

# **The Origins of Gravitational Wave Research in Italy**

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***'A Century of General Relativity', MPIWG Conference – 2-5 December 2015, Berlin***

# GWs in Rome: birth of an experimental activity



Sapienza University of Rome

**The first place in Italy where a research activity expressly devoted to GWs starts is Rome.**

# 1970: the birth of the gravitational wave group in Rome



**Key figures: Edoardo Amaldi  
and Guido Pizzella**

The group was born between  
september 1970 and 1971, on the  
initiative of Edoardo Amaldi and his  
young assistant Guido Pizzella

Guido Pizzella and Edoardo Amaldi at the  
General Relativity Conference in Padua in 1983.  
Photo shot by Emilio Segrè.

# The beginning of GW activity in Amaldi's words

*The idea of starting an experiment aiming to detect GW in Rome was stimulated by the Course on Experimental Tests of Gravitational Theories held in **summer 1961** at the **Scuola Internazionale E.Fermi in Varenna**, where the problem was discussed by **J.Weber**. The program remained rather vague for practical reasons until **1968**, when **W. Fairbank** spent a few months in Rome at **G.Careri's** low temperature laboratory. When Fairbank mentioned his intention of starting the development of a low temperature gravitational antenna, Careri who was informed for long time of the interest of E. Amaldi in the subject, suggested a first direct contact. This was the beginning of the collaborations between the groups of Stanford (W. Fairbank), Louisiana State University (W. Hamilton) and the Istituto di Fisica of Rome. Already at this stage a number of conversations with **R.Ruffini** stimulated the beginning of these researches.*

Amaldi, Pizzella. The GW experiment in Rome: progress Report.  
Internal Note 645, 10 November 1975



# Guido Pizzella



Guido Pizzella and Edoardo Amaldi in  
Rignano Flaminio, 1979

- **Sixties:** Pizzella spends several periods in USA, working mainly with Van Allen (Iowa University), encouraged by Amaldi with the aim of starting a space research group in Rome.
- **Since 1963** Pizzella becomes the leader of the group for space research in Rome (Heos, ESRO satellite, for solar wind measurements).
- **Summer 1970:** comes back from the USA with the idea of beginning an experiment in fundamental physics. Uncertainty between cosmic background radiation and gravitational waves.
- **September 1970:** proposes to Amaldi to begin a research activity for GW detection in Rome.

# Pizzella: GW detection or Cosmic Background Radiation?



- **1965:** Penzias A., Wilson R., A «Measurement of Excess Antenna Temperature at 4080 Mc/s», *Astrophys. Journ.*
- **1965:** Dicke R., Peebles P., Roll P., Wilkinson D., «Cosmic Blackbody Radiation», *Astrophys. Journ.*



- **1967:** Weber J., «Gravitational Radiation», *Phys. Rev. Lett.* Reporting the first possible gravitational wave signals, excitations of the detector well above thermal-noise
- **1968:** Weber J., «Gravitational-Wave-Detector Events», *Phys. Rev. Lett.*
- **1969:** Weber J., «Evidence for Discovery of Gravitational Waves», *Phys. Rev. Lett.*

# The beginning of GW activity in Pizzella's words



Guido Pizzella and Edoardo Amaldi in  
Rignano Flaminio, 1979

**Pizzella, 1990:**

*In **September 1970** I said to Amaldi: Professor, I want to make an experiment for the search of gravitational waves. His eyes lighted and he looked at me for a long while. In that moment nothing was more important than the decision that was to be made.*

# The start of Rome-Louisiana-Stanford collaboration



William Hamilton (Louisiana State University)



William Fairbank (Stanford University)



Guido Pizzella (Sapienza University)

- **April 1971: Pizzella, Cerdonio, Marconero and Modena** go to USA and visit Stanford (Fairbank), Louisiana (Hamilton) and the Bell Telephone Laboratory (Tyson) had constructed a GW Weber type detector.

## The originary GW group in Rome:

**Edoardo Amaldi, Guido Pizzella, Massimo Cerdonio, Renzo Marconero and Ivo Modena.**

# Keeping physics alive



Bombing of San Lorenzo district in Rome, 19 July 1943

# Edoardo Amaldi

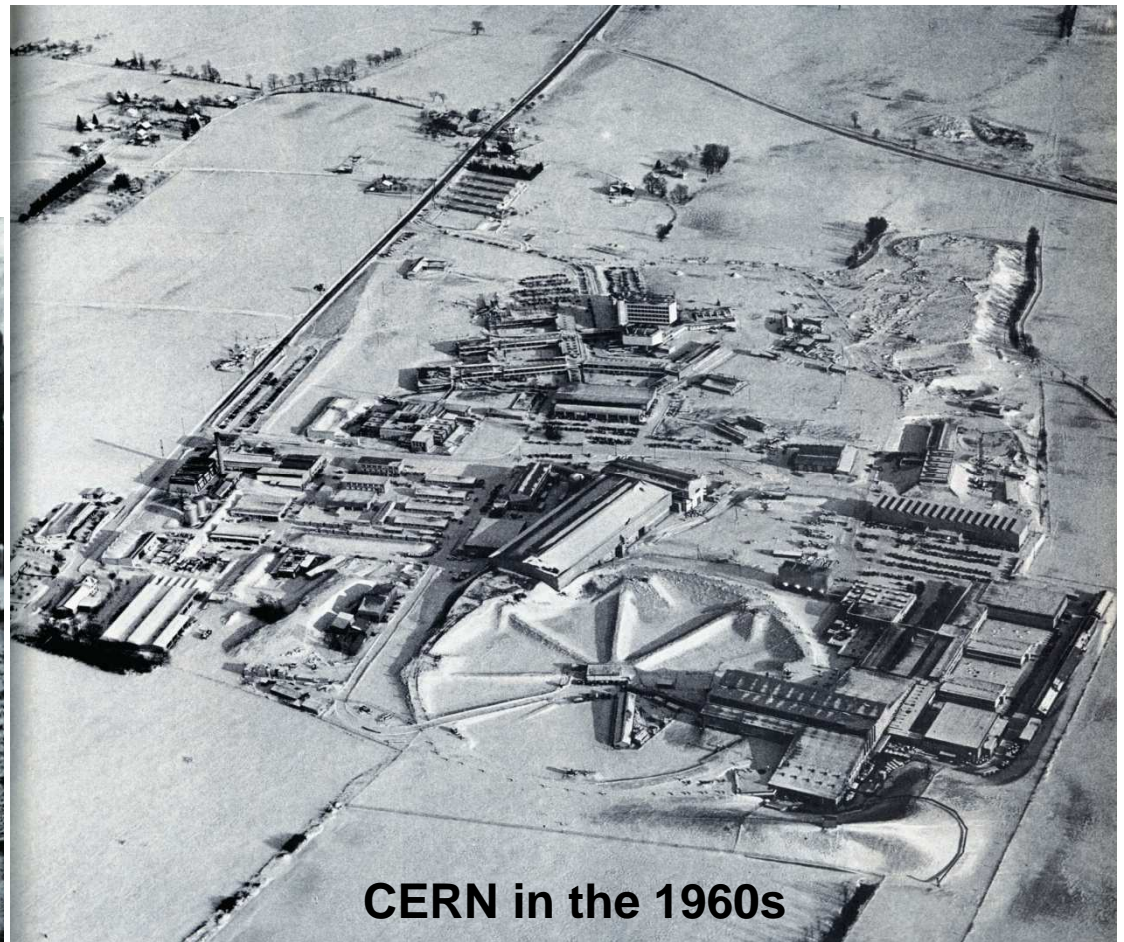


- 1954: birth of CERN. Amaldi had been the Secretary General in 1952-1954, in the delicate phase which brought to the definite affirmation of the European Laboratory project and the final ratification of the member states.

10 June 1955



Felix Bloch laying the 1° stone



CERN in the 1960s

# Edoardo Amaldi



- European Space Research: Amaldi's contribution to the foundation of ESA

ATV-2 Johannes Kepler  
ATV-3 Edoardo Amaldi  
ATV-4 Albert Einstein



16 December 1958

Prot.N° 4674/A

Distinguished Prof.  
Gino CROCCO  
College Road 74  
PRINCETON - N.J.

Dear Gino,

After our discussion at Salvini's home in Rocca di Papa at the end of July, I thought over the possibility to develop an appropriate activity in Europe in the field of rockets and satellites. It is now very much evident that this problem is not at the level of the single states like Italy, but mainly at the continental level. Therefore, if such an endeavour is to be pursued, it must be done on an European scale as already done for the building of the large accelerators for which CERN was created.

The launch of one or more Euroluna, performed by a dedicated European organisation, would definitely be of the highest importance, both moral and practical, for all the nations of the continent.

With these ideas in mind, at the end of July I wrote a letter to Broglio who replied, at the end of August, expressing his substantial agreement with the theoretical formulation of the problem but also a considerable scepticism with regards to the practical feasibility of an actual project.

During the Conference of Geneva, held in the first half of September, I had the opportunity to discuss it with Rabi who reacted very positively and stated that, if this would have developed further, he would have done everything possible for obtaining the support of the United States. Actually, himself being a representative of the United States in the NATO Science Committee, he thought that this could be the initiating body for this activity; however, I think this wouldn't be appropriate, as I shall explain later.

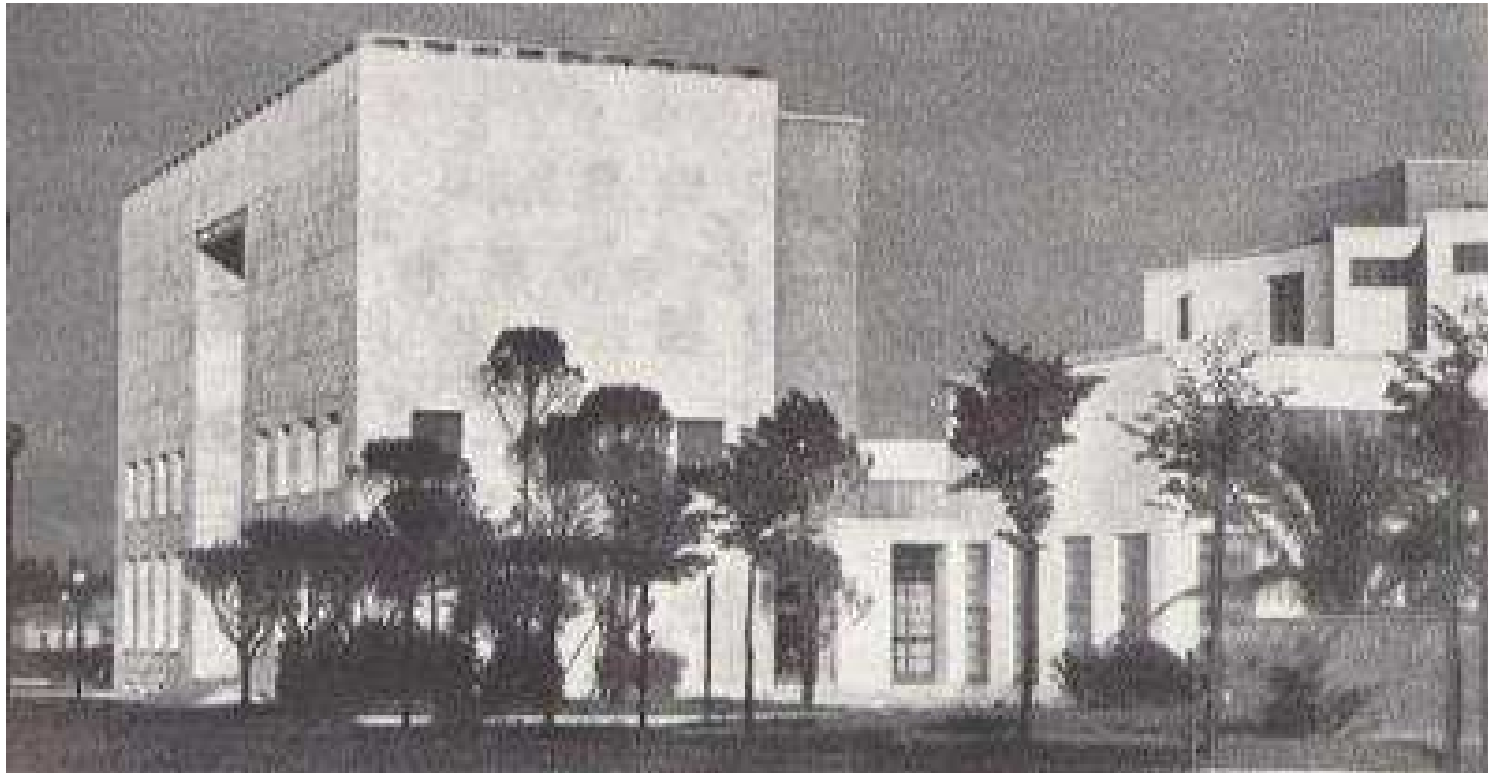
## The low water mark of General Relativity, 1925-1955



*Starting in the early 1920s, after the period of its reception, the general theory of relativity endured some very lonely years, something like a "desert crossing"; a difficult time, in any case, that was not to end before the late 1950s.*

**Jean Eisenstaedt, 1989**

# **General Relativity and Gravitational Radiation in Rome in the the late Fifties and early Sixties**



Istituto Matematico 'Guido Castelnuovo', University Sapienza

# General Relativity and Gravitational Radiation in Rome in the late Fifties and early Sixties



Carlo Cattaneo (1959)

- Degree in Mathematics under Levi Civita's supervision (1936, not on General Relativity).
- 1950s: he begins to work on General Relativity.

Lichnerowicz, Carlo Cattaneo, Rend. Acc. Linc., 1980:

*Très vite, Cattaneo va devenir, dans ce champ nouveau pour lui, un maître. Après l'élaboration d'une analyse critique de l'axiomatique de la relativité restreinte, il en vient dès 1958 à l'un des thèmes le plus importants de toute son oeuvre: la formulation relative des lois physique en relativité générale.*

# General Relativity and Gravitational Radiation in Rome in the late Fifties and early Sixties



Carlo Cattaneo (1959)

C. CATTANEO, General Relativity: Relative standard mass, momentum, energy and gravitational field in a general system of reference. *Nuovo Cim.*, 10, 1958, 318-337.

C. CATTANEO, On the energy equation for a gravitating test particle. *Nuovo Cim.*, 11, 1959, 733-735.

C. CATTANEO, Dérivation transverse et grandeurs relatives en relativité générale, *Compt. R.* 248 (1959)

C. CATTANEO, Conservation laws in general relativity. *N. Cimento* 10 (1958)

- **1958:** organizes a summer School on Relativity in Sestrier (Bergmann, Lichnerowicz, Synge)
- **Since 1961-62** Professor in charge for the complementary course of Relativistic Theories (for Maths and Physics students). The first Relativist Theories Cathedra in Rome will be established for him in the 1970s.

# Cattaneo's research group within the National Committee for Mathematics

1960-1961

Research group N. 36: Relativity

Director: Carlo Cattaneo

Research grant: S. Bonazzola

Researchers: L. Alfieri, G. Caricato, G. Ferrarese

1961-1962

Research Group N. 36: Einstein's theory of gravitation

Directors: Carlo Cattaneo and Antonio Signorini

Researchers: F. De Simoni, G. Caricato, G. Ferrarese, S. Bonazzola

Research grant: C. Rea

1962-1963

Research Group N. 36: Einstein's theory of gravitation

Director: Carlo Cattaneo

Researchers: G. Arcidiacono, S. Bonazzola, G. Caricato, F. De Simoni, G. Ferrarese

Research grant: V. Cantoni

## April 1963: Felix Pirani at Rome University to speak about GWs



Istituto Matematico 'Guido Castelnuovo', University Sapienza

### **S. Bonazzola (Interview 10 June 2015):**

3-4 seminars, about 10 people participating (only mathematicians, among which Bonazzola, Ferrarese and Arrigo Finzi). Main problem discussed: existence or not of GWs.

# Livio Gratton and the beginning of relativistic astrophysics in Rome



Livio Gratton (1910-1991)

- **1930:** graduates in physics. First thesis in Italy about relativistic cosmology, supervised by Castelnuovo and Levi Civita.
- **1949-1960:** professor and astronomer in Argentina.
- **1960:** returns to Italy with his family from Cordoba (Argentina). Ionized Gas Lab (Frascati) **His return had been prepared by Amaldi, who aimed at encouraging the creation in Rome of a research center for astrophysics and a school of astrophysics.**
- **Young relativists in the lab: Bruno Bertotti, Franco Pacini, Arrigo Finzi, Alfonso Cavaliere. Scientific exchanges with the GR group of Carlo Cattaneo.**

- **1962:** First roman cathedra in Astrophysics established for Gratton. In the next years the group will be displaced in Frascati, in the so called 'baracche' (huts).



# The relativistic astrophysics group in Rome

- Funding from CNR not sufficient to get instrumentation. Mainly theoretical studies of very modern problems: «properties of iperdense matter, gravitational collapse and neutron stars, equilibrium of large masses» (Activity Report 1963-1965, CNR Archives)
- Some group members: A. **Finzi**, G. **Szamosi**, G. **Setti**, F. **Pacini**, P. **Giannone**, A. **Cavaliere**. Collaborations (Pacini) with B. **Bertotti** form Ionized Gas Lab and S. **Bonazzola** from Institute of Mathematics 'Castelnuovo'

## Arrigo Finzi

- **1936-1937**: graduated with Levi Civita.
  - **1961-1962**: group of lessons at Physics Institute in Rome on problems of General Relativity.
  - **Main interests**: Astrophysics and General relativity.
- A. Finzi, *Gravitational attraction at long distance*, Nota interna n°24, 15-1-1963.
- A. Finzi, *On the validity of Newton's law at long distances*, Monthly Notices of the Royal Astronomical Society, Vol. 127, p.21, 1963
- **1969**: become professor at the Israel Institute of Technology in Haifa.



# Arrigo Finzi and Newton's Law

A. Finzi, *On the validity of Newton's law at long distances*,  
Monthly Notices of the Royal Astronomical Society, Vol. 127, p.21, 1963

1. *Introduction.*—It has been known for a long time (1, 2) that in the great majority of clusters of galaxies the relative velocities of the member galaxies are very large and do not seem, at first, to be compatible with the stability of the clusters. As the reality of this phenomenon seems to have been established beyond doubt, we are confronted with a problem to which no really satisfactory solution has been found so far within the framework of the accepted dynamical laws.

This problem, as well as a number of other problems in different fields of astrophysics, could perhaps be solved if one were prepared to assume that at a very long distance the attraction between two masses  $m_1$  and  $m_2$  decreases more slowly than  $1/r^2$  when the distance  $r$  increases. For the sake of clarity we shall formulate our hypothesis directly: we shall assume for the force  $F$  and potential  $V$  expressions such as

$$F = \frac{km_1m_2}{\rho^2} \left(\frac{\rho}{r}\right)^{3/2}, \quad V = -2 \frac{km_1m_2}{\rho} \left(\frac{\rho}{r}\right)^{1/2}; \quad (r \gg \rho). \quad (1)$$



At the end of the paper, Finzi acknowledges Amaldi, Bertotti, Gratton and Szamosi for critical reading. In a recent interview, Bertotti told me: «Amaldi was extremely fascinated by heterodox theories, as the one proposed by Finzi.»

# Bruno Bertotti



- **1953:** graduates in mathematical physics in Milan with Udeschini
- **1953-1956:** in Dublin, working at GR under Schroedinger's supervision.
- **1958-1961:** in Princeton, working in Wheeler's group (Bertotti-Robinson solution).
- **1961-1967:** Lab Ionized Gases, in Frascati. Collaborations with Pacini and Cavaliere.
- **1968-69:** European Space Research Institute (ESRIN) in Frascati.
- **1971:** since then professor in Pavia.

**Bertotti (1954)**, *On the two-body problem in general relativity*, Nuovo Cim. [Schroedinger's supervision]

**Bertotti, Plebansky (1960)**, *Theory of gravitational perturbations in the fast motion approximation*, Ann. of Phys

**Bertotti (1973)**, *Is the solar system gravitationally closed?*, Astrophys.Lett.

**Bertotti, Anile (1973)**, *Gravitational slowing down of solid spinning bodies*, Astron. Astrophys

**Bertotti, Catenacci (1975)**, *Effect of gravitational radiation upon electromagnetic waves in a dispersive medium*, Gen. Rel. and Grav.

# The Renaissance of General Relativity

- **1957-1960: Edoardo Amaldi**, President of IUPAP (1957-1960)
- **1960:** The Committee on General Relativity and Gravitation enters the IUPAP (International Union of Pure and Applied Physics)

**André Lichnerowicz and Marie Antoinette Tonnelat:** Presidents of the Committee

**Dmitri Ivanenko:** member of the International Committee on Gravitation and Relativity



# International Committee for General Relativity

Scatolo 4876 -  
Giny, Presidente (1957-60)

Prof. E. Amaldi  
President of IUPAP,  
Istituto di Fisica dell'Universita,  
Piazzale delle Scienze 5  
Roma, Italia

Dear Professor Amaldi,

above all may I with some retardation congratulate You and Your collaborators with beautiful  $\Sigma^+$  discovery; I was delighted to bring my congratulations personally here to Prof. Manfredini.

I permit me to send to You as the President of IUPAP the copy of my letter, as a member of International Gravitational Committee, to its President Prof. A. Lichnerowicz. Clearly the contact with IUPAP are highly desirable.

It is a pleasure to see the contacts between Italian and Russian science developing so nicely, only yesterday I have had the pleasure to meet here in Moscow during nuclear Conference Prof. H. Facchini, Prof. L. Colli and Dr. S. Ferroni.

With sincere wishes, also to all colleagues in Rome

Yours  
*D. Ivanenko*  
(D. Ivanenko).

Prof. D. Ivanenko  
Moscow-234, University,  
Zone I, No 80.

1960, August 22:  
Amaldi to Ivanenko

22 of August, 1960

Prof. D. Ivanenko  
University, Zone I, No 80  
MOSCOW-234  
USSR

I think this is a right moment for a wider development of the research activity on gravitation and general relativity

Dear Professor Ivanenko,

I thank you very much for your kind letter and for the copy of your letter to Prof. Lichnerowicz. I think that this is a right moment for a wider development of the research activity on gravitation and general relativity.

I hope to have pretty soon a new occasion to meet you.

Best regards,

sincerely yours,

(E. Amaldi)

# 1959: a question about gravity and the beta decay

From Amaldi's diary, January 1959

31S. Parto PAA 114 jet - sono a Roma  
in 1 1/2 ore - Nel pomeriggio parlo  
con Agno nella speranza di cercare  
un effetto del campo gravitazionale sulla  
disintegrazione  $\beta$ . La cosa ha origine  
dalla conversazione con Touschek la  
mattina di mercoledì 28 gennaio  
Jethron

6V. Penso tentare di appurare l'effetto  
del campo gravitazionale sulla disin-  
tegrazione  $\beta$  (In) - Piccolo effetto a

**«Is the decay constant of the various beta decay nuclei the same everywhere in the Universe, irrespective of the value of the local gravitational field?»**

**1959, 31 January (Saturday):**

«In the afternoon I speak with Agno of the possibility of looking for an effect of the gravitational field on the beta disintegration.

The idea comes from a discussion I had with Touschek the morning of Wednesday 28 January.»

**1959, 6 February (Friday) :**

«First experiment aiming at verifying the effect of the gravitational field on the beta disintegration (In). Small effect we don't believe in, because the precision of the experimental measurement is not sufficient.»

# Agno's and Amaldi's experiments

*Experiments based on the equivalence principle, according to which a centrifugal field generated by a rotation is locally equivalent to a gravitational field produced by a proper distribution of masses.*

M. Agno, E. Amaldi, *Experimental Search for a Possible Change of the  $\beta$  Decay Constant with Centrifugal Force*. Lincei, Memorie Sc. Fisiche, 1966.

## First experiments:

Sample of  $\beta$  radioactive body with **half-life of the order of 1 hour**, placed in a centrifuge for about 1 hour: activity measured repeatedly as a function of time, before and after centrifugation

In,  $G = 150,000 G_E$

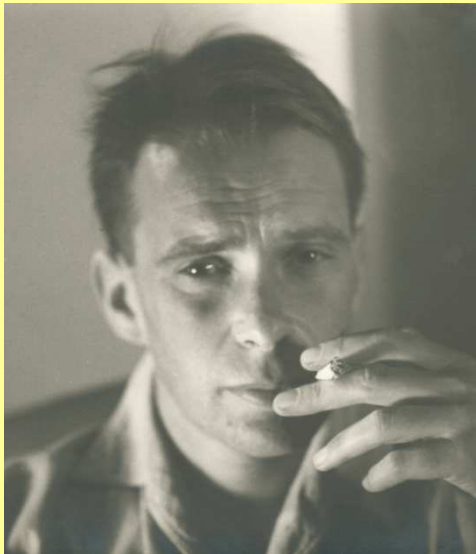
## Papers

- **1961** M. Agno, E. Amaldi, B. Rispoli, G. Sanna, *Misure di vita media di mesoni  $\pi$  su traiettoria rettilinea e circolare*, in *Raccolta delle comunicazioni del congressino 1960 sulla fisica e la ricerca di alta energia*. Frascati 16-17 Dicembre 1960
- **1963** M. Agno, E. Amaldi, G. Matthiae, B. Rispoli, G. Sanna, in *Raccolta delle comunicazioni del Congresso 1962 sulla Fisica e la Ricerca di Alta Energia*, Frascati 7-9 febbraio 1962
- **1963** M. Agno, G. Fronterotta, G. Matthiae, A. Reale (Laboratorio Fisica dell'Istituto Superiore di Sanità), Edoardo Amaldi (Istituto di Fisica), *Misura e vita media di mesoni  $\pi^+$  e  $\pi^-$  su percorso rettilineo e curvo*. Unpublished
- **1966** M. Agno, E. Amaldi, *Experimental Search for a Possible Change of the  $\beta$  Decay Constant with Centrifugal Force*. Lincei, Memorie Sc. Fisiche

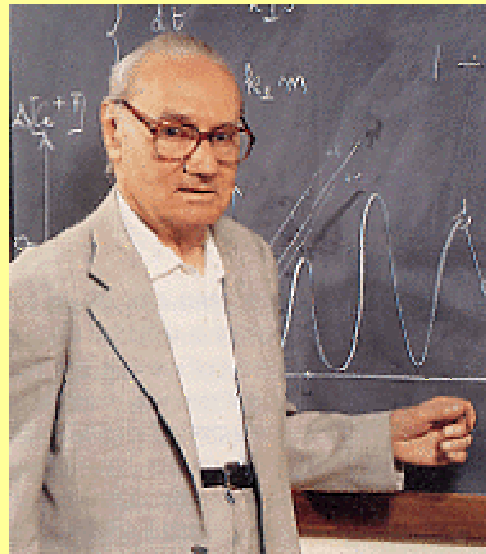
# 1959: a question about gravity and the beta decay

«Touschek was prompted to raise this question by the fact that in the history of physics it had happened several times that an apparent deviation from a conservative law was found, on close examination, to be the result of the perturbation caused by an external field [...]. Could not the non-conservation of parity observed for the weak interaction have a similar origin? This question as we learned later was raised also by other researchers.»

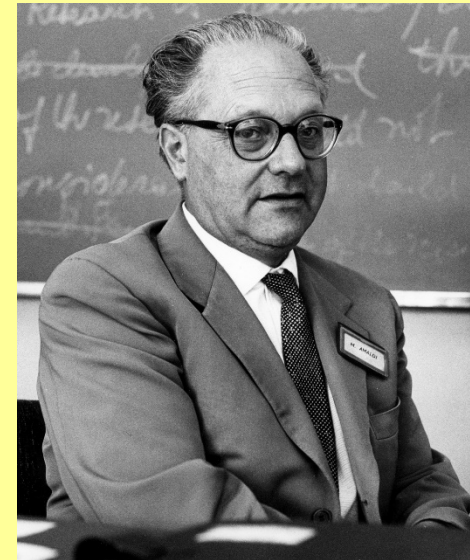
**M. Ageno, E. Amaldi**, *Experimental Search for a Possible Change of the  $\beta$  Decay Constant with Centrifugal Force*. Lincei, Memorie Sc. Fisiche, 1966.



Bruno Touschek (1921-1978)



Mario Ageno (1915-1992)



E. Amaldi (1908-1989)<sup>26</sup>

In 1960 another reason of interest in gravitation came to Amaldi from the East...

# Amaldi and Dmitri Ivanenko



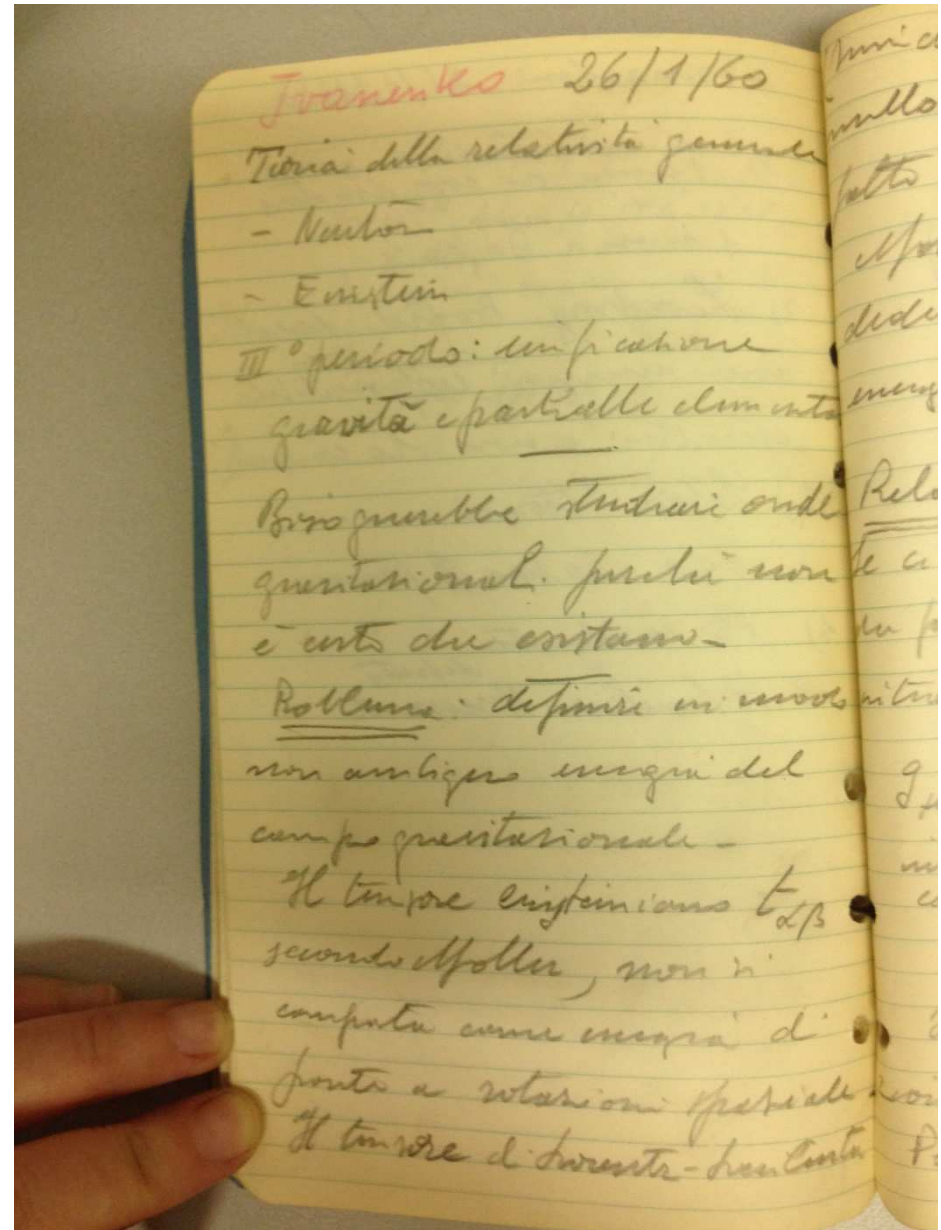
Ivanenko, Dirac and Heisenberg (Berlin, 1958)

- Dmitri Ivanenko (1904, 1994), Moscow University
- In 1947, D. Ivanenko and A. Sokolov developed a model of a graviton as a quantum (of spin 2) of a weak gravitational field: **possibility of transmutations of ordinary particles in a graviton by analogy with creation and annihilation of electron-positron pairs in an electromagnetic quantum**. The model was not correct, because of its approximation of weak field. Ivanenko turned again and again to this idea until he developed the new direction – gauge gravitation theory – in 1961.

# Amaldi and Dmitri Ivanenko

From Amaldi's Diary

- **1960 January-February:** during 20 days Ivanenko visited Italy including INFN in Frascati and Universities in Rome, Turin, Milan, Padua, Naples
- **1960 January 26:** Ivanenko gave a talk at the Physics Institute in Rome, titled *Remarks on transmutation of matter into gravitation*. (INFN Activity Report 1959-1960). Amaldi was present; it was only few days before he left for the inauguration of PS at CERN (February 5).



# Amaldi and Dmitri Ivanenko

From Amaldi's Diary

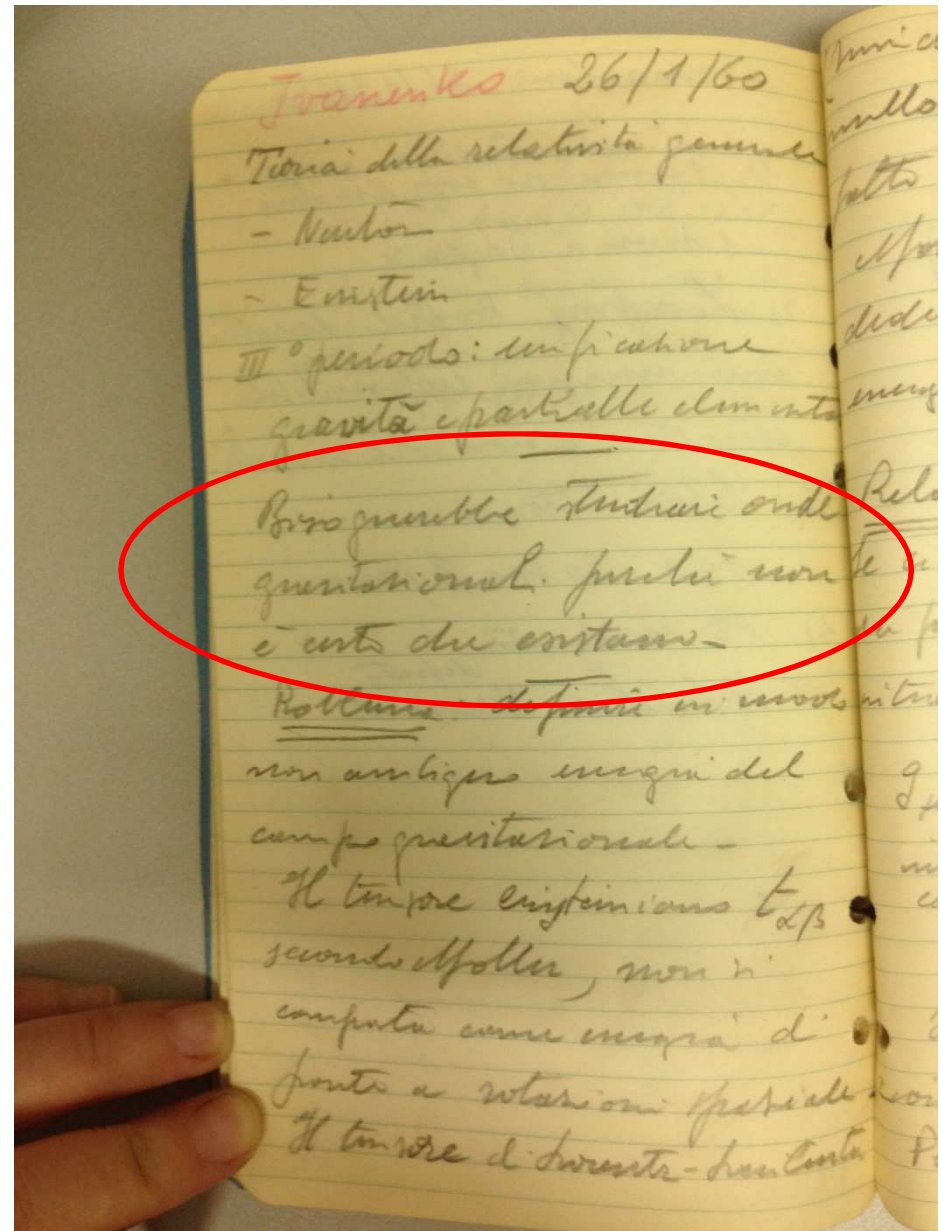
Ivanenko 26/1/60

Theory of general relativity

- Newton
- Einstein

III° period: unification of gravity and elementary particles

**It is necessary to study gravitational waves, because it is not sure they exist.**



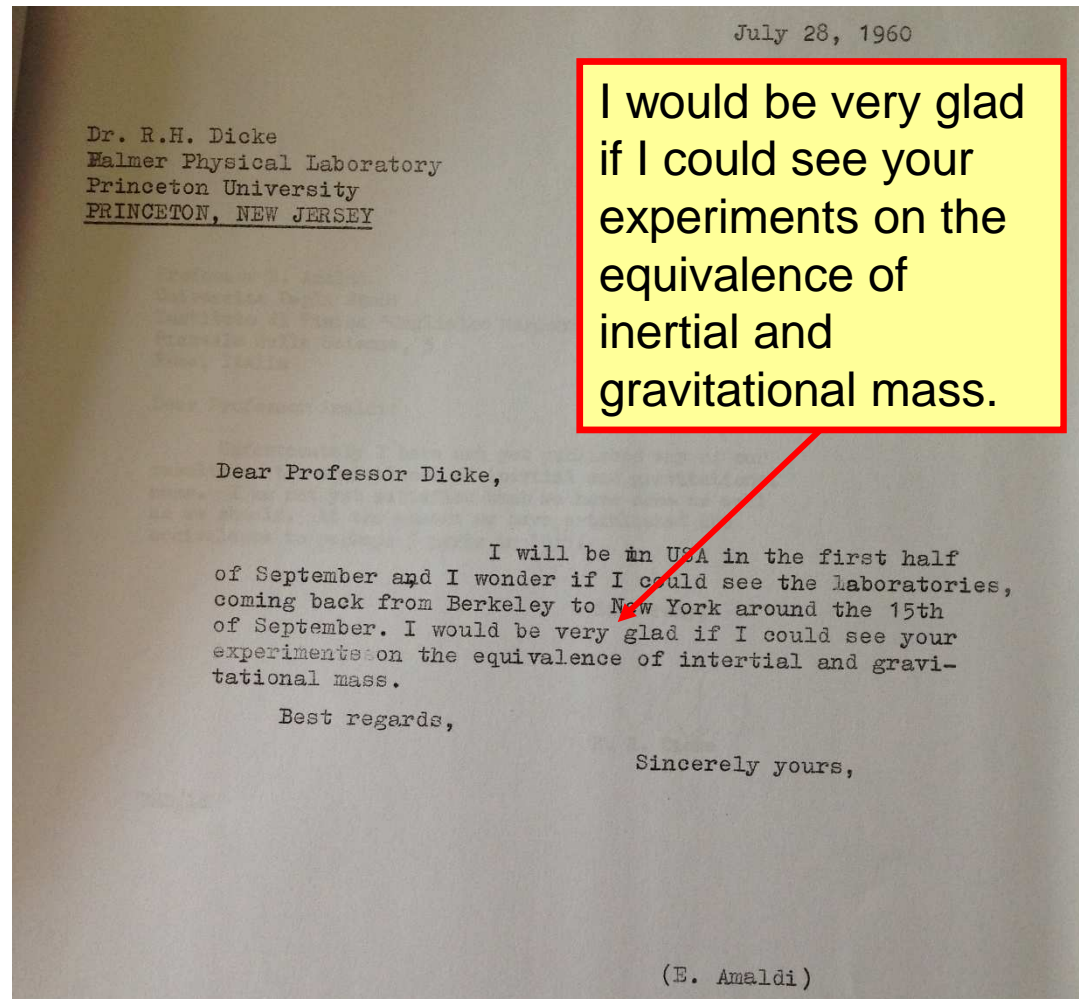
In 1960 another reason of interest in gravitation came to Amaldi from the West...

## 1960: Amaldi visits Robert Dicke's laboratory



In a previous letter of 10 February 1960, Amaldi had asked him preprints and internal notes about his results on the comparison between gravitational and inertial mass.

**1960, July 28:** Amaldi writes to Dicke, telling him he would like to visit his laboratory in Princeton on next September, after the Rochester Conference

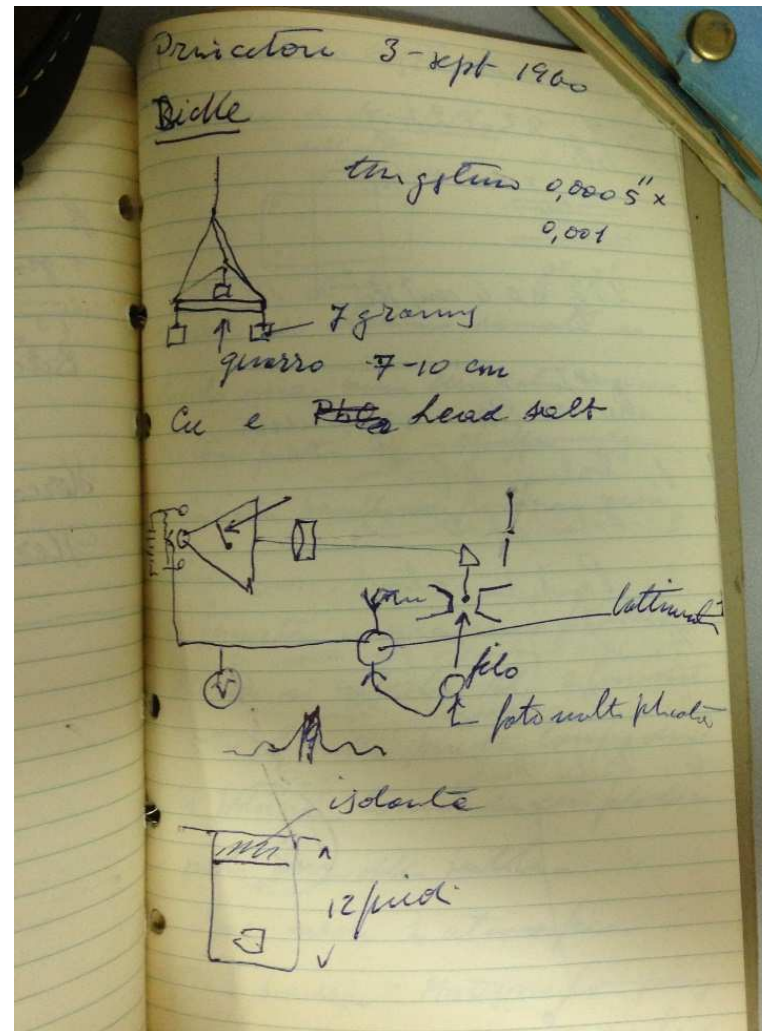


# 1960: Amaldi visits Robert Dicke's laboratory



1960, September 3: Amaldi visits Dicke in Princeton.

(It was possible to identify the date of Amaldi's visit to Dicke through the notes he wrote in his diaries)



Finally, in 1961, came the Varenna School  
on the Experimental Tests of Gravitational  
Theories...

# 1961, 19 June- 1 July: Varenna School on the Experimental Tests of Gravitational Theories



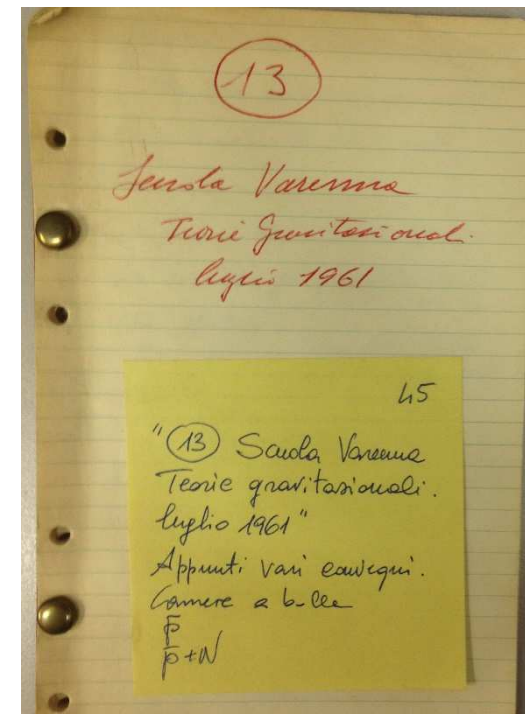
From his diaries, we know **Amaldi** was at the School in the days **27, 28 and 29 June**. There is a diary named after the Varenna school. Strangely it doesn't contain any reference to Weber. Instead, accurate annotations about Bertotti's topics are found.

**Director:** Christian Møller

**Some lecturers:** **B. Bertotti** (Laboratorio Gas Ionizzati, Frascati); **H. Bondi** (King's College, London); **R. H. Dicke** (Princeton); **J. Weber** (University of Maryland)

**Among the students** (24 in total), from Rome: **Silvano Bonazzola**.

Other interesting students: John Ellis (London); Donald Glaser (Copenhagen).



# Remo Ruffini



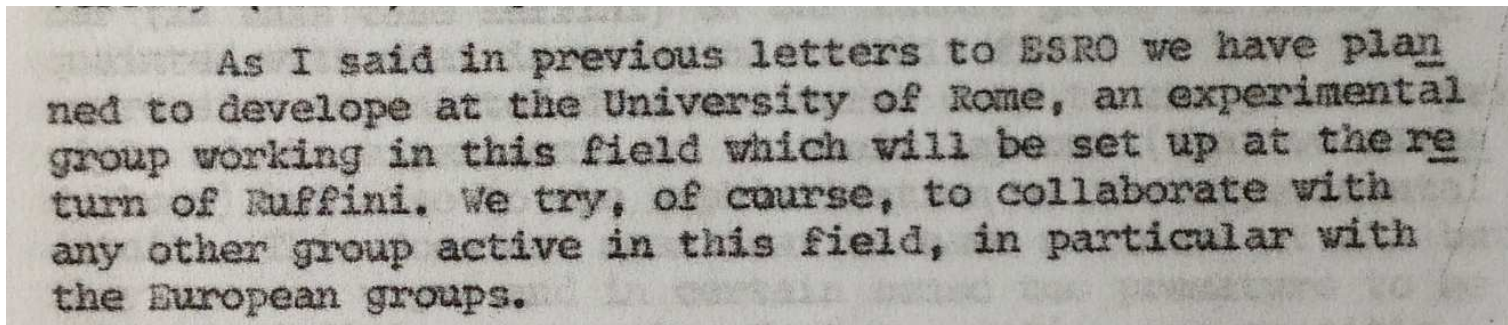
- **1966:** S. Bonazzola and F. Pacini, *Equilibrium of a Large Assembly of Particles in General Relativity*, Phys. Rev. 148, 1269. Critical mass of bosonic stars, theoretical work.
- **1966:** Refusing to do a thesis on particle physics at Cern, Ruffini said to Amaldi he would like to study GR. Amaldi replied: «There should be place for one in Italy!». The relationship between them strengthens during this period of GR studies.

Thesis with C. Cattaneo (Institute of Mathematics 'Castelnuovo'), under the supervision of S. Bonazzola, Cattaneo's assistant. Continuation of Bonazzola's and Pacini's theoretical work, applying numerical calculus with the newly arrived calculators.

- **1967, June-July:** Ruffini in Hamburg studying with **Pascual Jordan**, to learn more about GR and be prepared to go to work with Wheeler and Dicke.
- **1967, 1<sup>st</sup> September:** Ruffini starts to work in Princeton with Wheeler, it is his first time in USA.

# Remo Ruffini

- **1967, 7 July:** Amaldi writes to R. Lüst of the Max Planck Institute for Physics and Astrophysics, Munchen, 'in connection with the application presented by Dr. Ruffini for ESRO fellowship which would allow him spending two years to work experimentally (Dicke) and theoretically (Wheeler) at Princeton and also for some time at the Mariland University (Weber) on gravitation'



As I said in previous letters to ESRO we have planned to develop at the University of Rome, an experimental group working in this field which will be set up at the return of Ruffini. We try, of course, to collaborate with any other group active in this field, in particular with the European groups.

«Just to mention one possible line of research we are considering the possibility of establishing coincidences between **detectors of gravitational waves** placed at large distances (one in USA and one in Italy)»

# Remo Ruffini

- **1968, 9 february:** Ruffini writes to EA attaching an activity report he has prepared for ESRO to support the renewal of his fellowship for a second year at Princeton University:

« I have been in the U.S.A. since September 10<sup>th</sup>, 1967. The purpose of my studies here is to get acquainted with the most recent development in research on gravitation in the U.S.A., both experimental and theoretical. This is in connection with a new research program on gravitation (experimental and theoretical) established at Rome University where I am a member of the Physics Department Faculty. This research program is under the general leadership of Professor Edoardo Amaldi. The new group puts strong emphasis on the more physical aspects of gravitation. The new group will work in close collaboration with the “Gruppo Spazio” at Rome University (Professor Guido Pizzella) with the Italian Space Research Organization (Professor Broglio), with other Italian universities and such European organizations as ESRIN and ESRO. [...] It is also expected that a substantial contribution will be given to this new group from outstanding scientists belonging to such other institutions, as Professor John Archibald Wheeler, Professor Tullio Regge, Professor Robert Dicke. [...] Researches on gravitation are not by any means new at Rome University. Quite a part from earlier work on gravitation theory of Tullio Levi Civita and Enrico Fermi, significant investigation have been carried out in this field in the past few years (measurement of muon and beta decay in non-inertial frames; theory of superdense stars; theory of gravitational radiation). »

Who???

CNR Astrophysicist group,  
directed by Gratton

# The start of GW detection in Rome



- **September 1970:** Guido Pizzella is finally back from the USA and proposes to Amaldi to start an activity in GW detection.

**Amaldi had finally found  
the right man!**

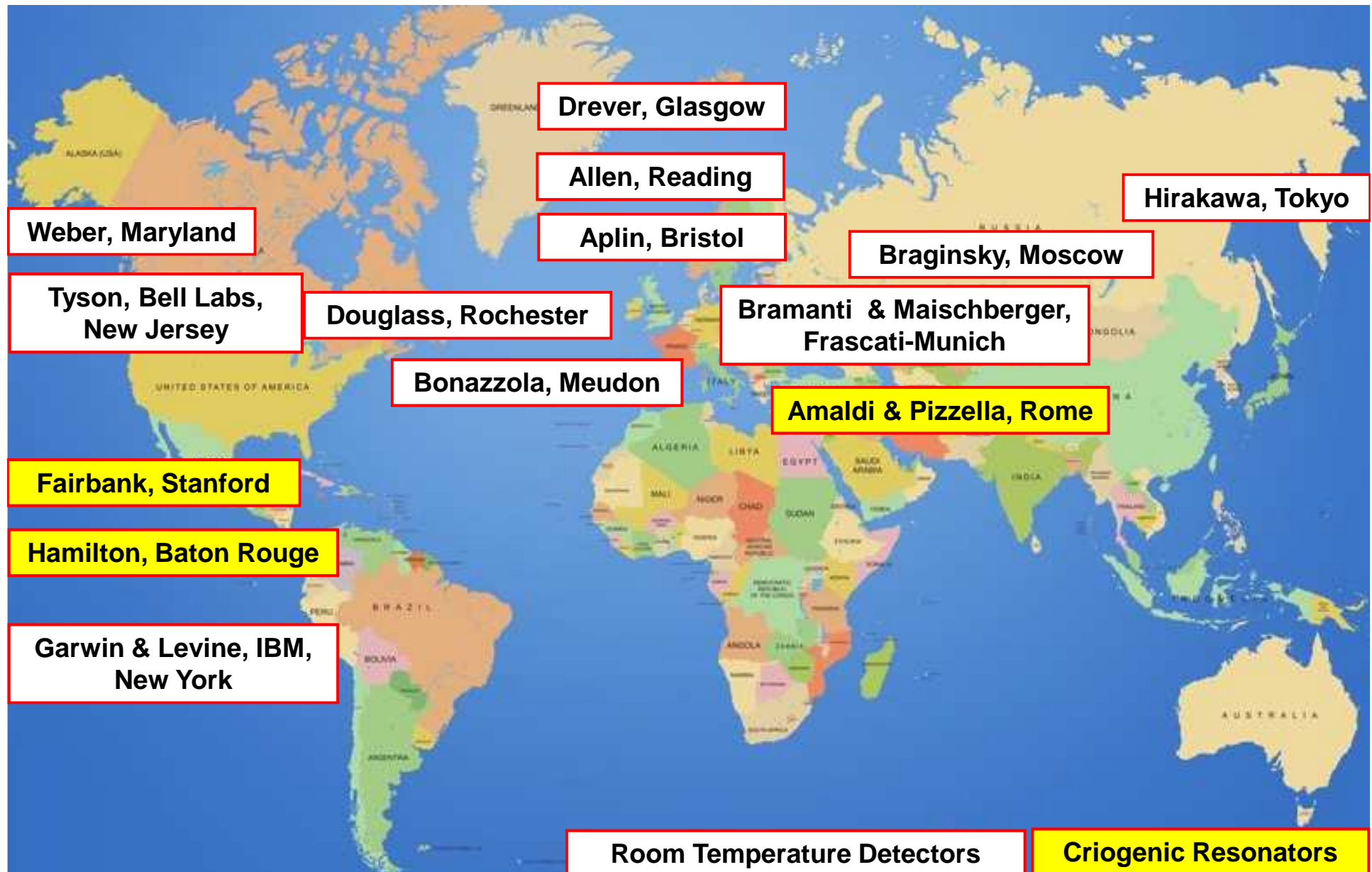
**The originary group in Rome:**  
**Edoardo Amaldi, Guido Pizzella,**  
**Massimo Cerdonio, Renzo Marconero**  
**and Ivo Modena.**

## Some years later...



1973, Monterotondo (near Rome), Laboratory 'Nuovo Pignone' of the ENI group. From Left: G.V. Pallottino, I. Modena, G. Pizzella, E. Amaldi...

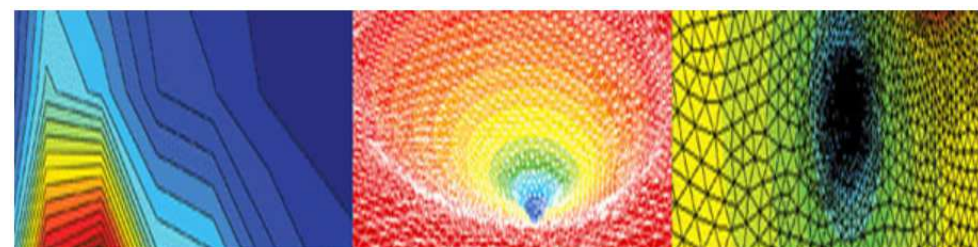
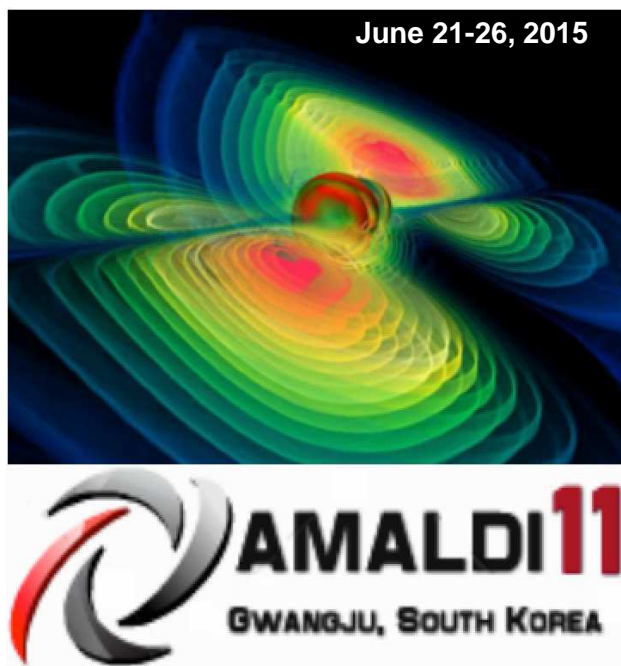
# 1970-1975: a picture of GW detection in the World





**Thank you for your attention!**  
**Any questions?**

# Edoardo Amaldi Conferences on Gravitational Waves



7th Edoardo Amaldi Conference on Gravitational Waves  
8-14 July 2007 / Sydney Australia



The image shows the LISA Pathfinder satellite in space. It has a large, rectangular solar panel array on top, covered in blue solar cells. The main body of the satellite is gold-colored with a large white rectangular patch. Various instruments and antennas are visible on the sides. The background is a starry space with a bright yellow star in the upper left.

**LISA Pathfinder  
Launched on 2  
December 2015**

# Backup Slides

# Joseph Weber, father of resonant bar detectors



- **1955-1956:** fellow at Princeton, working on general relativity with Wheeler.
- **1957:** Weber, Wheeler, «Reality of the Cylindrical Gravitational Waves of Einstein and Rosen»
- **1960:** Weber, «Detection and generation of gravitational waves», Phys. Rev.
- **1961:** Publishes the book «General Relativity and gravitational waves».
- **1967:** Weber, «Gravitational Radiation», Phys. Rev. Lett. Reporting the first possible gravitational wave signals, excitations of the detector well above thermal-noise
- **1968:** Weber, «Gravitational-Wave-Detector Events», Phys. Rev. Lett.
- **1969:** Weber, «Evidence for Discovery of Gravitational Waves», Phys. Rev. Lett.

# Massimo Cerdonio



- **1964:** gets his degree in physics in Rome, under Giorgio Careri's supervision (low temperature lab). He gets an expertise in superconductivity and Josephson junctions and SQUIDs.
- **1967-1969:** Cerdonio collects Weber's works about GW detectors and suggests the idea of setting up a low temperature resonant bar, to increase the detector's sensitivity to GWs. (Careri's used to stimulate his students to propose their own ideas about new experiments.)
- **1968:** Fairbank spends a sabbatical period in Rome, visiting Careri's lab. Cerdonio reports to CNR about the first working SQUID set up in Italy.
- **1971:** he becomes part of Pizzella's GW team. He suggests to call Ivo Modena, expert in low temperature physics.

# The start of GW detection in Rome

## The originary group:

**Edoardo Amaldi, Guido Pizzella, Massimo Cerdonio, Renzo Marconero and Ivo Modena.**

- **1970:** In Nov. - Dec. Pizzella and Marconero visit the groups of W.D.Allen at the University of Reading and of P.S.Aplin in Bristol, who were constructing room temperature Weber type detectors. Discussions with Bertotti and Cabibbo about Weber's experiments.
- **1971:** In January Amaldi receives confidentially from Remo Ruffini the Stanford and Louisiana proposal for a detector consisting in a 5 ton aluminum bar cooled to very low temperature (0.003 K) employing a SQUID amplifier coupled to a resonant transducer.
- **April 1971:** Pizzella, Cerdonio, Marconero and Modena go to USA and visit Stanford (Fairbank), Louisiana (Hamilton) and the Bell Telephone Laboratory (Tyson) had constructed a GW Weber type detector. With Hamilton they visit Mississippi-NASA Test Facility Center where the Universities of Stanford and Louisiana had agreed to construct the cryostats for their detectors.

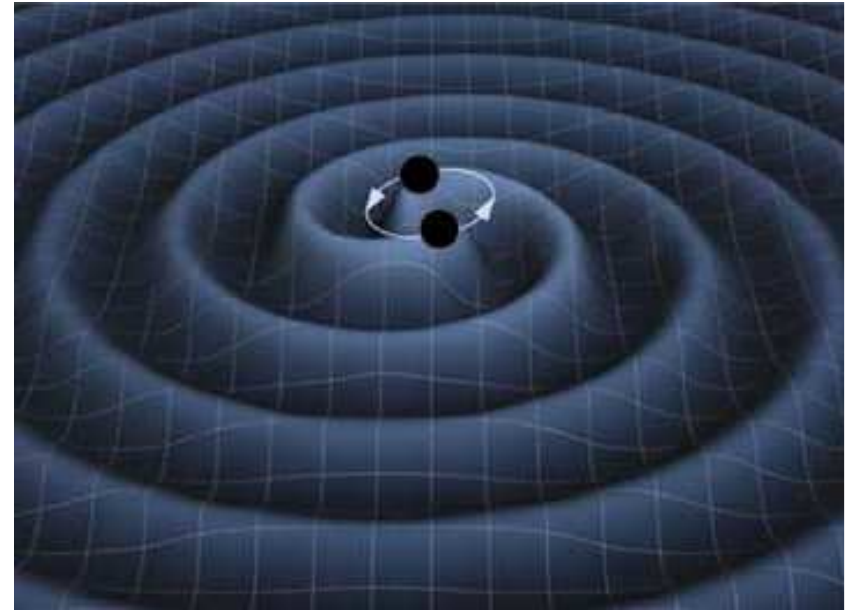
## Still few years later...



Eugenio Coccia, Massimo Bassan, Edoardo Amaldi, ..., Sergio Frasca

# To be or not be: a GW problem

- **1916, June 22:** Einstein presents at the Prussian Academy his first paper on GW «Approximate integration of the equations of the gravitational field». In the weak field approximation the linearized equations admit solutions propagating in space with velocity  $c$ .
- **1918:** Einstein publishes the paper «On gravitational waves». Answer to critical remarks by Levi-Civita.
- **1922:** Eddington, «The propagation of gravitational waves». No mechanical system built by man can produce detectable GWs.
- **1956:** Pirani, Proceedings of the Chapel Hill Conference.
- **1959:** Bondi, Royaumont Conference. A GW crossing a mechanical oscillator would alter its length.
- **1960:** Weber, «Detection and generation of gravitational waves», Phys. Rev.



# The Renaissance of General Relativity

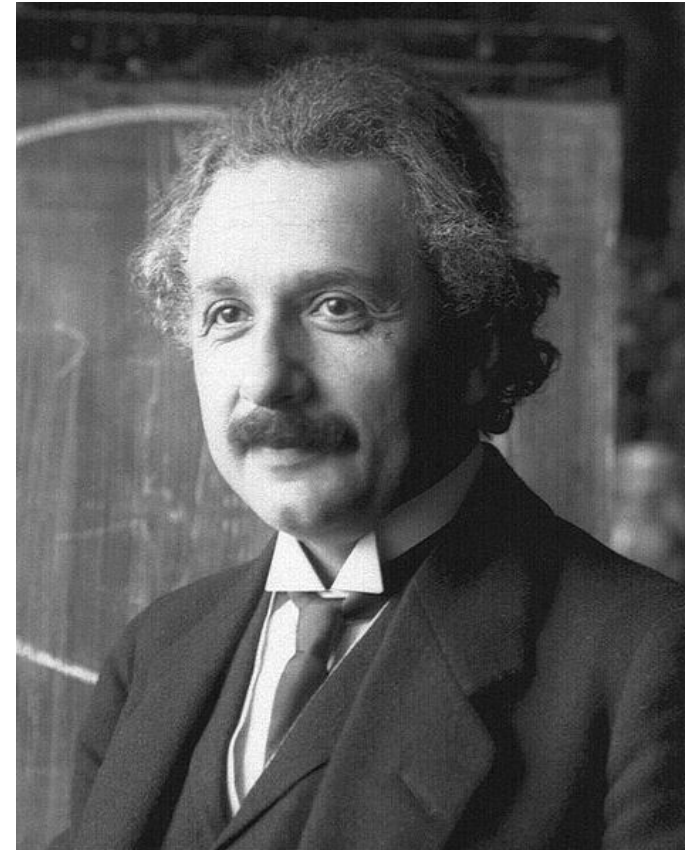
- 1955, Bern: GR0 Conference for the Jubilee of Relativity Theory
- 1957, Chapel Hill: GR1 Conference on the Role of Gravitation in Physics
- 1959: Committee on General Relativity and Gravitation
- 1959, Royaumont (Paris): GR2 Conference on Relativistic Theories of Gravitation

- 1963: Discovery of quasars
- 1964: First detection of cosmic background radiation
- 1967: First observation of pulsar

**It was the birth of  
Relativistic Astrophysics**

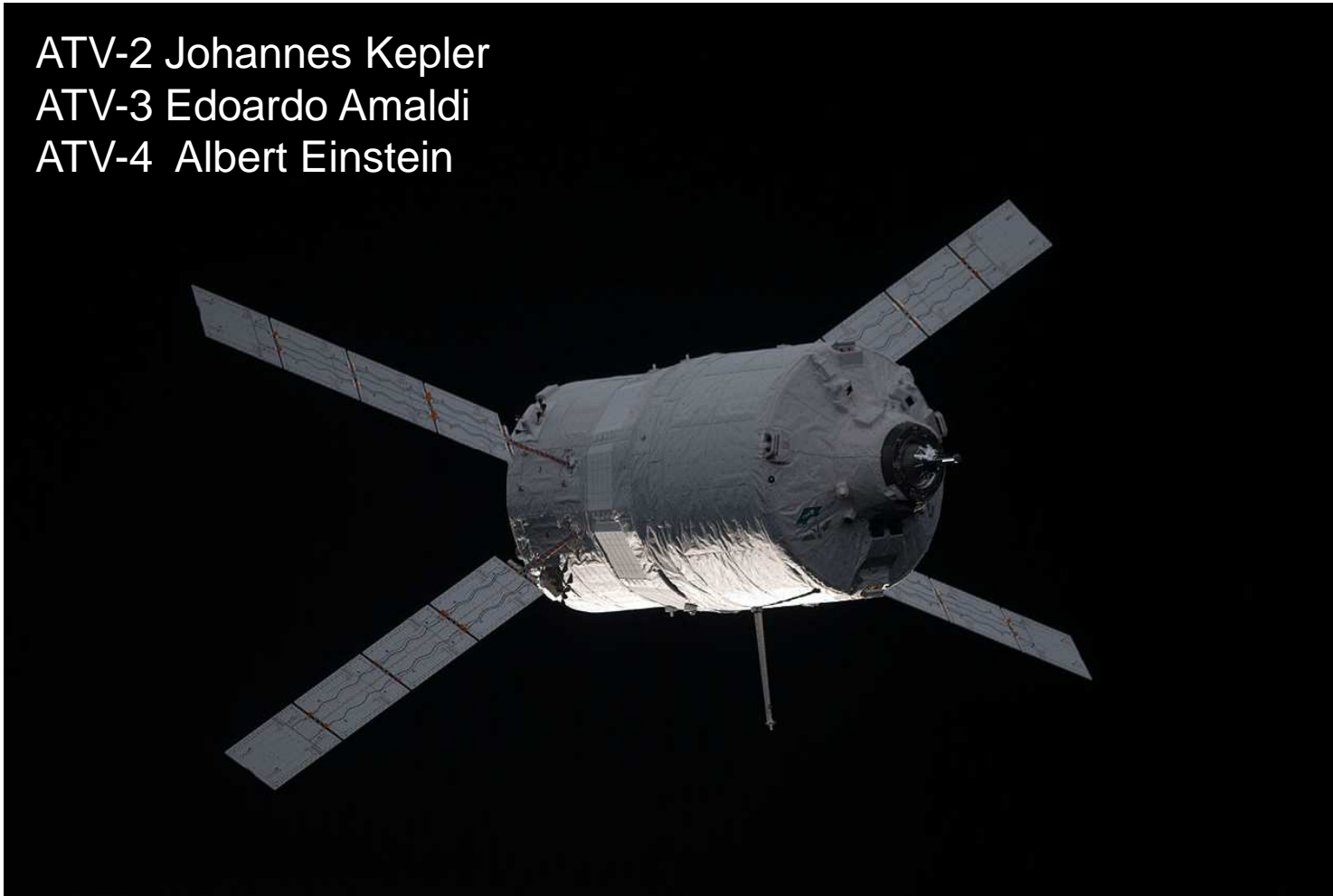
# The birth of General Relativity

- 1915, November: Einstein presents to Royal Prussian Academy of Sciences his theory of gravitation (and Explanation of the Perihelion Motion of Mercury from General Relativity Theory)
- 1919: second experimental confirmation by Arthur Eddington, the bending of light rays during solar eclipse



# Edoardo Amaldi in the 50s and 60s

ATV-2 Johannes Kepler  
ATV-3 Edoardo Amaldi  
ATV-4 Albert Einstein



European Space Agency's "**Edoardo Amaldi**" **Automated Transfer Vehicle-3** (ATV-3) approaches the **International Space Station**. The unmanned cargo spacecraft docked to the space station at 6:31 p.m. (EDT) on **March 28, 2012**, delivering 220 pounds of oxygen, 628 pounds of water, 4.5 tons of propellant, and nearly 2.5 tons of dry cargo, including experiment hardware, spare parts, food and clothing.

# Edoardo Amaldi



- Enrico Fermi and the young researchers in the Institute of via Panisperna in Rome

O. D'Agostino, E. Segrè, E. Amaldi, F. Rasetti, E. Fermi (1934). Picture shot by B. Pontecorvo.

## 1961, 19 June- 1 July: Varenna School on the Experimental Tests of Gravitational Theories

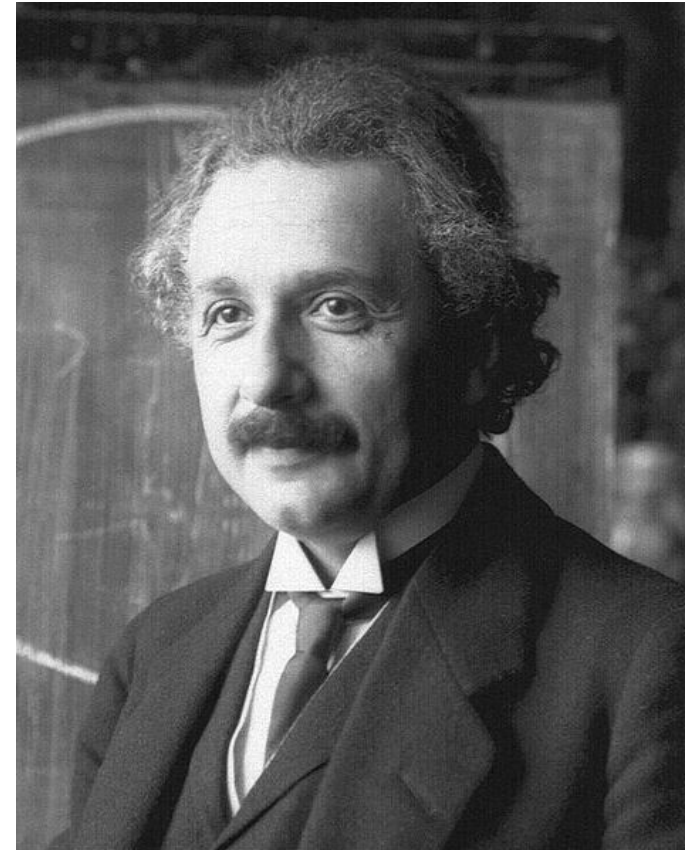


Joseph Weber 1919-2000

Furthermore, the exchange of letters between Amaldi and Weber is very poor, considering that Weber is the father of gravitational wave detection and considering what Amaldi writes in the note quoted at the start of this talk. During the Sixties only one short letter written by Weber to Amaldi (15 September 1967)!

# The birth of General Relativity

- 1915, November: Einstein presents to Prussian Accademy of Sciences his theory of gravitation (and Explanation of the Perihelion Motion of Mercury from General Relativity Theory)
- 1919: first experimental confirmation by Arthur Eddington, the bending of light rays during solar eclipse
- 1929: Hubble discovers that Universe is expanding



## 1959: a question about gravity and the beta decay

«Touschek was prompted to raise this question by the fact that in the history of physics it had happened several times that an apparent deviation from a conservative law was found, on close examination, to be the result of the perturbation caused by an external field [...]. Could not the non-conservation of parity observed for the weak interaction have a similar origin?

This question as we learned later was raised also by other researchers.»

**M. Ageno, E. Amaldi**, *Experimental Search for a Possible Change of the  $\beta$  Decay Constant with Centrifugal Force*. Lincei, Memorie Sc. Fisiche, 1966.

**Mme C. S. Wu**, Rev. Mod. Phys., 31, 783, 1959:

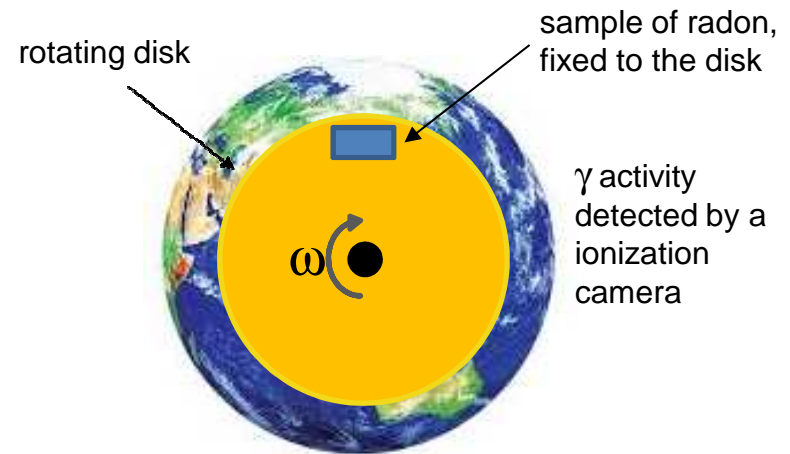
«is there any connection between the  $\beta$  interaction and the gravitational field?»



# A long-standing problem...



E. Rutherford and A. Compton, 1919



Does centrifugal acceleration affect the activity of radioactive bodies?

Experimental results: no variation  $\gamma$  ray intensity emitted by Rn sample for different  $\omega$

Heat flow through Earth's surface deduced from observed temperature gradient and thermal conductivity of the crust



Density of heat sources should decrease with depth

**But main sources of heat are radioactive substances, whose density increases with depth!**

# Amaldi interests in gravitational field and beta decay

- **1960 January 19**, CERN: Amaldi discusses with the Christian Møller (Copenhagen, fundamental contributions to theory of gravitation) the experiment about the half-life of centrifugated  $\pi$  (Source: Amaldi's diary). They are at CERN to discuss the scientific programs to be developed at the Proton Synchrotron (PS), which will be inaugurated on February 5.
- **1964 November 21**: Amaldi writes to J.L. Synge (Dublin)

- **1973-1974**: Amaldi writes to Møller and also to Francis Perrin, to ask their opinion about Ageno's and his 1966 work, published by Lincei.

In 1960 another reason of interest in gravitation came to Amaldi from the East...

The reasons why we disturb you with such a question are threefold.

The first is that neither Ageno nor I, are professional in relativity and related subjects, so that we do not have the "feeling" of what can be of interest at the experimental level in this field. The second is that from the reading of a number of papers and books of yours we arrived both to have a great admiration for your clarity of views. The third reason, is that reading we got both the impression that you are

# Amaldi and Dmitri Ivanenko

From Amaldi's Diary

Problem: define in a not ambiguous way the energy of the gravitational field. The Einstein tensor  $t_{\alpha\beta}$  as defined by Møller does not behave as energy for a spatial rotation. The tensor of Lorentz-Levi Civita is identically null. Now it looks like it has been achieved a relevant progress: Møller, Mitskeric deduct an expression for the energy of the gravitational field.

Relationship between gravity and particles

If gravitational waves exist carrying energy they would interact with particles:

[equation]

interactions among gravitons (spin 2) with all the particles

[equation]

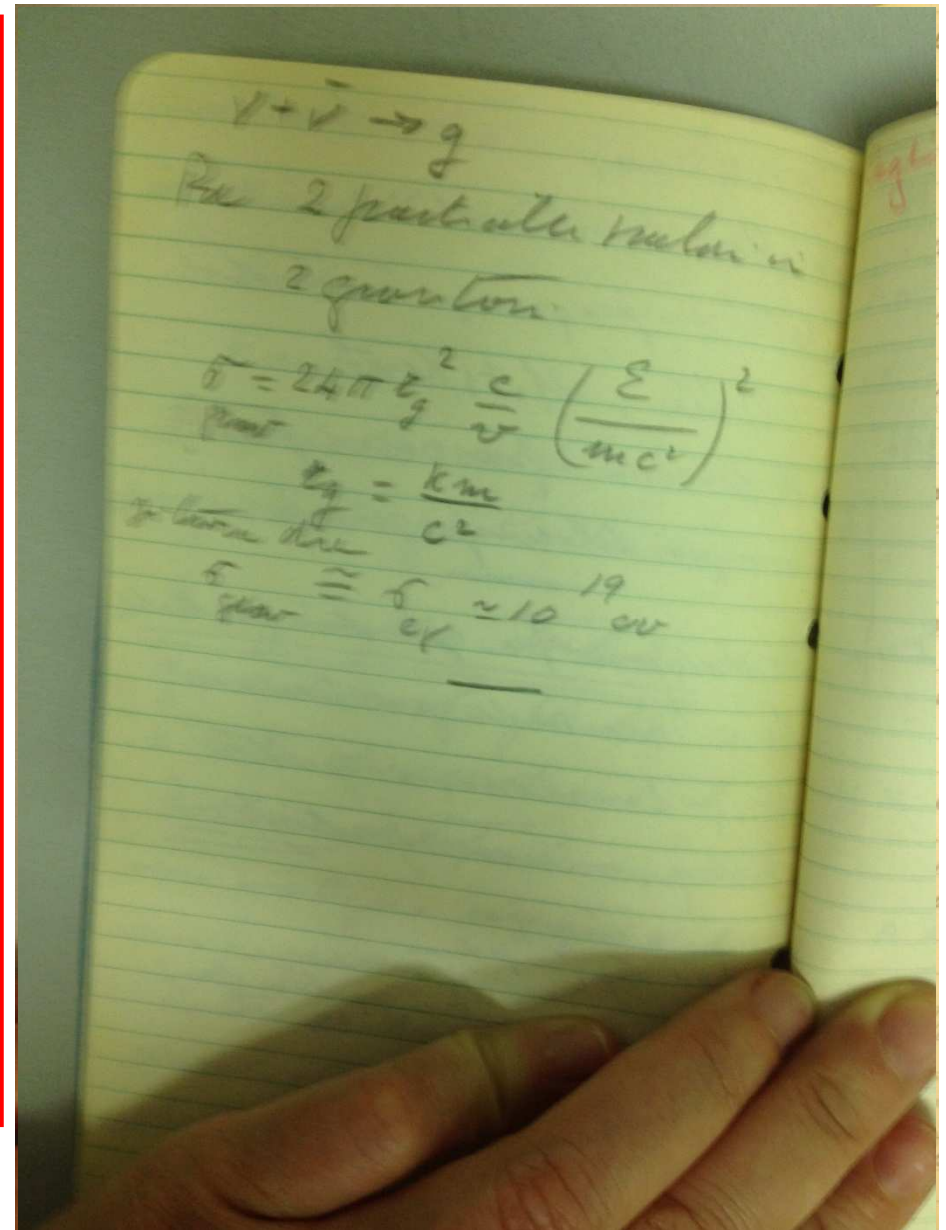
It might be possible a transmutation of particles in gravitons.

For example: [equation]

For 2 particles in

2 gravitons

[equation]



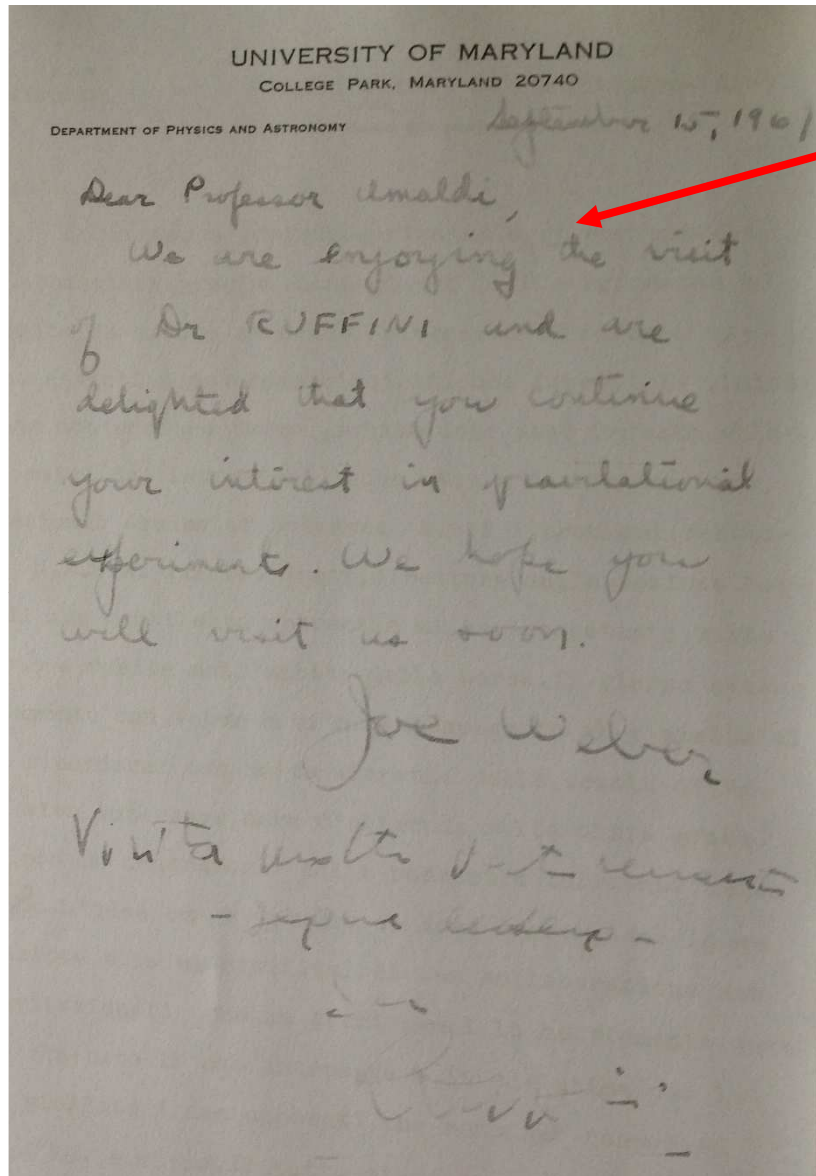
# Remo Ruffini



- In 1967 Amaldi writes several times to CNR and to ESRO for funding Ruffini's training in USA with Wheeler, Dicke and Weber and the motivations are repeatedly explained: **opening a research activity in Rome for GW detection.**
- **1967, 14 April:** EA writes to CNR, concerning the request of 6 months fellowship for Ruffini to be spent in USA since the next september:

«The aim of creating an experimental group on gravitation has a great interest for this Institute and in particular for me personally; I think Ruffini has the right qualities in order to make this effort with good perspectives of success.»

# Remo Ruffini



- **1967, 15 September.** Letter from Weber to Amaldi:  
«We are enjoying the visit of Dr. Ruffini and are delighted that you continue your interest in gravitational experiments. We hope you will visit us soon. »
- **1967, 20 September.** Letter from Ruffini to Amaldi:  
« Weber oltre a ricordarsi con molta simpatia della scuola di Varenna mi ha parlato con vivo interesse, come d'altronde molta altra gente qui, del suo **esperimento con la centrifuga sulla possibile influenza nella costante di decadimento beta**. L'idea che la scuola di Roma proseguisse in esperimenti sulla gravitazione e la possibilità di una collaborazione sia sul campo delle onde gravitazionali che in altri campi lo ha vivamente interessato. »