubts in the 1980s. In 1984, motivated by the problem of naturalness in the Standard Model, Gatto and collaborators proposed an effective model of weak interactions in the presence of a heavy Higgs, later known as the BESS (Breaking Electroweak Symmetry Strongly) model [35]. The unitarity limit of the Standard Model in the presence of a heavy Higgs [36] was tackled around 1986, with the participation of a new PhD student, Ferruccio Feruglio, who was to become one of Gatto's closest collaborators.

An interesting line of research was about a non-linear realisation of the SUSY algebra by means of supersymmetric constraints [37]. This paper went completely ignored at that time, but today the constraints technique has become very popular in supergravity (see for instance [38]).

Symmetry Breaking in QCD at finite temperature and density was reconsidered in 1989, to point out the possible existence of a tricritical point in the QCD phase diagram [39]. Gatto's group was the first to make this proposal, together with Asakawa and Yazaki [40].

The LEP era started in 1989 and Gatto's group spent much time in analysing the data in the context of the BESS model [41], also in collaboration with Guido Altarelli who had moved permanently to CERN.

An entirely new line of researches about the phenomenology of heavy mesons started in 1993 with the collaboration of Beppe Nardulli from Bari and two new PhD students of Gatto, Di Bartolomeo and Deandrea. The conclusion was a *Physics Report* [42] which is very much quoted also nowadays.

At the end of the nineties, there was a strong interest in QCD at high density and very low temperatures, the typical conditions for a neutron star. Gatto and Casalbuoni devised an effective QCD Lagrangian to describe this situation [43]. Following this paper a new collaboration with Nardulli and several of his students in Bari started. Among the most interesting results, a paper showing the instability of the so-called gCFL phase of QCD.

Gatto continued this interesting line with several students of Nardulli, the latest generation of phenomenology-oriented people to be formed by him. Among them Antonio Polosa on return from Finland. The last published work by Gatto was still in this area and had to do with the inverse magnetic catalysis in QCD at finite density and temperature [44].

The collaboration with Casalbuoni ended with a report in *Reviews of Modern Physics* [45], initiated in 2006 and completed in 2014.

A true passion for physics accompanied Gatto during all his long and fruitful trajectory, with 280 published papers and more than 15 000 citations.

The path taken by physics to get to the Standard Theory looks like a windy and bumpy road, curves and bumps representing changes in perspective and unexpected discoveries. At the curves, many cars went off the road and were lost to the subsequent progress, but not Gatto's car. He was able to adapt, follow and sometimes predict where the next curve would arrive, and succeeded to stay on the road all the time.

Another exceptional aspect was his capacity to form new generations, putting young people on the front of research, that they would later themselves continue. He respected the capacity of young people to come up sometimes with bright ideas, and was never hard on them when they were going astray.

A vivid description of Gatto at work in Geneva was provided by Ferruccio Feruglio (I got a similar recollection from Giorgio Parisi):
...once per week, the whole group was used to migrate to Gatto's office to have a blackboard discussion, where also some of the younger collaborators dared to expose some point or some new idea. The idea was to abandon immediately if Gatto pronounced the famous words: "Very interesting. I have never seen this in all my career...". Then we knew that we were completely off the track. In this way, very gently but at the same time very firmly, Gatto was keeping up the pressure on us and was directing to accomplishment of all the planned projects.

Awards and recognitions

Gatto has received many awards and recognitions. Among them:

Prize for Weak Interactions, Bologna, 1984. Premio Nazionale del Presidente della Repubblica, 1975. Premio per il Centenario della Società Italiana di Fisica, Campidoglio 1977. Medaglia di benemerito della SIF in 2002. Premio Enrico Fermi della Società Italiana di Fisica, 2003.

Gatto was members of several prestigious associations. Fellow of Accademia delle Scienze, Torino, 1973. Fellow of the American Physical Society, 1973. Fellow of Accademia dei Lincei from 1975, Socio Nazionale from 1996.

Acknowledgements

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Era malato da tempo. Pur non essendoci più incontrati da diversi anni avevamo mantenuto una certa corrispondenza con notizie reciproche. Nel suo ultimo messaggio in cui si congratulava per il raggiungimento dei miei 90 anni, rammaricandosi di non poter essere presente al Simposio di Legnaro, così si esprimeva: *"…A causa della mia cattiva salute raramente mi posso interessare a quanto accade in fisica […] ho letto della cerimonia in tuo onore, mi congratulo pr i tuoi 90 anni […]. Io purtroppo passo metà del mio tempo in ospedale ed ho gravi problemi, oltre ad essere rimasto solo, come sai".* L'essere rimasto solo per lui significava il non avere più accanto, ed erano molti anni ormai, Regine, la sua adorata moglie, *Reginetta* come amava chiamarla e come pure la chiamavamo io e Claudine, legati come eravamo da una vecchia affettuosa amicizia con frequenti incontri in particolare durante il suo soggiorno a Padova negli anni '70 e qualche volta a Ginevra quando a me capitava di frequentare il CERN. (Marco, mio figlio riusciva a vederlo nei suoi passaggi a Ginevra.) Un'amicizia che del resto datava per Raoul e per me, dagli anni della Scuola Normale a Pisa negli anni '50 e che aveva cementato un rapporto fraterno che ci avrebbe legato insieme anche con Carlo Castagnoli, per età il maggiore di noi e lui, Raoul, il più piccolo. Aveva, seguendo i consigli del primo, preso la via "romana" per laurearsi con Bruno Ferretti (particolare curioso la sua tesi verteva su "*I modelli a shell dei nuclei atomici"* che furono invece pane quotidiano per me nella mia carriera di fisico nucleare). Da Roma sarebbe partita poi la sua importantissima attività scientifica come ricercatore teorico e apprezzato ed amato capo-scuola. Di ciò altri hanno parlato e parleranno (in particolare i suoi ex-allievi, i "gattini") e qui Luciano Maiani.

Conta per me ricordare come la SIF, seconda madre comune dopo la Normale, doveva ritrovarci insieme dal 1977 (Presidente Carlo, io Vice-Presidente e Raoul dopo qualche anno Vice-Direttore de *La Rivista del Nuovo Cimento*). È in questa qualità che, insieme con me, direttore, e Pio Picchi, secondo Vice-Direttore della Rivista, contribuì in modo essenziale alla rinascita e al rinnovamento editoriale della Rivista (in particolare durante il periodo della mia Presidenza dal 1981 al 1998) che poi proseguì nel tempo con successo, oggi più che mai evidente sotto la direzione di Luisa Cifarelli e dell'attuale Consiglio. La sua dedizione e la sua competenza, prestata fino al 2003, quando entrambi lasciammo l'incarico, furono inestimabili anche per ciò che riguarda altre attività editoriali della SIF, per esempio nella fondazione de *Il Nuovo Saggiatore* nel 1985. È stato inoltre direttore di due corsi della Scuola Internazionale di Fisica "Enrico Fermi" nel 1971 ("*Developments in High-Energy Physics"*) e nel 1980, insieme con Giovanni Costa ("*Theory of Fundamental Interactions*").

Nel ricordare inoltre che egli, insieme con Nicola Cabibbo e Luciano Maiani, ha ricevuto, tra i numerosi riconoscimenti, il Premio Enrico Fermi della SIF nel 2003, aggiungerò che nel 1984 aveva già ricevuto un riconoscimento alla conferenza di Bologna per il 50° anniversario della Fisica delle Interazioni Deboli e che è stato tra i fisici insigniti di riconoscimento e diploma in occasione delle celebrazioni del Centenario della SIF (Roma, Campidoglio 1997).

Ricordarlo quindi è non solo ripetere i suoi meriti scientifici ma ritornare alla sua storia umana ricca di valori e qualità non comuni che ispiravano stima, affetto e ammirazione. Piuttosto schivo e lontano dalla benché minima presunzione, dotato di una squisita sensibilità culturale ed umana, rendeva preziosa la sua amicizia. Dei suoi figli, della sua famiglia, dei suoi nipoti, non resta che condividere non solo il cordoglio ma una grande nostalgia.

Renato Angelo Ricci
Presidente onorario SIF