Domenico Pacini, the forgotten pioneer of the discovery of cosmic rays

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Abstract

About a century ago, cosmic rays were identified as being a source of radiation on Earth. The proof came from two independent experiments. The Italian physicist Domenico Pacini observed the radiation strength to decrease when going from the surface to a few meters underwater (both in a lake and in a sea). At about the same time, in a balloon flight, the Austrian Victor Hess found the ionization rate to increase with height. The present article attempts to give an unbiased historical account of the discovery of cosmic rays – and in doing so it will duly account for Pacini’s pioneering work, which involved a technique that was complementary to, and independent from, Hess’.

1. Introduction

It is generally well known, since Faraday’s early observations, that electroscopes spontaneously discharge. This phenomenon remained unexplained until the beginning of the XX century: its explanation paved the way to one of mankind’s revolutionary scientific discoveries: cosmic rays.

Since the early XX century cosmic rays were used to probe and understand the constituents of matter. Indeed many early discoveries in particle physics (antimatter, mesons, muons, baryons, ...) were made while studying cosmic rays. Cosmic rays are still being used in the framework of fundamental physics, as well as to investigate astrophysical properties of their sources.

In 1896 the French physicist Henri Becquerel discovered the instability of some chemical elements. Some years later Marie and Pierre Curie discovered
that Radium showed that same behavior: such transmutation processes were then called “radioactive decays”. In the presence of a radioactive material, a charged electroscope promptly discharges. It was concluded then that some elements were able to emit charged particles, that in turn were responsible for discharging the electroscope. An electroscope’s discharge rate was then used to gauge the level of radioactivity.

The spontaneous discharge observed in electrosopes made it evident that in insulated environments, too, a background radiation did exist. The obvious questions concerned the nature of such radiation, and whether it was of terrestrial or extra-terrestrial origin. It was generally believed that its origin was likely related to radioactive materials, hence its terrestrial origin was a commonplace assumption. An experimental proof, however, seemed hard to achieve.

At the very beginning of the XX century, several scientists made experiments about penetrating radiation, trying to understand its origin and nature.

Around 1910, the Austrian Victor Hess and the Italian Domenico Pacini simultaneously and independently carried out two different, ingenious, and complementary research lines that would eventually clarify the origin of the yet mysterious ionizing background radiation.

Pacini made several measurements to establish the variations of an Ebert electroscope’s discharge rate as a function of the environment: he placed the electroscope on the ground, on the sea a few km off the coast, and a few meters underwater. He reported those measurements, the ensuing results, and their interpretation in a note titled “La radiazione penetrante alla superficie ed in seno alle acque” (“Penetrating radiation at the surface of and in water”) [3]. In that paper Pacini wrote: “Observations carried out on the sea during the year 1910 [4] led me to conclude that a significant proportion of the pervasive radiation that is found in air had an origin that was independent of direct action of the active substances in the upper layers of the Earth’s surface.” What was he lacking, at that time, before he could reach a

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1 Cline in 1910 summarizes the status of the art: experiments were mainly oriented to measure the daily variations or seasonal variations. Cline cited the work by the Italian Domenico Pacini about the daily variations of the radiation measured on the sea at Sestola, in Italy. Pacini’s measurement was remarked in Cline’s paper as a first evidence of the atmosphere being the main responsible of the penetrating radiation, excluding the Sun as the main origin.
firm conclusion about the extraterrestrial origin of the ionizing background radiation? Only in 1911 did Pacini develop his experimental technique for underwater measurements, that allowed him to measure a significant decrease in the discharge rate when the electroscope was placed underwater. “The apparatus ... was enclosed in a copper box so that it could immerse in depth. ... From June 24 to June 30 observations were performed with the instrument at the surface, and with the instrument immersed in water, at a depth of 3 meters. ... [It] appears from the results of the work described in this Note that a sizable cause of ionization exists in the atmosphere, originating from penetrating radiation, independent of the direct action of radioactive substances in the soil.”

Who was Domenico Pacini and, while Victor Hess [5] is honored as the discoverer of cosmic rays, why did Pacini’s contemporary (or even earlier) discovery go unnoticed and was soon forgotten (notably in Italy)? Personal stories and historical events contributed to this outcome.

Domenico Pacini (Figure 1) was born on February 20, 1878, in Marino, near Rome. He graduated in Physics in 1902 at the Faculty of Sciences of Rome University. There, for the next three years, he worked as an assistant to Professor Pietro Blaserna while also studying electric conductivity in gaseous media under the supervision of Alfonso Sella. In 1904 he set out to study the infamous N-rays: he performed an experiment, the (null) results of which were communicated in a letter to Nature [6] as “careful experiments made ... with the object of observing the effects of n-rays described by M. Blondlot and other investigators.” Though “observations were made under very favourable conditions,” he “was unable to detect any increase of luminosity of a phosphorescent screen caused by unknown rays from strained or tempered steel, an Auer lamp, a Nernst lamp, sound vibrations, or a magnetic field, though various French observers have affirmed that in each of these cases N-rays are emitted which produce an effect upon the screen”. In 1906 Pacini was appointed assistant at Italy’s Central Bureau of Meteorology and Geodynamics, heading the department that was in charge of studying thunderstorms and electric phenomena in the atmosphere. (Most of the department’s experimental work was carried out near Castelfranco Veneto, near Padova.) Pacini’s held that position until 1927, when he was upgraded to Principal Geophysicist. After several more years of work as an assistant professor in Rome, finally in 1928 he was appointed full professor of Experimental Physics at the University of Bari, where he was incharge of setting up the studies of Physics within the Faculty of Medicine. While in
Bari, his research interests mainly focused on the diffusion processes of light in the atmosphere. Domenico Pacini died of pneumonia in Rome on May 23, 1934, shortly after his marriage.

The long way that led Pacini to the hypothesis of cosmic rays started from his studies on electric conductivity in gaseous media that he performed at the University of Rome during the early years of the XX century. While working at the Central Bureau of Meteorology, he became interested in the problem of the ionization of air. During 1907–1912, he performed several measurements on the air’s conductivity on the ground (at different elevations, including at sea level), on the sea, and (later in 1911) underwater [4, 3, 7]. Those measurements, performed with electrosopes (Figure 1), were aimed at checking whether the radioactivity within the Earth’s crust was sufficient to explain the ionization effects (about 13 ions per second per cubic centimeter of air) that had been measured on the Earth’s surface. Pacini concluded that the Earth’s radioactivity alone was not sufficient to explain the observations.
Pacini made several measurements on an Italian Navy ship (the *caccia-torpediniere* “Fulmine”, Figure 1). First he concluded that the ionization above the sea, at sea level, and far from the coast, was consistent with that measured at ground level on land. From 1910 on, Pacini proposed a new experimental technique that proved very successful and was to become important for later developments of physics: he measured the radiation intensity in water, at a depth of 3 meters, in the Genoa Gulf and in the Bracciano Lake (near Rome), proving that the radiation was significantly smaller underwater than on the ground. To explain his results, that marked the beginning of the underground/underwater technique for cosmic-ray studies (that has been implemented so many times up to this day), Pacini proposed the existence of a radiation of extraterrestrial origin – later to be called “cosmic rays”. A few months later Victor Hess, using balloon flights, confirmed those results with measurements that eventually earned him the Nobel Prize for Physics in 1936, two years after Pacini’s death.

In his paper containing the interpretation of such results [3], published a few months before the paper by Hess, Pacini was evidently aware of Hess’ results as he did quote them correctly. Some excerpts from mail exchanges that occurred between the two scientists in 1920 are very illuminating on
Figure 3: The cacciatorpediniere “Fulmine”, used by Pacini for his measurements on the sea.

the issue of the priority in discovering cosmic rays. (Such exchanges were reported in the Pacini commemoration held in Bari in 1935.) On March 6, 1920, Pacini wrote to Hess: “...I had the opportunity to study some of your papers about electrical-atmospherical phenomena that you submitted to the Principal Director of the Central Bureau of Meteorology and Geodynamics. I was already aware of some of these works from summaries that had been reported to me during the war. [But] the paper entitled “Die Frage der durchdring. Strahlung ausserterrestrischen Ursprungs” (“The problem of penetrating radiation of extraterrestrial origin”) was unknown to me. While I have to congratulate you on the clarity in which this important matter is explained, I have to remark, unfortunately, that the Italian measurements and observations, which take priority as far as the conclusions that you, Gockel and Kolhörster draw, are missing; and I am so sorry about this, because in my own publications I never forgot to mention and cite anyone...”. The answer by Hess, dated March 17, 1920, was: “Dear Mr. Professor, your very valuable letter dated March 6 was to me particularly precious because it gave me the opportunity to re-establish our links that unfortunately were severed during the war. I could have contacted you before, but unfortunately I did not know your address. My short paper “Die Frage der durchdring. Strahlung ausser-
errestrischen Ursprunges” is a report of a public conference, and therefore has no claim of completeness. Since it reported the first balloon measurements, I did not provide an in-depth explanation of your sea measurements, which are well known to me. Therefore please excuse me for my unkind omission, that was truly far from my aim ...”. On April 12, 1920, Pacini in turn replied to Hess: “... [W]hat you say about the measurements on the penetrating radiation performed on balloon is correct; however the paper “Die Frage der durchdring. Strahlung ausserterrestrial Ursprunges” lingers quite a bit on measurements of the attenuation of this radiation made before your balloon flights, and several authors are cited whereas I do not see any reference to my relevant measurements (on the same matter) performed underwater in the sea and in the Bracciano Lake, that led me to the same conclusions that the balloon flights have later confirmed.”

Edoardo Amaldi had no doubt that Domenico Pacini was indeed the discoverer of cosmic rays. This is reported in a letter that E. Amaldi wrote on July 14, 1941, to the Director of the Physics Institute of Rome University, Antonino Lo Surdo (the letter belongs to the Amaldi Archive at the “La Sapienza” University of Rome [8]). E. Amaldi’s letter was motivated by an article that had earlier appeared on a local newspaper, in which it was stated that nuclear physics and cosmic ray physics were “Jewish sciences”. Here is the relevant quote from E. Amaldi’s answer: “... this statement appear so strange to anyone who knows, as you certainly do, that the Italian Domenico Pacini was the discoverer of the Cosmic Rays and only afterwards did the German Hess, Kolhörster, etc. follow ...”.

The route to cosmic rays, opened by Pacini, continued in the following years and, after the second world war, Italy took up a leading role in the field. Back in those years most of the research was performed at laboratories placed on mountain tops. In Italy the most important one was located at Testa Grigia on the Plateau Rosa, at an altitude of 3500 meters on the Matterhorn. A team from the University of Padova established an observatory at the Passo Fedaja on the Dolomites near Belluno, at an elevation of approximately 2000 meters: thanks to the Società Adriatica di Elettricità (SADE), the observatory had enough electric power to run a large magnet for experiments that used counters and cloud chambers.

The complementary work by Pacini and Hess were seminal in starting, respectively, underwater and upper-atmosphere/space studies of cosmic rays.

Is it possible to say now, as Edoardo Amaldi did once, that “the Italian Domenico Pacini was the discoverer of the Cosmic Rays [and was followed]
by the Germans Hess, Kolhörster etc.”? A great discovery is in general the result of joint efforts by many people. It is certainly true that Pacini wrote, in as early as 1910 [4], that the action of active substances in the soil was not sufficient to explain the observed properties of the penetrating radiation; and that he was the first to publish such a statement. However, a whole community of researchers was already involved in that field. Pacini’s work was carried out in difficult conditions because of lack of resources available to him, because of lack of scientific freedom during the crucial years when he was working at the Central Bureau of Meteorology and Geodynamics, and finally because of the substantial indifference his work was met with by the Italian academic world – a fact that still today is sadly evident to anyone who treads non-mainstream scientific paths.

We conclude by remarking that, as described in the Bulletin of the Società Aeronautica Italiana, at the beginning of the XX century an Italian balloon, named after Jules Verne, did reach a height of about 5000 meters. This proves that in Italy, too, a balloon-borne experiment would have been technically feasible in those years. An open-minded national research agency – such as it did not exist in Italy in those days – can really be the key to success in experimental Physics. This may be a lesson Domenico Pacini has taught us, for the present time as well as for future times.

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