100-th Anniversary of CR Discovery, Development of Different CR Aspects and Contribution of V.L. Ginzburg in CR Astrophysics, Applications to the Problem on Space Weather Effects on Satellites, People Health, and the Earth's Environment

Lev Dorman (1,2) and Irina Dorman (3)

1. Tel Aviv University
2. IZMIRAN, Moscow
3. Institute of History of Science and Technology, Moscow

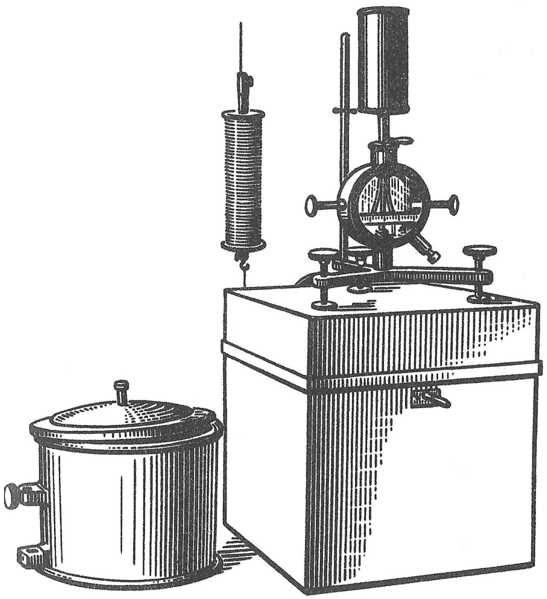
Marie Curie (1898, 1899)

- Marie Curie (1898), studying uranium and thorium radiation, wrote "for interpretation of spontaneous radiation of these elements it is necessary to imagine that all space is crossed by the beams similar to beams of the X-ray, but considerably more penetrating. These beams can be absorbed only by certain elements with the big nuclear weight, such, as uranium and thorium". In other work, Curie (1899) continues the thought: "Uranium and thorium radiation is the secondary issue caused by beams, similar to gamma-rays. If these beams exist, their source may be the Sun, and in that case will be various at midnight and at midday. However I could not find out it". The first time - Cosmic Rays.

Research of Air Ionization Sources and Discovery of Cosmic Rays

1. Electricity dispersion through air (18th-19th Centuries)

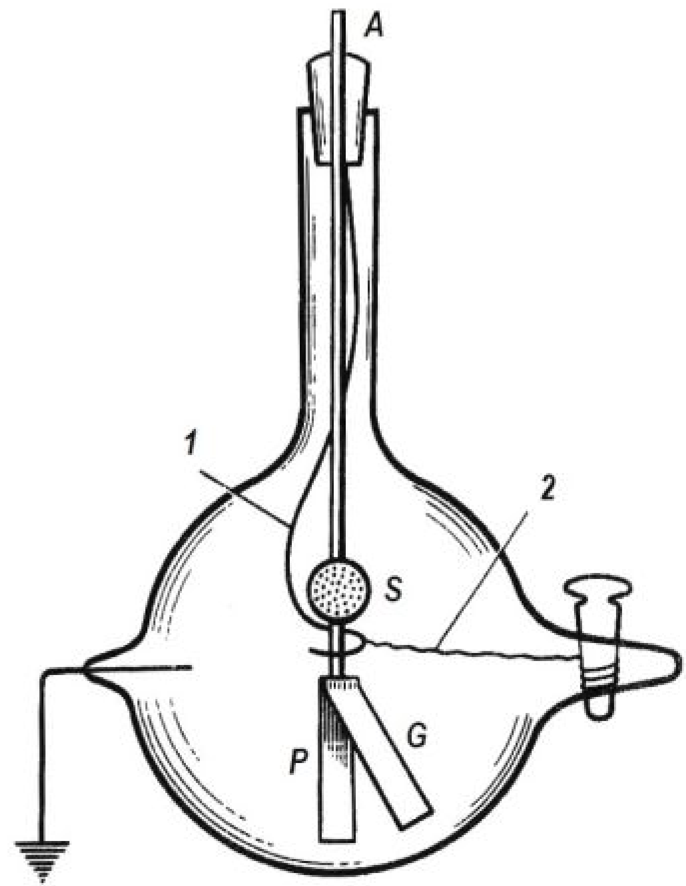
- Charles Coulomb (1785)
- **2. Experiments of J.J. Thomson in Cavendish Laboratory**
- (under the influence of X-rays and radiation from radioactive elements, electric conductivity of gases strongly increases-the end of 19^{th} Cent.)
- **3.** Marie Curie (1898), studying uranium and thorium radiation, wrote as much at the end of the 19th century "for interpretation of spontaneous radiation of these elements it is necessary to imagine that all space is crossed by the beams similar to beams of the X-ray, but considerably more penetrating. These beams can be absorbed only by certain elements with the big nuclear weight, such, as uranium and thorium". In other work, Curie (1899) continues the thought: "Uranium and thorium radiation is the secondary issue caused by beams, similar to g-rays. If these beams exist, their source may be the Sun, and in that case will be various at midnight and at midday. However I could not find out it".



4. Experiments of J. Elster and H. Geitel (1900)
Using this device from April until August, 1900 measurements of electro-conductivity of air at various points (Biskra, Algeria, island Capri, island Spitsbergen, Luchano), at various heights above sea level were done. All these experiments, naturally, led to a conclusion that the basic source of ionization of air are the radioactive emanations accumulating in atmosphere, and the radioactive substances contained in the Earth's crust.

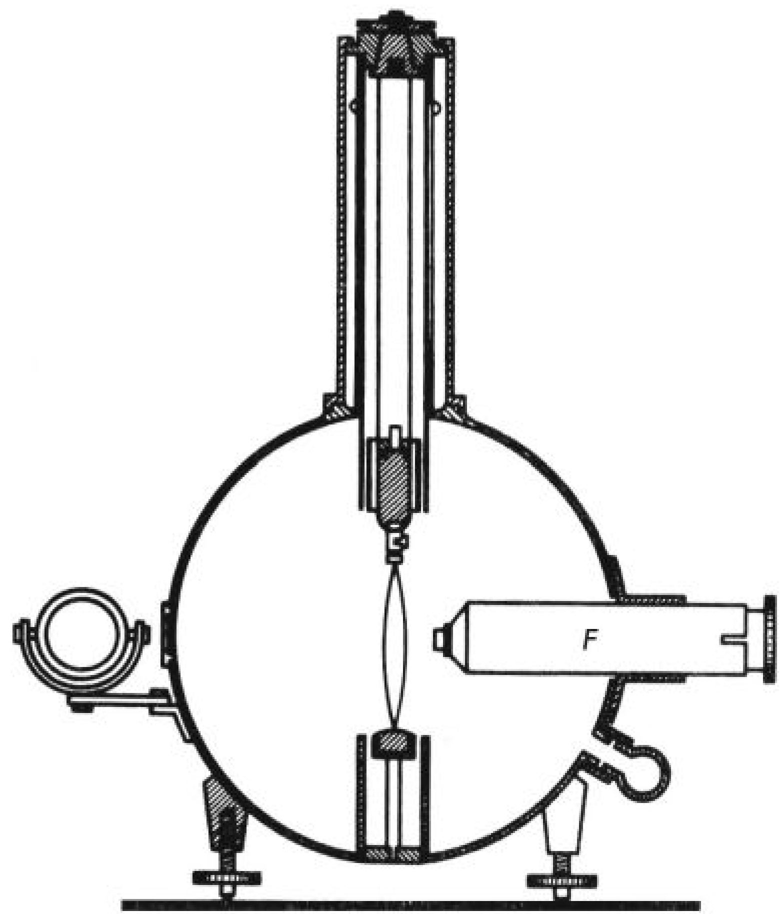
Experiments of C.T.R. Wilson (1900-1901) and thoughts on possible extraterrestrial origin of air ionization sources

- The method of definition of speed of ionization offered by C.T.R. Wilson beca-me the standard in research of that time
- "… formation of ions in air is caused by radiation which arises out of our atmosphere to similarly X-rays, but possesses considerably bigger penetrating ability."
- However, having measured the speed of formation of ions in a railway tunnel without having found out reduction of speed of ionization in comparison with usual conditions, Wilson changed his opinion: "It is improbable therefore that ionization is caused by radiation passing through our atmosphere. Most likely, as has concluded H. Geitel, this is property of air".



Air ionization and radioactive substances (1902-1910)

- E. Rutherford and H. Cooke (1903) surrounded an electroscope with a lead layer to get rid of radioactive radiation from laboratory walls. They with surprise found out that even though in a five ton weight of lead the speed of ionization considerably decreases, it remains to equal to 6 pairs of ions in cm3 per second. They believed that all observable ionizationhad a radioactive origin.
- In 1909 German physicist T. Wulf (1909) improved the old-fashioned electroscopes, replacing gold leaflets with two thin metal wires tensed by means of an easy quartz thread.
- Wulf (1910) lifted the device to the top of the Eiffel tower (a height of 330 m) and found out that the speed of ionization decreases with height much more slowly than it was expected: at the bottom of the tower it equaled to 6 ions cm-3s-1, and at top - 3.5 ions cm-3s-1. For an explanation of the received results, T. Wulf saw two possibilities: either gamma-radiation absorption in the atmosphere is much less than was estimated earlier, or iron parts of the tower radiate, being an additional source of ionization.



The first measurements of air ionization on balloons by A. Gockel up to altitude 4500 m (1909-1911)

- The pressure in the device that A. Gockel used fell in the process of the sphere lifting, and consequently, speed of ionization could decrease simply
- A. Gockel understood that "recalculation of observable ionization on initial pressure can give even increase in ionization with height", but any definitive conclusions could not be made.
- The results received by A. Gockel did not bring any clarity to the question of sources of ionization of air; at best, they drew the attention of researchers to the study of absorption of gamma-radiation in air.
- "In general, before Victor Hess's flights, all experimental results, - as wrote R. Millikan (1930) - could be interpreted as the proof of that all ionization of atmospheric air is caused by sources of a radioactive origin”.

Discovery by Victor Hess of radiation from space (1911-1912)

- Victor Franz Hess was born on June 24, 1883 in Austria to a family of a forester. In 1905, he finished University in Graz and at the same place in 1910 received his PhD. Since 1910, V. Hess, under the direction of Stefan Meyer, was engaged in radioactivity study. Therefore, in 1911 he undertook two flights on balloons to learn at what height g-radiation propagates from the radioactive substances that are in earth crust.
- Knowing the works of A. Gockel, V. Hess placed the device in a hermetic vessel so that the pressure of air in it remained constant at all heights. He did it because he was surprised by results of the flight of A. Gockel, and explained the absence of falling of air ionization rate with height exclusively by lack of tightness of his device.
- However, having reached heights of 1100 m, V. Hess in both cases, like A. Gockel, does not observe an appreciable fall of ionization rate in comparison with measurements near terrestrial surface. Therefore V. Hess (1911) made the assumption that "there should be other source of a penetrating radiation in addition to gamma-radiation from radioactive substances in earth crust".

In 1912 with the assistance of the Viennese Academy of Sciences he made seven more flights in which he used the two-wired Wulf's electrometers with walls of thickness 3 mm that gamma-rays only got through, and both electrometers had hermetic cases. The third Wulf's electrometer with walls of 0.188 mm thickness was non-hermetic and intended for simultaneous studying of behavior β-beams. Threads of electrometers were charged to voltage U = 200 V to provide a saturation current in the chamber; then the speed of the system discharge was observed continuously.

The first flight from this series was performed on April 17, 1912 during a partial solar eclipse. Any reduction of ionization rate during eclipse time was not observed, and from a height of 2000 m the ionization rate increased from what Victor Hess has drawn a conclusion has been fixed even that as the eclipse has not affected an ionizing radiation, the Sun cannot be its source. In other flights, that Victor Hess did not find a difference in measurements of ionization rate

between day and night confirmed his point of view.

- The seventh most well-known, famous flight began on August 7, 1912 at 6 o'clock in the morning about the city of Aussiga in Austria. In the balloon's gondola, there was a pilot, the meteorologist and Victor Hess. At this time the balloon was filled with hydrogen (earlier Victor Hess filled balloons with warmed-up air) and record at that time the height of 5350 m. At midday the balloon landed near the German city of Piskov, 50 km to the east of Berlin, having flown 200 km.

From the Table it is visible that to a height of 1000 m there was a reduction of ionization rate on the average on 0.7-1.5 ion.cm-3s-1 (in some flights it reached 3 ion.cm-3s-1) that is caused by absorption of g-radiation of the earth crust. "From here, - V. Hess wrote, - we conclude that at earth crust radiation gives ionization rate only

nearby 3 ion.cm-3s-1 in zinc electrometer". Further at increase in height from 1000m to 2000 m ionization rate slowly increased, and in the range of heights between 4000 m and 5200 m it has appeared already on 16-18 ion.cm-3s-1 more than ionization rate on a surface of the Earth.

Table 1.1. The dependence of ionization rate from the altitude. According to V. Hess (1912).

Average height from the earth, m	Observable ionization rate, ion.cm^{-3}s^{-1}		Average height from the earth, m	Observable ionization rate, ion.cm^{-3}s^{-1}	
	The first device	The second device		The first device	The second device
0	16.3 (18)*	11.8 (20)	1000-2000	15.9 (7)	12.1 (8)
Up to 200	15.4 (13)	11.1 (12)	2000-3000	17.3 (1)	13.3 (1)
200-500	15.5 (6)	10.4 (6)	3000-4000	19.8 (1)	16.5 (1)
500-1000	15.6 (3)	10.3 (4)	4000-5200	34.4 (2)	27.2 (2)

*The figures in brackets means the number of observations from which the average was obtained.

- V. Hess experimentally defined that at a height of 500 m the earth crust g-radiation decreases by more than 5 times and, certainly, cannot make considerable ionization at larger heights. The congestion of radioactive emanations in the atmosphere, by V. Hess' estimations, could cause only 1/20 of all ionization observed at heights from 1 to 2 km, and with increase in height an emanation role, naturally, should become even less. As a result V. Hess came to the conclusion that it is possible to explain all experiments only by the existence of the radiation coming from the outside, of extraterrestrial origin.
- Reporting in September 1912 at Session in Munster results of the flights, V. Hess made following sensational conclusion: "Results of the presented observations are better can be explained by the assumption that radiation of the big penetrating ability is coming into our atmosphere from above and even in its bottom layers makes a part of the ionization observed in closed vessels" (Hess, 1912). V. Hess named the discovered ionizing radiation ultra-gamma radiation to underline its big penetrating ability.
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- **In 1919** Victor Hess received the Liben award for discovery of "ultra-radiation" and soon after that he became a professor of experimental physics at University in Graz. In 1921 - 1923 Victor Hess worked in the USA. In 1923 he came back to the University in Graz, and in 1931 was appointed to be director of the newly based Institute of Radiology in Innsbruck. Near Innsbruck Victor Hess has based on a mountain Hafelekar station for continue observation and studying of cosmic rays (this station works until now). In 1932 Charl Zeis's Institute in Yen awarded Victor Hess with the memorial award and medal of Abbe; he also became a member-correspondent of the Viennese Academy of Sciences.
- **In 1938**, Victor Hess was compelled to leave his native land because of prosecution by the Nazis, and moved to the USA, where until 1956 he worked at Fordham University. Victor Hess died in **1964** at the age of 81, two years after the solemn anniversary devoted to the fiftieth

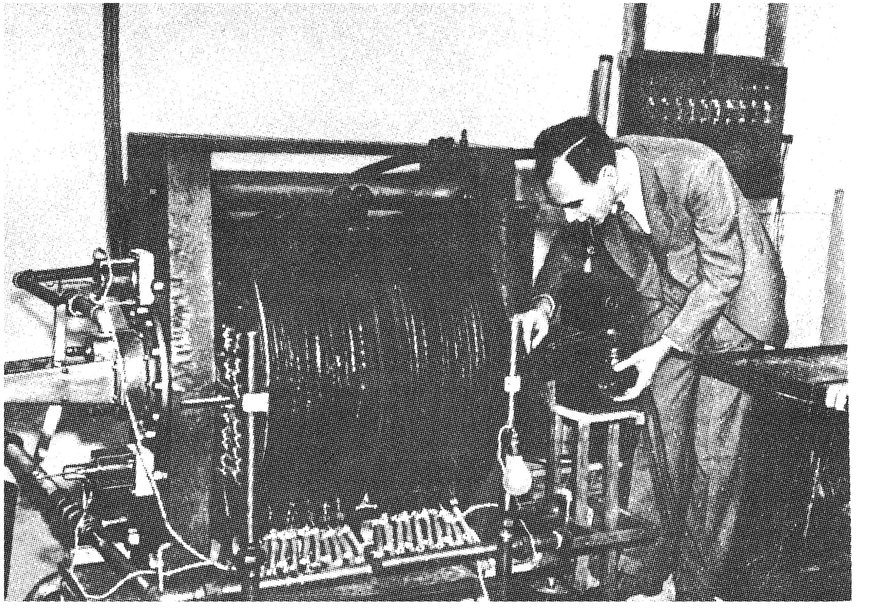
  anniversary of the discovery of space radiation.

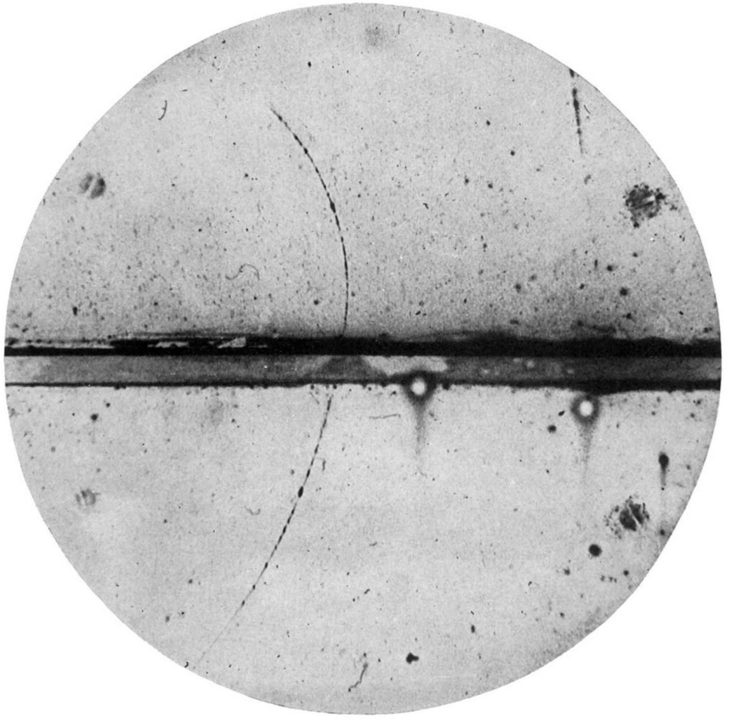
Discovery of Positrons in Cosmic Rays (1932)

In 1928 the young English physicist-theorist P.A.M. Dirac (he was at that time only 26 years) made an attempt to combine main principles of quantum mechanics with the special theory of relativity and developed the relativistic quantum equation for electrons. This equation consistently considered presence in the electron of spin and allowed explaining the thin structure of the spectrum of the hydrogen atom. However the big lack of the Dirac's theory, according to the majority of theorists known at that time, was that it predicted existence of anti-particles.

- Discovery in 1932 by C.D. Anderson of a positron in CR was triumph of the theory of P.A.M. Dirac. Connection between rather narrow area, - physics of CR,- and fundamental problems of all physics became obvious.
- The history of this discovering starts from using Wilson's chamber inside of strong magnetic field. D. Skobelzyn (1929) as a result of the experiments with Wilson's chamber placed in magnetic field by intensity 1000 Gs, has come to conclusion that the bottom limit of energy of particles of cosmic radiation makes 20 MeV.

- In the summer of 1930 R.A. Millikan and his young employee Charles Anderson designed in a laboratory of the Californian Institute of Technology Wilson's vertical chamber in which unlike all before used chambers the piston moved upwards and downwards, instead of horizontally.
- The chamber in the size 17x17x4 cm3 was located between poles of a powerful magnet on which winding the current in 2000 A was passed (produced 24,000 Gs)
- C.D. Anderson obtained this photo of great scientific and historical signifycance, at August 2, 1932. This photo had been proved existence of the first antiparticle – positron.





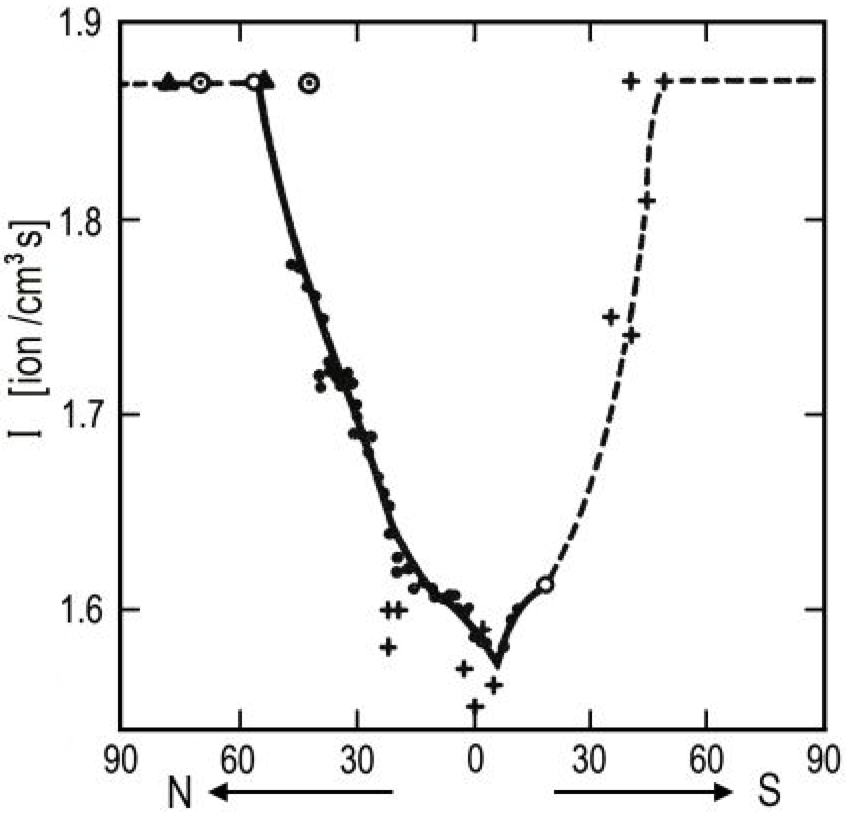
Nobel prize for discovery CR and positron

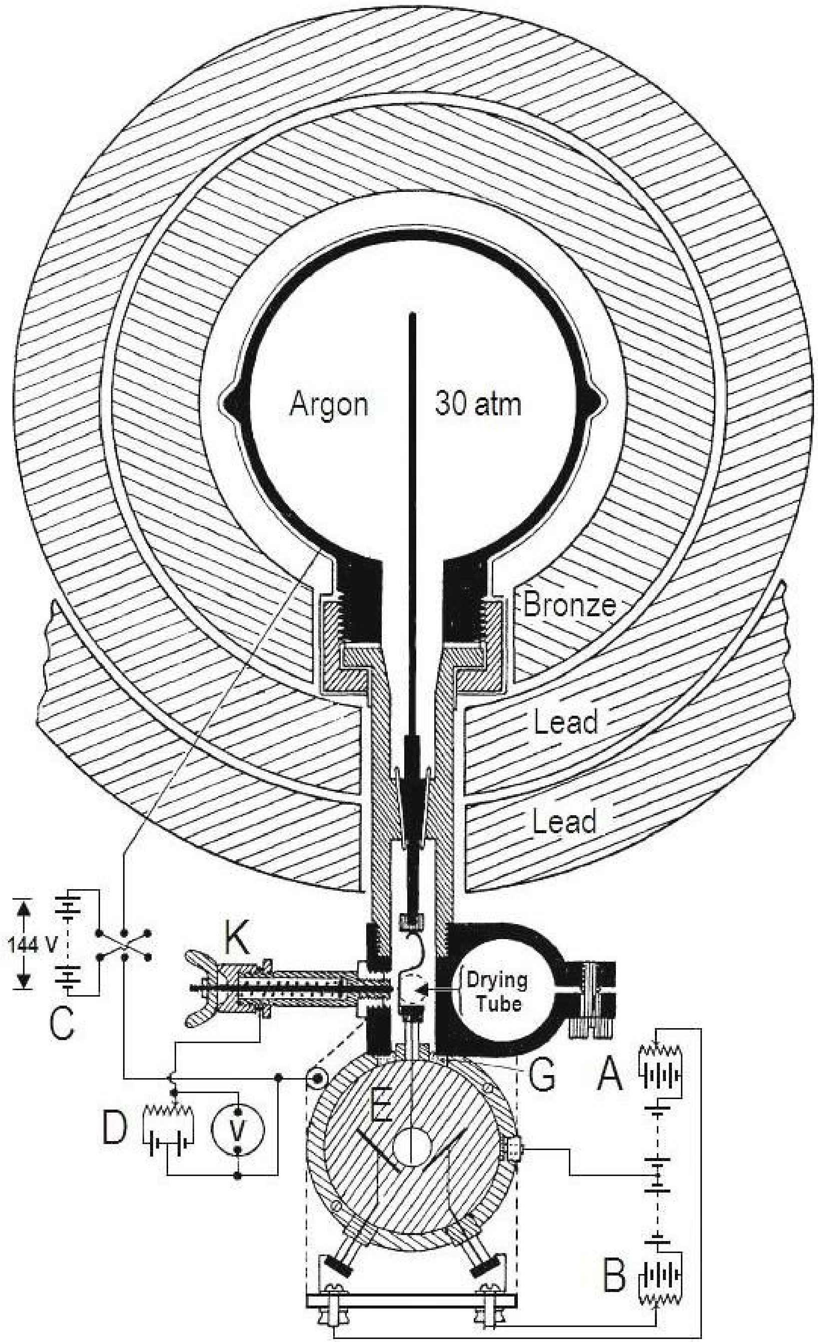
Nobel Prize for discovery CR and positron (1936)

- The Nobel Prize in Physics was shared by Victor Hess, for the discovery of cosmic rays, and Carl Anderson, for the discovery of the positron. Arthur Compton, in his letter nominating Hess for the prize, wrote, “The time has now arrived, it seems to me, when we can say that the so-called cosmic rays definitely have their origin at such remote distances from the Earth, that they may properly be called cosmic, and that the use of the rays has by now led to results of such importance that they may be considered a discovery of the first magnitude.”

Early Studies of Cosmic Ray Geomagnetic Effects
Discussion: gamma rays or charged particles ?

- The latitude effect was discovered for the first time in 1927 by the Dutch physicist J. Clay (1927). By the steamship "Slamat" he came back to Holland from the island of Java, measuring with ionization chambers.
- Arthur Compton (1932, 1933) organized in 1932 eight expeditions for CR research at various latitudes.

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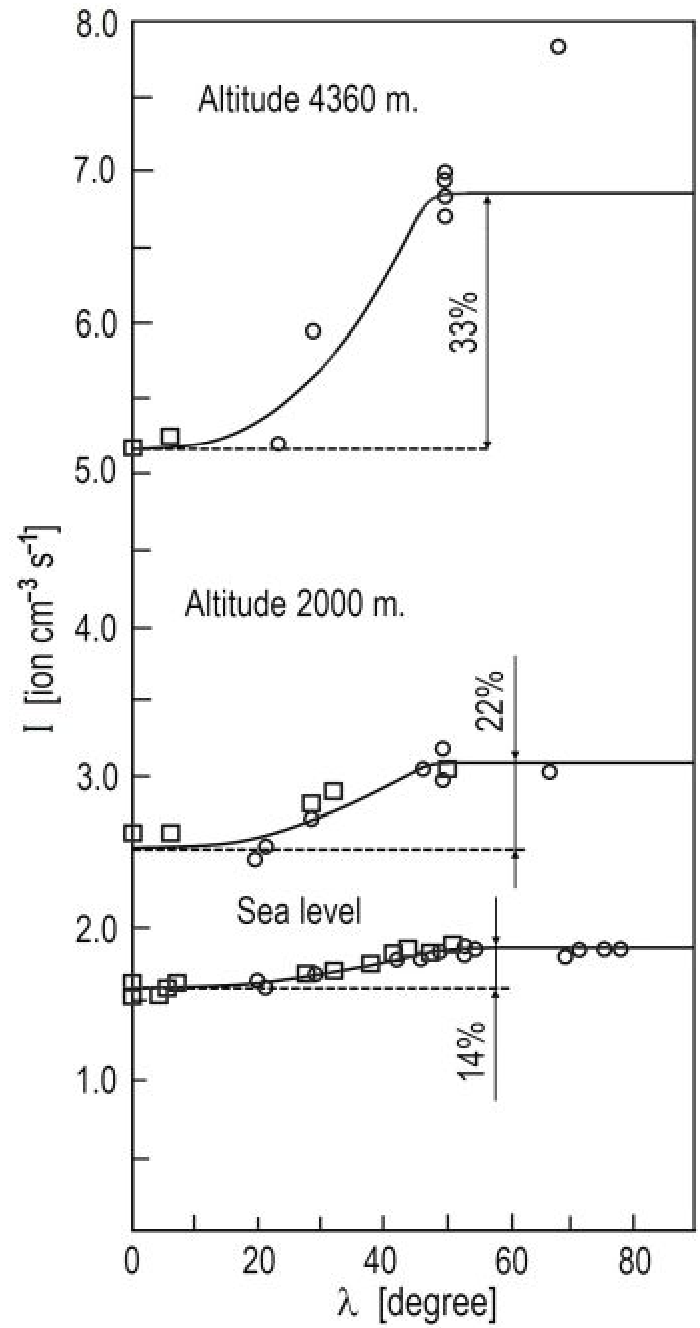
Altitude 4360 m.
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Sea level
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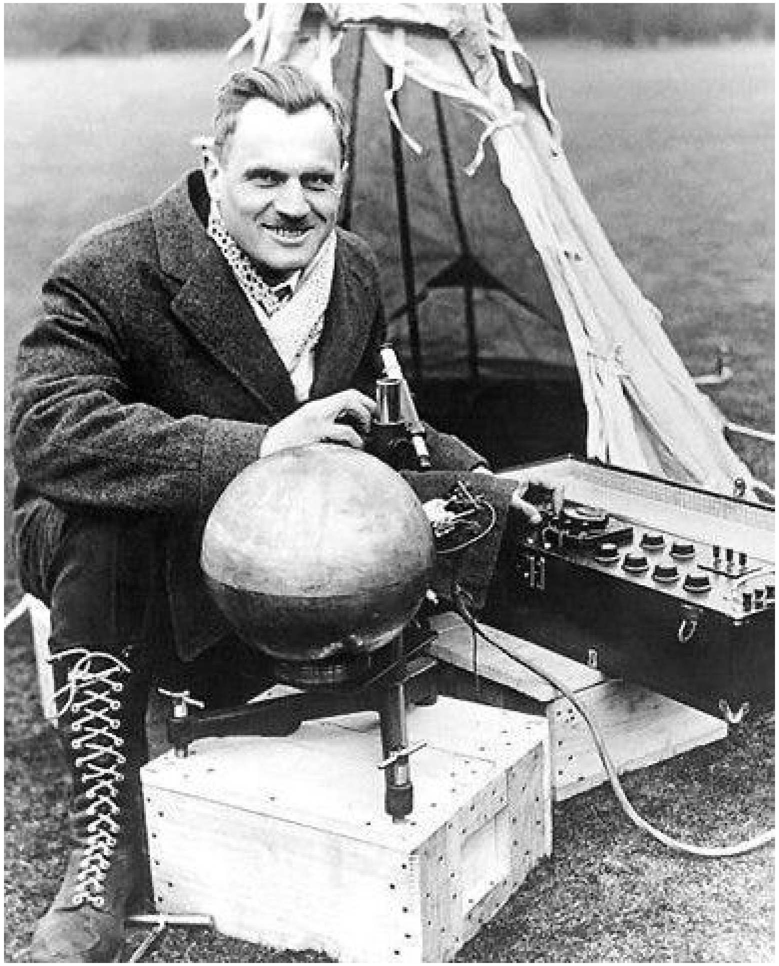
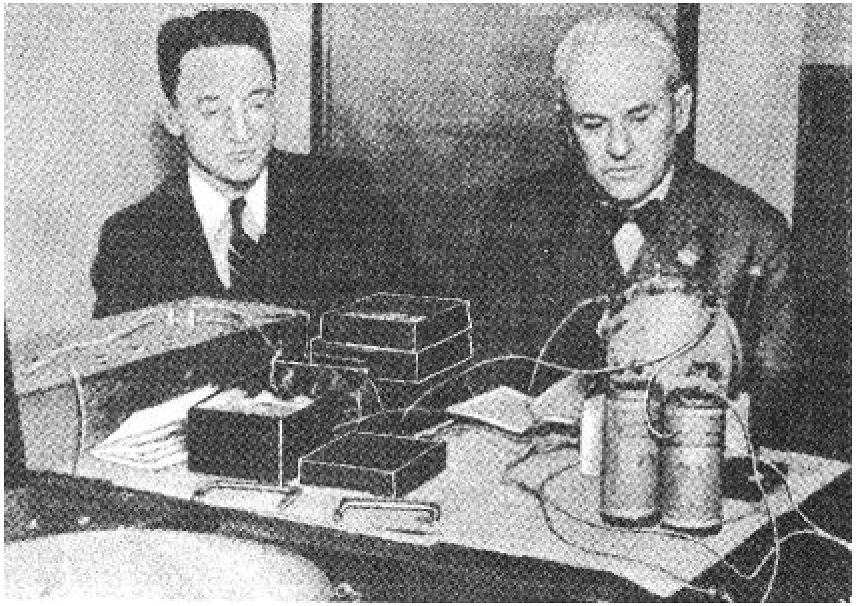




In November 1932, H.V. Neher informed R. Millikan from Peru that his new device also has not registered change of CR intensity with latitude. R.A. Millikan immediately organized a press conference and informed reporters on the absence of CR latitude effect.

Recognizing after some time the existence of CR latitude effect, R.A. Millikan of anything never spoke more about "birth cries" atoms, having given to priests to solve, "whether the Founder continues work".


MEET IN FRIENDLY RIVALRY

Robert A. Millikan, Pasadena (Left), and Arthur H. Compton, Chicago, Who Today Discussed Physical Research Findings

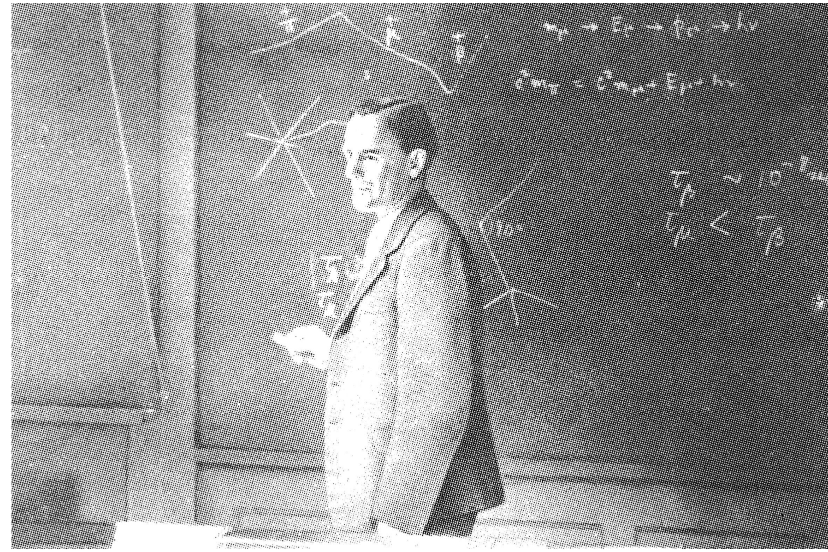
COSMIC RADIATION FOES BATTLE OVER THEORIES OF ORIGIN

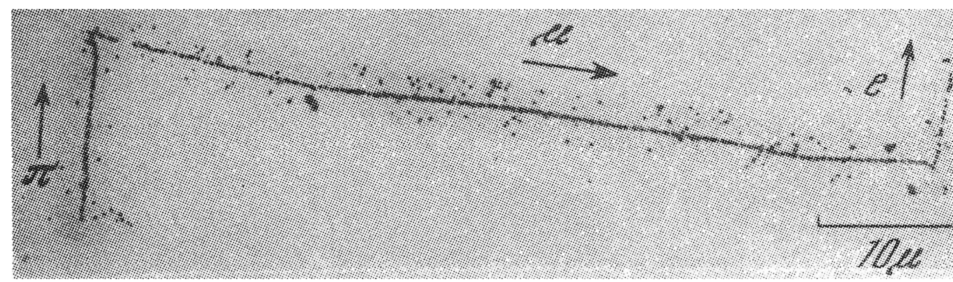
P.S-N. Dec.30 '32

Dr. Robert A. Millikan, Dr. Arthur H. Compton Present Opposing Ideas on Whether Cosmos Being Recreated or Disintegrated

Discovery of muons, pions, and hyperons in CR

- Anderson and Neddermeyer (1936) found in many photos traces of particles with magnetic rigidity Hρ in limits from 105 to 106 Gs.cm which passed through the lead plate in the thickness of 3.5 mm, without creating any appreciable secondary particles and losing much less energy, than it was predicted by the theory for electrons.
- Discovery of mesons and theory of nuclear forces
- Discovery of meson's decay and cosmic ray temperature effect
- Experimental checking of meson's decay and its dependence from energy
- Direct observations of meson's decay in Wilson's chamber
- Using time delay coincidences schemes for determining decay time of rest meson
- Discovery of meson-atoms formatted by negative mesons
- Experimental determination of formation meson-atoms in different substances with small and big Z
- The sharp contradiction between experiments with muons and predictions from H. Yukawa's theory
- Supposition on two types of mesons
- 1947-pions, Powell et al.



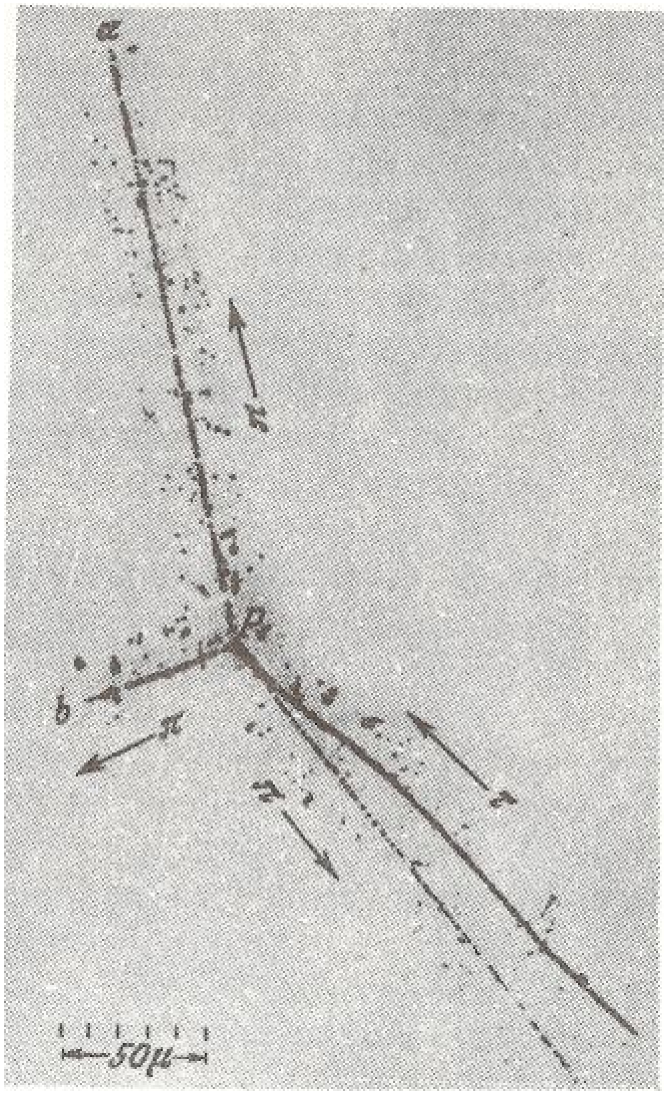


$$\pi^- \to \mu^- + \tilde{\nu}_\mu, \quad \pi^+ \to \mu^+ + \nu_\mu$$

$$\mu^- \to e^- + \tilde{\nu}_e + \nu_\mu$$

$$\mu^+ \to e^+ + \nu_e + \tilde{\nu}_\mu$$

- Formation in 1940s many mountain stations for cosmic ray research and search of new particles
- Discovery in cosmic rays V-particles
- Spontaneous disintegration of V0-particle and existing of its two types
- Spontaneous disintegration of charged V-particles
- Discovery by photo-emulsion and by other methods tau-particles
- Discovery in photo-emulsions and by other methods a big number of new particles (varitrons) and possible errors
- Renaming of V- and tau-particles and discovery ksi-minus and sigma-plus hyperons
- Classification and main properties of particles discovered in cosmic rays
- Cosmic rays as a source of high-energy particles for research in elementary particle physics



$$\Sigma^+ \to p + \pi^0, \quad \Sigma^+ \to n + \pi^+$$

$$\Xi^- \to \Lambda^0 + \pi^-$$

Early Studies of Cosmic Ray Variations

- The first attempts to establish a site of a source of cosmic rays
- Discovery of cosmic ray barometric effect
- Search of cosmic ray periodic variations basing on data corrected for barometric effect
- Increasing of interest to search cosmic ray variations in sidereal time after hypothesis of W. Baade and F. Zwicky
- Development of precision ionization chamber for cosmic ray variation research
- Establishment of the first world network of cosmic ray variation stations
- Discovery of cosmic ray solar-daily variations
- The initial investigations of temperature effect of cosmic ray hard component
- Discovery of cosmic ray 27-day variation
- Discovery of cosmic ray 11-year variation
- Discovery of cosmic ray variations during magnetic storms: planetary character of cosmic ray intensity decreasing
- The initial attempts to explain cosmic ray Forbush-decreases
- Discovery of cosmic ray variations connected with powerful chromosphere’s flares: generation of solar cosmic rays

Early Cosmic Ray Origin Theories

- **Hypothesis on Supernova explosions as main source of CR**
- As noted W. Baade and F. Zwicky (1934a), the frequency of Supernova explosions in every stellar system is about one in several hundred years (see Fig. 13.1). During the lifetime of Supernova (about 20 days) the intensity of total radiation (visible and invisible) is about 3.8×10^48 erg/s. During its life Supernova emit at least 105s×3.8×10^48 erg/s = 3.8×10^53 erg. If suppose that in each nebula supernova explosion is one in thousand years and suppose that main part of energy is going for CR generation, the expected intensity will be about 0.002 erg/(s.cm^2) which is comparable with the observed about 0.003 erg/(s.cm^2).

- **Hypothesis on the Sun as main source of CR**
- R.D. Rihtmyer and E. Teller (1948) have stated idea that CR basically are generated on the Sun and are kept by magnetic fields in interplanetary space. Detailed development of a hypothesis of a solar origin of CR is given in H. Alfvén's works (1948, 1949). He has come to a conclusion that in interplanetary space protons should be accelerated in addition up to energies, equal 5×10^13 eV.
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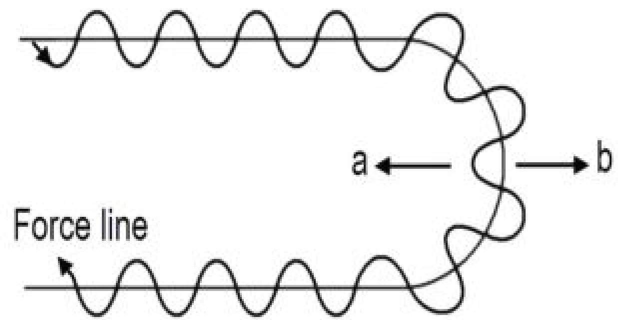
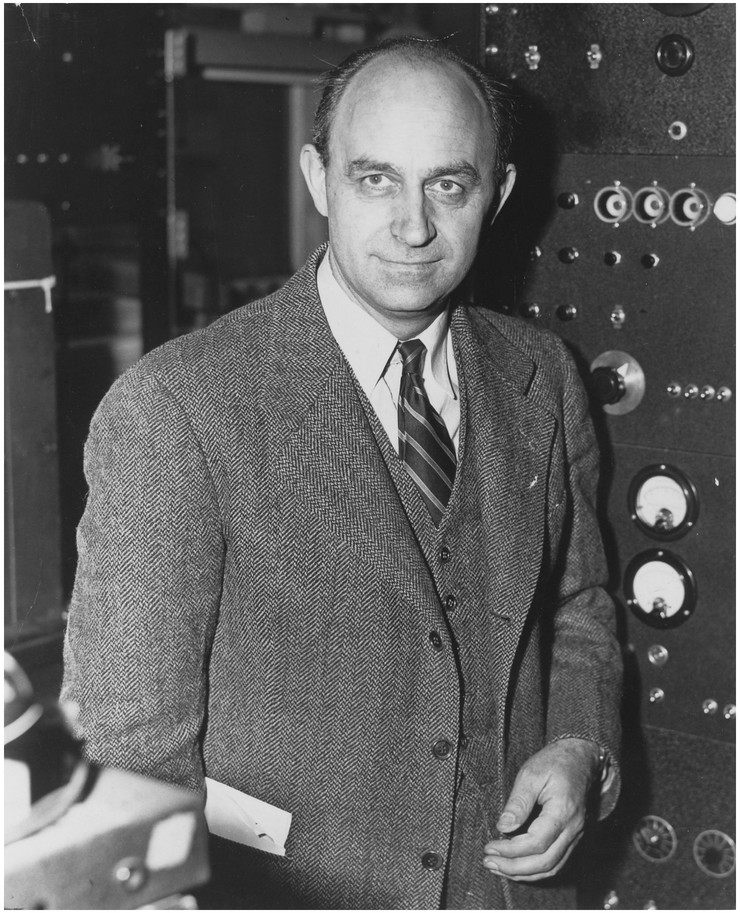
- **Statistical mechanism of particle acceleration in interstellar space: possible main source of CR**
- E. Fermi (1949) has developed the mechanism of statistical acceleration of particles by chaotically moving interstellar magnetic clouds. According to E. Fermi, at each collision of a charged particle moving with velocity **v**, with magnetic cloud moves with velocity **u**, changes its energy according to the relation

$$\left(\Delta E/E\right)_{\pm} = \pm 2uv/c^2$$

- where the upper sign is for head-on collisions and bottom sign for overtaking collisions.





- **Metagalactic model of CR origin**
- Hypothesis of metagalactic origin of CR, at that time seriously was not discussed because of big difficulty with balance of energy. The energy included in CR in our Galaxy is about 1 eV/cm^3 ~ 10^-12 erg/cm^3. If suppose that about the same CR energy density is in the Metagalaxy (i.e. metagalactic origin of CR), in this case the energy in CR should be one order with energy of rest mass of the Universe. This huge value of total energy in CR, seems, absolutely not real.

- **Hierarchical model of CR origin**
- In connection with the difficulties of the model of metagalactic CR origin, G. Cocconi (1951) has offered "hierarchical" model of CR origin according to which small energy particles are generated by the Sun and stars, particles of higher energies - by moving magnetic clouds in interstellar space, and particles of ultrahigh energy - in the Metagalaxy. In this case, the difficulties with total energy in CR will be not appeared, however, there was a new stubborn question: how to explain that in various sources spectra of CR are similar and intensities smoothly pass from one to another.

- **Radio-astronomical theory of CR origin**
- The cardinal decision of CR origin problem managed to be found only a few years later, in 1953, when it was formulated the so-called radio-astronomical theory of CR origin (V.L. Ginzburg, 1953a,b; I.S. Shklovsky, 1953). This theory based on the hypothesis of W. Baade and F. Zwicky (1934a,b) on the main source of CR in the Galaxy (Supernova explosions) and observations of synchrotron radiation of relativistic electrons. According to the radio-astronomical theory, the basic acceleration of particles occurs not in interstellar space, but in explosions of Supernova and their remnants, where can realize the mechanism of statistical acceleration developed by E. Fermi (1949). In interstellar space, there is only a propagation of CR including electrons, which synchrotron radiation in galactic magnetic fields allows to explain observable not thermal galactic radio emission.

Cosmic Rays as Universal Phenomenon in the Universe

It is natural to define CR as particles and photons with energies at least several orders of magnitude higher than the average energy of thermal particles of background plasma. There is internal CR, generated inside the background plasma of object considered, and external CR generated in other objects and propagated to the object considered. We are now aware of CR of different origin:

Extragalactic CR of very high energy (up to 1021 eV) are generated in radio-galaxies, quasars and other powerful objects in the Universe and come through intergalactic space to our Galaxy, to the Heliosphere and into the Earth's atmosphere. Therefore, they are external CR relative to our Galaxy.

Galactic CR, with energy at least up to 1015-1016 eV, are generated mainly in supernova explosions and supernova remnants, in magnetospheres of pulsars and double stars, by shock waves in interstellar space and other possible objects in the Galaxy. These CR are internal relative to our Galaxy and external to our Heliosphere and the Earth's magnetosphere.

- **Solar CR**, with energy up to GeV, generated in the solar corona in periods of powerful solar flares, are internal CR for the Sun's corona and external for interplanetary space and the Earth's magnetosphere.
- **Interplanetary CR**, with energy up to MeV, are generated by a terminal shock wave at the boundary of the Heliosphere and by powerful interplanetary shock waves. They are internal to our Heliosphere and external to the Earth's magnetosphere.
- **Magnetospheric (or planetary) CR**, with energy up to 10 MeV for Jupiter and Saturn, and up to 30 keV for the Earth, are generated inside the magnetospheres of rotating magnetic planets.
- **Two maxima in particle energy distribution in magnetized space plasma (Maxwell and CR)**
- **Transfer energy from macroscopic movings and magnetic fields to charged particles - CR (a big difference in effective temperatures)**

Formation of CR spectrum and upper energy limit

- In practice the thermodynamic equilibrium between macroscopic magnetized plasma motion and CR charged particles can not be reached, since the energy increase is hardly limited and the formation of energy spectrum is determined by the following three important factors
- **The rate of energy increase** during the acceleration process
- **The energy loss of accelerating particles** by ionization and nuclear interactions (important for small and middle energy), on interactions with magnetic field (synchrotron radiation; important for electrons), interactions with photons (especially with relict photons at , important for very high energy particles
- **Particle escaping from the acceleration region**

Main aspects of CR research

- **The firth aspect** of CR research: Studies in CR and on accelerators for elementary particle and high energy physics
- **The second aspect**: Influence of the atmosphere and atmospheric processes on CR
- **The third aspect**: Influence of CR on the atmosphere and atmospheric processes
- **The fourth aspect**: CR interactions, propagation, non-linear effects, and acceleration in space plasmas
- **The fifth aspect**: CR in magnetospheres of the Earth and other planets
- **The sixth aspect**: Solar neutrons and gamma-rays, and related phenomena
- **The seventh aspect**: Charged energetic particles of solar, heliospheric, and planetary origin
- **The eighth aspect**: Galactic CR propagation and modulation in the Heliosphere.
- **The ninth aspect**: CR generation and propagation in the Galaxy
- **The tents aspect**: CR generation and propagation in the Metagalaxy
- **The eleventh aspect**: CR as element of space weather and as instrument for forecasting of dangerous phenomena.