# Written by Lightning

## A short story of lightning recorders: ceraunographs, electrographs, klydonographs

## Part 1 From Becaria's Ceraunograph to Gergely Palatin's Detector

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### Foreword

Since the mid-18th century atmospheric electricity both in fair weather and during thunderstorms was detected and measured with a series of instruments such as spark gaps, electric chimes, electroscopes, electrometers and later galvanometers, which were generally connected with an aerial.[1] Lightning recording devices were mainly developed in the framework of wireless technology, between the very end of the 19th and first years of the 20th century, but their origins go back to the ceraunographs proposed in the 1780s. In this article in two parts I will retrace the history of the instruments which allowed to register directly (on paper, resin, photographic film, etc.) lightning strikes or sudden variations of atmospheric electricity field during a thunderstorm.

### Beccaria's Ceraunograph and its Modifications

Giovanni Battista Beccaria (1716–1781), the renowned Italian "electrician" taught physics in various Italian cities and finally occupied the chair of experimental physics at the University of Turin. He was an excellent experimenter and his researches in the field of electricity (in which he supported Franklin's single fluid theory) were among the most remarkable of his time. In 1780, Beccaria described the first lightning recording apparatus and also invented its name – ceraunograph.[2] The term derives from the Greek words κεραυνός (thunderbolt) and γράφω (to write).[3]

Beccaria's first ceraunograph was composed of a clockwork mechanism with a vertical axle (Fig. 1). A horizontal recording paper disk was inserted on it. The disk was supported by a series of radial straws inserted in the axle. A flat circular box with a circular opening protected the clockwork. The rim of the opening carried a horary annular-shaped scale divided in 12 hours and minutes. A radial line had to be marked on the recording disk in correspondence of the XII (midday or midnight), so that it was possible to have a time reference. The pointed lower end of an aerial conductor[4] (electrode 1) terminated near the upper face of the paper disk, while the upper end of a second wire (electrode 2), which was grounded, ended near the lower face of the disk. The terminals of the two electrodes were aligned along a same radius of the disk, but their distances from the centre were slightly different.

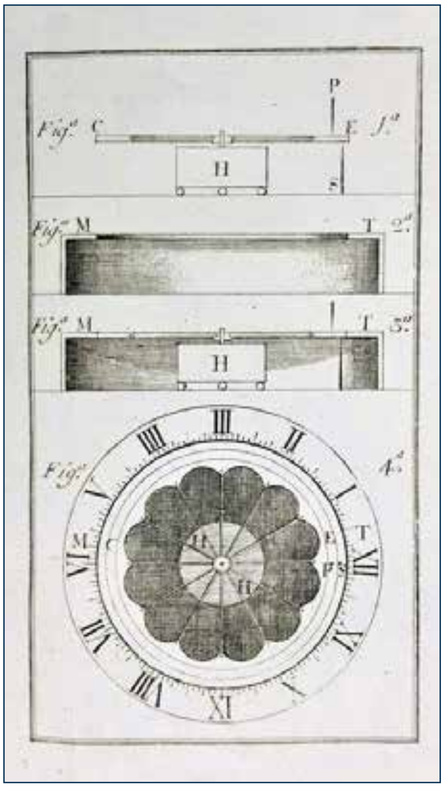

Fig. 1 *The original ceraunograph described by Beccaria. The top image shows the disk inserted on the clockwork mechanism. P and S are the electrodes connected respectively with the lightning rod and with the ground. In the other images the instrument in its box with the horary dial. (Beccaria 1780,* op. cit. *note 2).*

During a thunderstorm, lightning induced voltage surges in the aerial conductor. If a lightning discharge was strong or close enough to the ceraunograph a spark jumped between the gap of the conductors and perforated the paper disk. From the size of the hole it was possible to estimate the intensity of the lightning. From its position on the disk with respect to the XII hour line, it was possible to determine the time of the discharge. Furthermore, according to Beccaria, if the position of the hole corresponded to the upper electrode (1), the lightning occurred downward from the clouds to the earth. On the other hand, a hole aligned with the lower grounded electrode (2) indicated an upward discharge from the earth to the clouds.[5] However, the ceraunograph was a very imperfect instrument. The sparks produced by two or more lightning events in rapid succession proceeded to pass throughout a single hole instead of perforating the paper several times.[6] Furthermore, sometimes the spark did not perforate the disk in correspondence with one of the electrodes, but somewhere between them.

Beccaria was not satisfied with this first apparatus and in the same paper he proposed a second improved version. There is no original illustration of it, but from the description I could draw an ideal reconstruction. (Fig. 2) The instruments consisted of four parallel and horizontal cylinders, which could rotate easily. Two of them were placed higher than the other. A paper roll was wrapped on the first cylinder. The paper tape passed between the two electrodes (1 and 2) over the pair of higher cylinders and was rewound on the last one. This was connected with a rope to the driving weight of a pendulum clock. The descent of the weight moved the cylinder and rewound the tape. Finally, a counterweight on the first cylinder kept the tape in tension. With a long tape, on which there was a horary scale for many days, it was possible to have a long recording with several thunderstorms registered. By using a clock with a long and relatively fast movement of the descending weight, the risk of having a single hole for more than one spark was reduced.

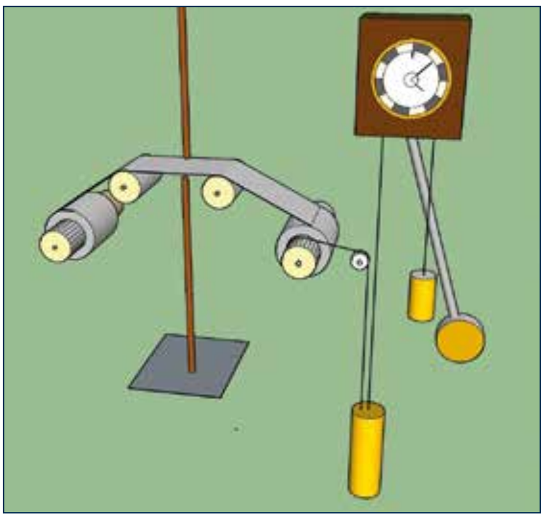

Fig. 2 *A modern illustration reconstructing the second version of Beccaria's ceraunograph. The electric discharges were recorded on a long roll of paper passing between the two electrodes. The inscribed paper was rolled around a cylinder moved by the falling weight of a pendulum clock. (Diagram of the author).*

Unfortunately due to his poor health, Beccaria could not experiment with

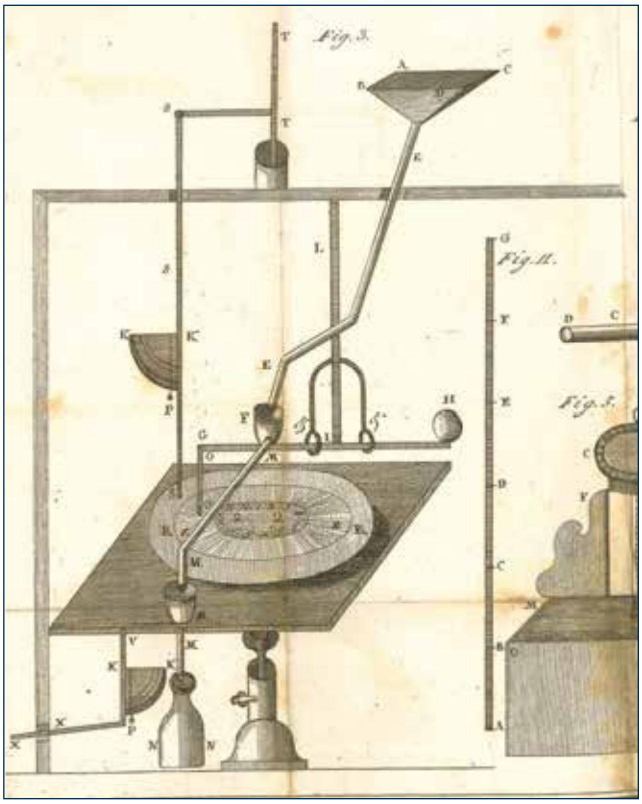

Fig. 3 *Cavalli's cronio-ceraunometer. The croniometer recorded the hour and then quantity of rain on the internal ring of the clockwork driven disk. The quadrangular funnel collected the rain which filled the small vessel fixed on the lever with a pen. Electric discharges were recorded with the ceraunograph on the external part of the disk. The bar connected to the lightning rod and the one going to the ground are equipped with quadrant electrometers. (Cavalli, 1785,* op. cit*. note 8).*

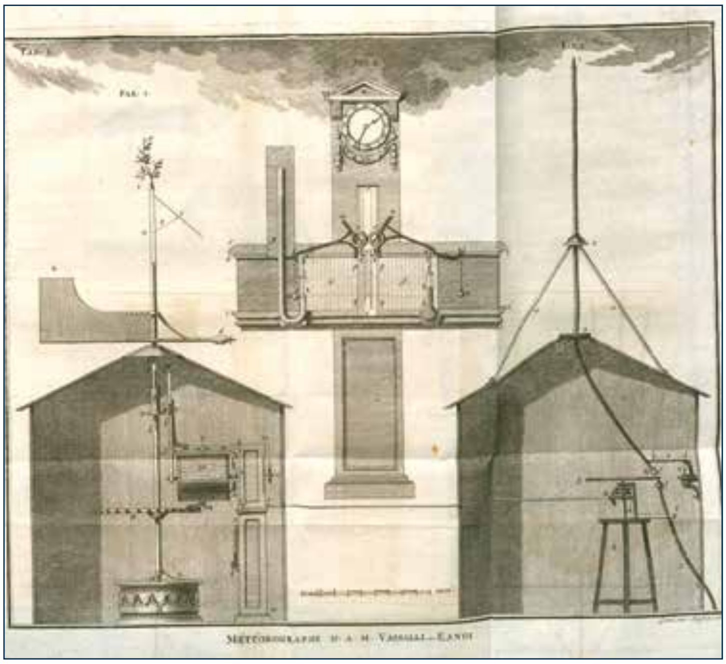

Fig. 4 *The very complicated meteorograph proposed by Vassalli-Eandi. The recording anemometer and a recording wind vane with their recording drum are on the left; the barograph and the thermograph together with a clock are placed in the centre, while on the right there is the ceraunograph. The latter was actioned by a glass rod connected with the clockwork of the anemograph. (Vassalli-Eandi. 1803-4,* op. cit. *note 12).*

this second ceraunograph. But an almost identical instrument was made following Beccaria's suggestion by Francesco Giuseppe Gardini (1740–1816) a physician and natural philosopher, who had been a disciple of Beccaria himself.[7] Gardini described his ceraunograph in 1785 and extensively used it in his studies on the influence of electricity on plants.

In the same year, the Roman abbot and astronomer Atanasio Cavalli (1729–1797) described a new instrument which he baptised with the name of *cronio-ceraunometer*[8] **(**Fig. 3**).** This was the combination of the first Beccaria's ceraunograph with a recording rain gauge, which had been invented by the Italian chemist, physicist and meteorologist Marsilio Landriani (1751–1815). In Landriani's *Chronihometro*[9] the rain was collected by a funnel and through a pipe that filled a small vessel placed at one of the extremities of a lever connected to a spring. A pencil was inserted vertically in the same lever and under it there was a rotating disk with a horary scale mounted on the axle of a clockwork mechanism. During the hours of rain the weight of the vessel (which remained full of water) lowered the lever and thus the pencil was in contact with the disk and marked a trace on it.[10] When the rain ceased the vessel was completely emptied by a special syphon and the action of the spring raised the lever. With Landriani's apparatus it was possible to record the hours of rain and because the water coming from the vessel was collected in a graduated cylinder so that it was also possible to measure the quantity of fallen rain. Cavalli profited from the fact that both the chroniometer and the ceraunograph were equipped with a rotating recording disk. With the chronio-ceraunograph it was possible to record one near the other and on the same disk the hours of rain as well as the time of the electric discharges. By comparing the two traces one could attempt to establish some relationship between the two meteorological phenomena. The instrument was installed in the Roman private observatory known as Specola Caetani.[11]

Around 1800 the Italian physicist and mathematician Antonio Vassalli Eandi (1761–1825) proposed a complex meteorograph.[12] The apparatus included an anemograph and a wind vane, a barograph, a thermograph and a Beccaria's ceraunograph[13] (Fig. 4). The disk of the ceraunograph rotated thanks to the clockwork moving the recording drum of the anemograph. The ceraunograph was located in a separate electric pavilion and therefore the movement of the clockwork was transmitted to the disk via a connecting glass shaft and some gears (Fig. 5). But this meteorograph was probably never constructed. In the 1780s the Italian physician Pietro Moscati (1739–1824), who was interested in the influ-

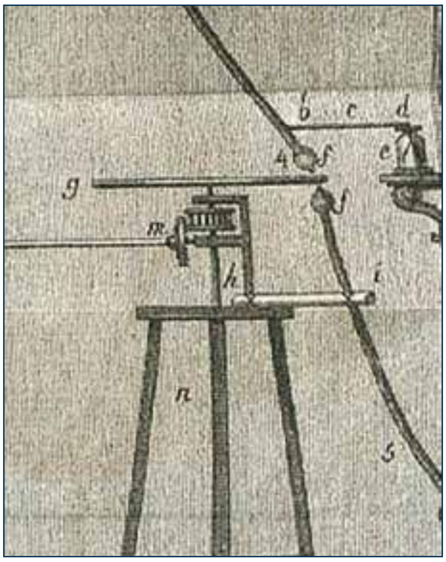

Fig. 5 *The detail of the ceraunograph illustrated in the previous image. The electrode connected with the lightning rod ended near the upper face of the disk. It was also connected with a gold leaves electroscope, which detected the atmospheric electricity when this was too weak for producing a spark across the disk. (Vassalli-Eandi. 1803-4,* op. cit. *note 12).*

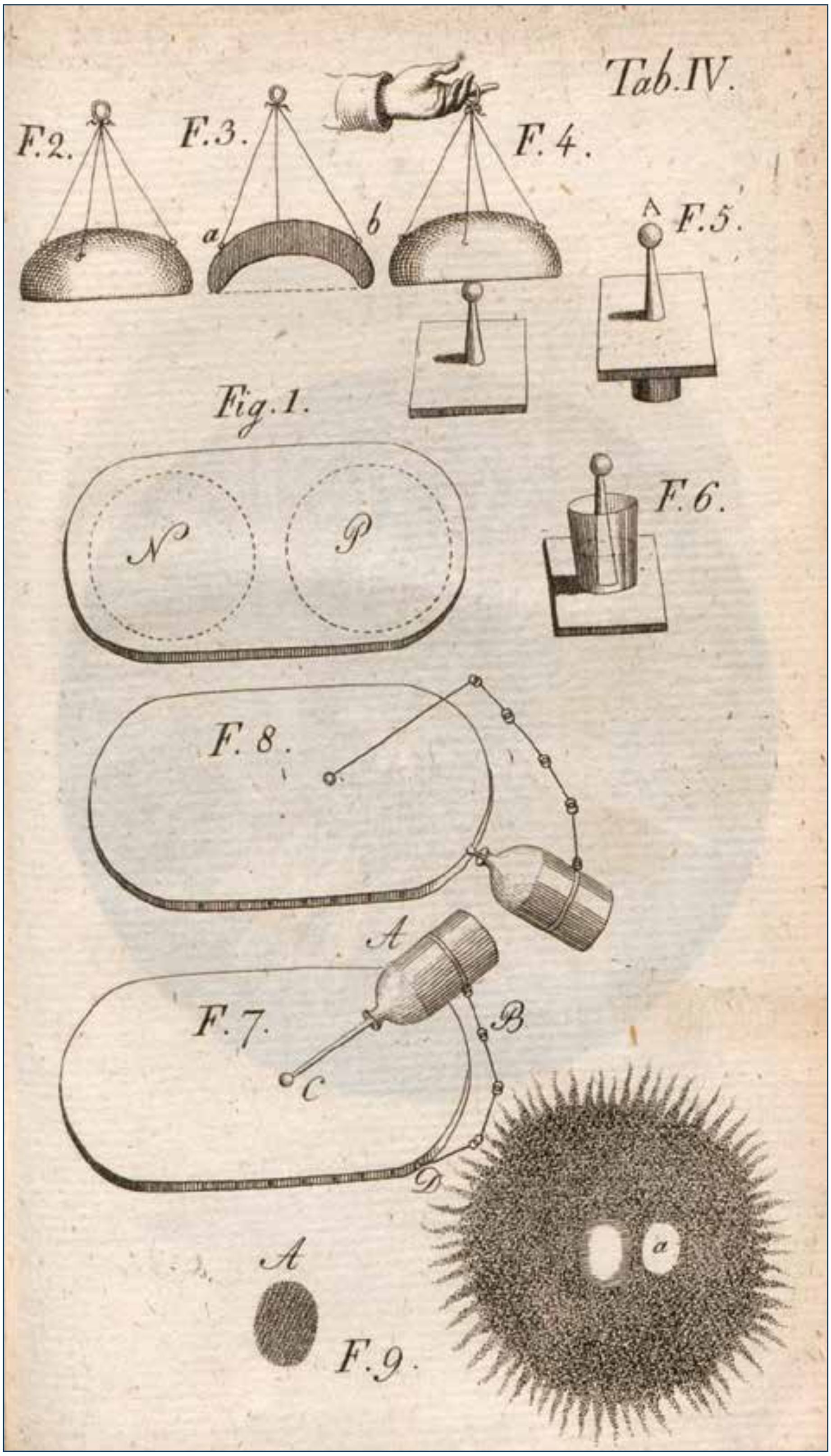


Fig. 6 *Some of Lichtenberg's experiments. Images F.7 and F.8 show how to write on a resin plate with a charged electrode (Lichtenberg, 1778*, op. cit. *note 16).*

ence of the environmental and meteorological conditions on human health and hygiene, installed in Milan a well-equipped meteorological observatory with a series of sophisticated recording apparatus. Among them there was an '*elettrografo*', which was an improved and more sophisticated version of the first ceraunograph described by Beccaria[14] (Fig. 6).

By the end of the century various apparatus of this kind were installed in Italy. However, in spite of the fact that ceraunographs were also mentioned in foreign scientific literature[15], it does not seem that these instruments were common outside Italy.

## Lichtenberg's Figures and Ronalds's Electrograph

In 1777, the German physicist and satirist Georg Christian Lichtenberg (1742–1799) discovered the famous figures named after him.[16] The two-dimensional Lichtenberg figures are produced when a powder (chalk, red lead, sulphur, etc.) is sprinkled on electric charged dielectric plate (resins, hard rubber, glass, etc.). The figures are different depending of the charge of the plate. Generally positive figures show larger arborescent patterns, while negative ones are smaller and have a sharp circular or globular boundary almost entirely devoid of branches. Lichtenberg made many experiments. In one of them, he traced some lines on a resin plate with the top of the internal electrode of a charged Leiden jar. The lines (drawing or writings) clearly appeared when the resin was sprinkled with powder (Fig. 6). In 1778, Lichtenberg also proposed (but probably never realised) a device for recording important variations of atmospheric electricity with a clockwork-driven tin drum which was covered with a layer of resin. An electrode connected with a kite was fixed perpendicular to the drum and its pointed end was placed near to the surface. After a complete revolution of the drum, some electroscopic powder was sprinkled on the resin and a registration of the variations of the electrical state of the air appeared.[17] In fact, the electrical discharges induced in the antenna connected to the kite charged different areas of the resin which produced various Lichtenberg figures. Similar experiments were also made by the English clergyman and physicist Abraham Bennet (1749–1799). He devised a special electric pen (in fact a very thin Leiden jar, which was repeatedly charged by touching a larger jar) and with it he traced drawings on a resin cake. He also used a simple apparatus which allowed him to draw spirals, circles and volutes with his pen.[18] Bennet also mentioned an instrument imagined by Landriani for recording atmospheric electricity on a rotating resin plate.[19]

But in spite of many ideas which remain only on paper, probably the first functional recording apparatus using Lichtenberg's figures was described in 1823 by the English scientist and inventor Francis Ronalds (1788–1873), who was one of the pioneers of electric telegraphy and who made extensive studies on atmospheric electricity. Around 1813, Ronalds was informed by his friend the pioneer electrician George Singer (1786–1817) of Landriani's recording apparatus.[20] Ronald first imagined a kind of recording instrument (essentially for

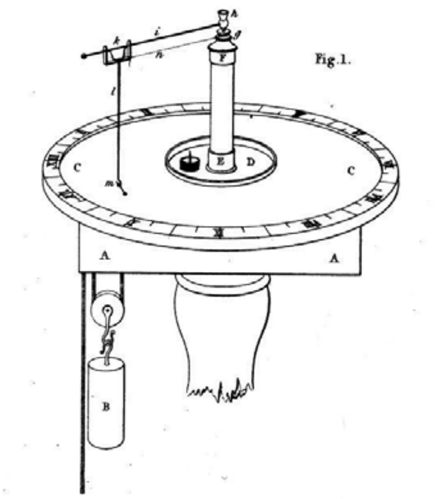


Fig. 7 *The first Ronalds electrographs. The resin did not move, while the arm supporting the wire with the beads rotated on the resin disk. (Ronalds, 1823*, op. cit. *note 21).*

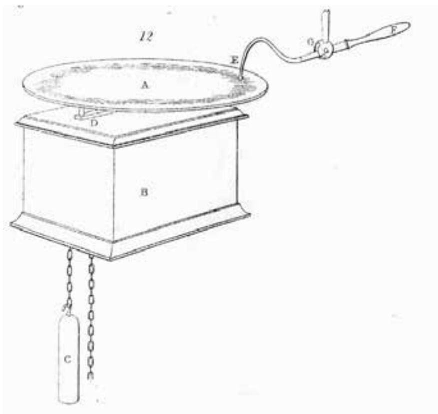


Fig. 8 *The second simplified version of Ronalds electrograph. The resin covered disk was inserted on the arbour of the clockwork and rotated. The moveable arm was connected with a lightning rod. (Ronalds, 1845,* op. cit*. note 24).*

studying fair weather electricity) with a series of very well insulated electrometers. They were charged one after another by a moveable electrode connected to the aerial conductor so that each of them could give the electrical state of the atmosphere at different times during a period of a day or more in the absence of an observer. Around 1814–15 Ronald considered using a disk of resin for recording the variation of atmospheric electricity and proposed his *electrograph*, which in fact was the first apparatus of this kind which was carefully designed and constructed. This apparatus also allowed one to register the electric discharges induced in the aerial conductors by lightning strikes. Ronald's first description of the electrograph appeared only in 1823[21] (Fig. 7). A box contained a weight-driven clockwork mechanism. On the box there was a circular wooden plate with a hole in its centre and a time scale divided into hours and minutes on its periphery. A removable disk of resin with a hole was placed on the plate. A glass tube covered with a cap was inserted into the former and protected a glass stem connected to the clockwork. The stem had a metallic cup at its upper end with a thin horizontal steel rod. On it there was a fork-shaped slider which supported a vertical wire. A small gold bead touching the resin was hanging from a wire with a hook. A fine thread was attached to the slider and to the top of the cap of the glass tube. When the clockwork was working the glass stem and the rod rotated with the vertical wire and at the same time the thread was wrapped on the cup of the glass tube. In such a way the gold bead traced a spiral on the resin cake. The cup contained some mercury and the wire connected with an antenna or a lightning rod was dipped in it. So the bead electrically charged the plate along the spiral path following the changes of the atmospheric field.[22] This apparatus allowed one also to register the voltage surges induced in the aerial conductors by lightning strikes. Finally after several hours the plate was removed and sprinkled with powder (Ronald suggested the use of common dry hair powder!). A spiral with an array of Lichteberg's figure appeared and the variations of their form and breadth corresponded to the changes of the electrical state of the air.

In the 1840s Ronalds modified and simplified his electrograph (Fig. 8). In the new version, a plate with a thin coat of resin rotated while the electrode connected with the antenna moved on it like the tone arm of a modern record player. This instrument was adopted in the 1843–44 in the Kew Observatory[23] and later also in the Greenwich Observatory until at least 1846.[24] Ronald was never very satisfied with the electrograph because of problems in making the resin coating, which had to be perfectly compact, homogeneous and of uniform thickness. In Kew a calotype image of a Lichtenberg spiral-shaped figure was successfully taken, but finally Ronalds abandoned the device and focussed his attention on developing new photographic recording instruments such as the photo-electrograph.[25]

## Going Wireless

After the 1850s, Beccaria's ceraunographs were forgotten and Ronalds's electrographs were abandoned. The study of fair weather atmospheric electricity continued in many observatories and with improved recording instruments, but for almost half a century no new specific instruments for registering lightning strikes were proposed.

But in the second half of the 19th century a series of discoveries and inventions opened the way for a new generation of thunderstorm detectors and recorders. In the 1860s, the Scottish mathematical physicist James Clerk Maxwell (1831–1879) developed his unified theory of electromagnetic radiation which brought together electricity, magnetism and light as different manifestations of the same phenomenon. Maxwell's four equations describe the behaviour of electric and magnetic fields and how they are generated by charges and currents. An important consequence of the equations is that they show how fluctuating electric and magnetic fields propagate as electromagnetic waves. Their existence was demonstrated experimentally by the German physicist Heinrich Hertz (1857–1894) in the 1880s. In 1890 the French physicist Édouard Branly (1844–1940) invented the so called '*radio-conducteur*': an insulating tube (ebonite, glass, etc.) containing some metallic filing between two electrodes.[26] Branly discovered that the electric resistance of the filings, which was normally in the order of $10^6$ ohm, could suddenly decrease to $10^3$ or even $10^2$ ohm and became a conductor when in the presence of electromagnetic oscillations. He also observed that the high resistance state of the device could be re-established by simply tapping on the tube. A spark discharge of a Leyden jar or of an electric machine, were enough to drastically change the resistance of the coherer. According to the common explanation at the time, when electromagnetic waves were set up in the neighbourhood of the device, electromotive forces were generated in it which appeared to fuse the filings together, that is, to cohere the particles, and thus their electrical resistance decreased.[27] The term coherer, which became commonly used, was introduced by the British physicist and inventor Sir Oliver Lodge (1878–1955). Lodge, who in the 1880s made several researches on lightning, lighting rods, electrical sparks, and oscillatory discharges of Leyden jars, was one of the pioneers of wireless transmission. In his experiments and demonstrations with Hertzian waves he used improved Branly's coherers. Lodge (and others) had also observed that the coherer also responded to atmospheric discharges.[28] Following his research, he also believed that lightning, like for example the sparks of Leiden jars, were oscillatory discharges producing damped electromagnetic waves. This erroneous belief was the commonly accepted until the beginning of the 20th century. Today we know that lightning events are rapidly pulsating unidirectional discharges, however for this discussion it is enough to know that their radio frequency electromagnetic fields act on the resistance of coherers. Furthermore since the 1890s, with

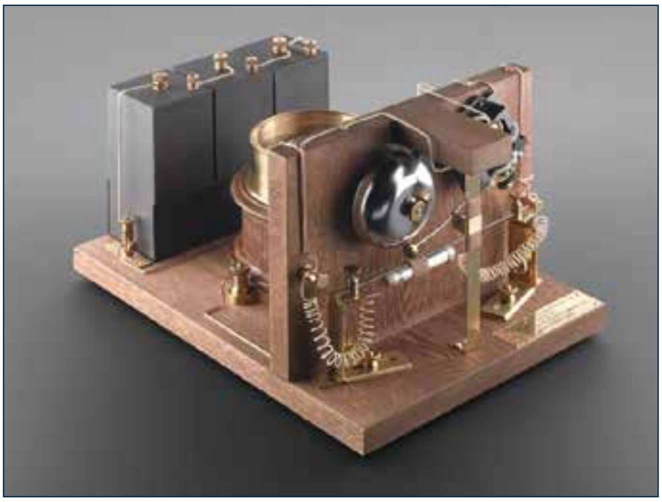

Fig. 9 (and Cover) *Lightning detector of Alexander Stepanovich Popov.*

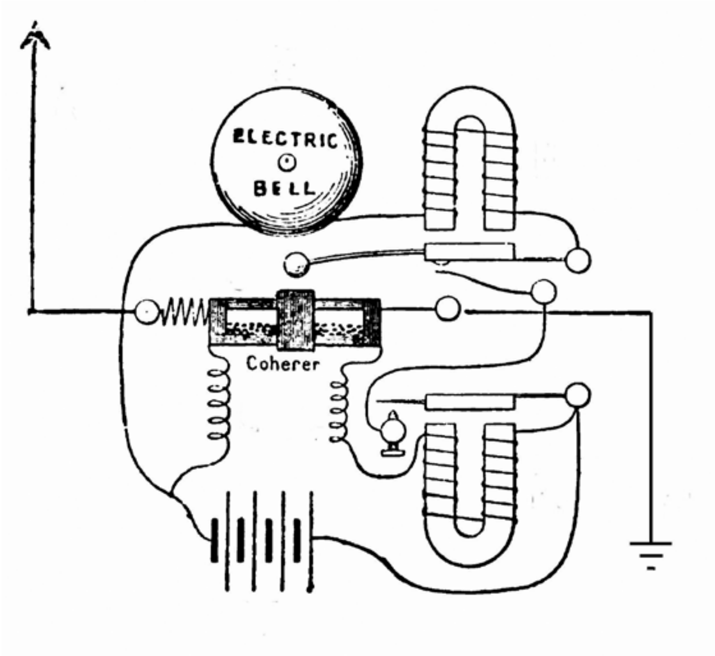


Fig. 10 *Original scheme of Popov's lightning detector. The same kind of circuit was used by several devices of the same type and by the early wireless receivers. (Popov, 1896,* op. cit. *note 30).*

the rapid development of wireless technology other types of radio wave detectors were developed.[29] The invention of the coherer opened the way to the wireless transmission of signals, and to a completely new system of detecting and recording lightning discharges.

## Popov Lightning Recorder

The Russian physicist Alexander Stepanovich Popov (1859–1906)(the name is sometime spelled Popoff) is today remembered as one of the most important pioneers of wireless communication. Popov was particularly interested in electrical technology and in 1883 became instructor and chief of laboratory in the Navy's Torpedo School at Kronstadt. Here he became familiar with the works of Hertz, Lodge and Branly, and after having improved the metallic powder coherer, in 1895 he built an apparatus which could detect electrical oscillations produced by the discharges of electrical machines, and induction coils, as well by the sparks generated by opening or closing an electric circuit including an electromagnet, a capacitor or an inductance. But his apparatus, which was described in 1896, also recorded '*the action of electric atmospheric disturbances*' when it was connected with an antenna or a lightning conductor.[30] (Fig. 9 and Cover).

In Popov's original detector one of the terminals of the coherer was connected to an antenna and the other was grounded. **(**Fig. 10**)** But it was also part of a circuit with a battery and a relay. The latter could operate an electric bell. Thanks to the radio noise generated by a lightning strike the resistance of the coherer suddenly dropped so that the current of the battery could switch on the relay and operate the electric bell. But the bell hammer hit the coherer and restored its original high resistance state, so that the detector was ready to receive a new signal. (The reset contrivance using the alarm bell for tapping the coherer was an original invention of Popov.) Two choke coils in the coherer's leads prevented the radio signal across the coherer from short circuiting by passing through the DC circuit. This basic circuit was reproduced with some variation in most lighting recorders proposed in the following years. In July of 1895 an improved detector with the addition of an electromagnetic pen with a Richard frères[31] recording drum, was installed on the roof of the Institute of Forestry of St. Petersburg. The apparatus was tested during the summer with the collaboration of G.A. Luboslavsky and several lighting strikes were recorded. In 1895–96 Popov's attention was attracted by the new rays discovered by Röntgen, as he continued to improve his detectors and recorders. In fact one of them was installed in 1896 at the annual fair of Nizhny Novgorod and when Popov read about Marconi's experiments and suddenly resumed his experiments with wireless transmission. But his further researches go beyond the frame of this article.[32] Popov's device certainly was the first wireless apparatus for registering lightning strikes.[33] In the next few years several inventors, physicists, electrical engineers proposed a series of similar lightning recorders.

## Boggio Lera's Lightning Recorder

In 1898 the Italian physicist and mathematician Enrico Boggio Lera (1862–1956), who was professor at the Royal Technical Institute of Catania and at the Royal School of viticulture and oenology, after having repeated some of Marconi's first experiments decided to test if his receiving apparatus was influenced by lightning.[34] He observed that his device was detecting also very far electrical discharges as well as very faint heat lightning. Boggio-Lera considered that it would have been useful to add a recorder to the detector. Then, with the support of the Director of the School of viticulture, in July 1899 he was able to install his apparatus in the observatory of the Institute. His first recorder included a metallic powder coherer (whose terminals were connected to an antenna and to the ground), lightning arrester, a Leclanché cell, a Hipp relay, 3 Radiguet cells and an electric hammer for tapping the coherer (Fig. 11). The signals generated by lightning strikes were recorded on the paper fixed on the clockwork driven cylinder (2 revolutions in 24 hours) of a common Richard's meteorological recording apparatus. A simple mechanical contrivance slowly moved the recording pen in the vertical direction so that the trace of the latter appeared as a spiral with a spire every 12 hour. The electric circuit of the recorder was not really different from other similar apparatus, but Boggio-Lera modified it by adding a second relay, an electric cell and by slightly modifying the electric circuit in order to distinguish between far and near lightning **(**Fig. 12**).** In fact by properly regulating the tension of the spring of the relays (and thus their sensitivity) and the one of the hammer, he could record in a different way the feeble effect of a far thunderstorm and the stronger one of a local storm. The first ones were marked with a ½ millimetre trace on the recording drum, the latter with a 2 mm one.

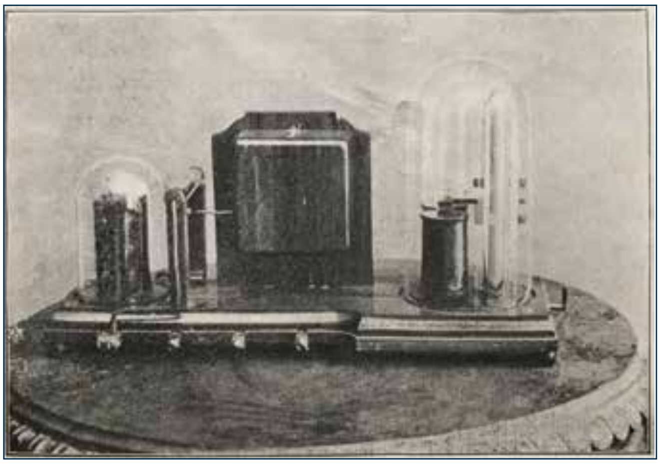

Fig. 11 *This Boggio-Lera lightning detector (without recording device) was installed in the Royal School of viticulture and oenology of Catania. From left to right: lightning protector, metallic powder coherer, electric de-cohering hammer and Hipp's relay. (Boggio-Lera, 1901*, op. cit. *note 34).*

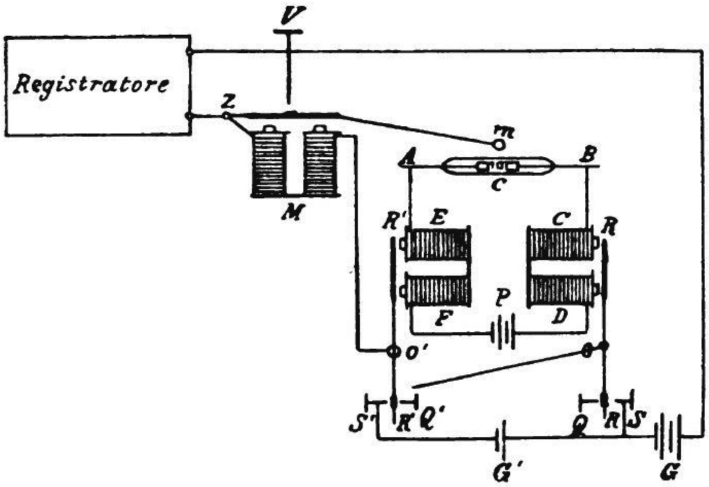


Fig. 12 *This scheme illustrates the Boggio-Lera lightning recorder with two relays (R and R'). With it one could register in a different way the faint and far lightning and the stronger one of a local storm. (Boggio-Lera, 1900*, op. cit. *note 34).*

Boggio-Lera also proposed a three-relay apparatus in order to differentiate local, far and very far lightning strikes. But it is not certain that such an instrument was constructed. Finally in 1902 he wrote a new article relating a series of modifications of the detector and of the coherer in order to increase the sensitivity of the apparatus and to avoid that of electrical oscillations disturbing the action of the relays. In fact, he was looking for a better solution than the inductances, which were often used as a filter in these kind of detectors.[35]

## Tommasina's Electro-radiophone

In 1899 Thomas Tommasina (1855–1935), a Swiss artist who turned into a physicist, discovered that with a certain type of carbon powder it was possible to construct a special 'auto de-cohering coherer'.[36] The powder was inserted in the hole of a small ebonite plate between two mica plates. Two wires assured the connection with the carbon. The device had a remarkable propriety. The resistance of the powder suddenly dropped under the action of an electromagnetic disturbance, but immediately after that, the coherer became de-coherised and the resistance returned to its original high value without any mechanical action. In 1900 Tommasina, who knew the work of Boggio Lera, proposed a lighting detector called '*electro-radiophone*'[37] (Fig. 13). The very simple apparatus was composed of a telephone receiver containing a small carbon coherer sealed in a glass tube. The coherer was inserted in series in the circuit including a battery and the telephonic electromagnet. Finally the terminals of the electromagnets were connected with a grounding wire and an antenna made of three 30 metres long wires. With the electro-radiophone Tommasina could clearly hear the various sounds produced by far-off lightning. When a thunderstorm was approaching the crackling sounds changed and became more intense. For example, on the 29th of September 1899, with fair weather the electro-radiophone produced various noises indicating a far-off storm. These increased in intensity and frequency until, after three and half hours, a violent thunderstorm started where the laboratory was located.[38] Tommasina hoped that his simple instrument could have been useful on board of ships for detecting and understanding the trajectory of thunderstorms.

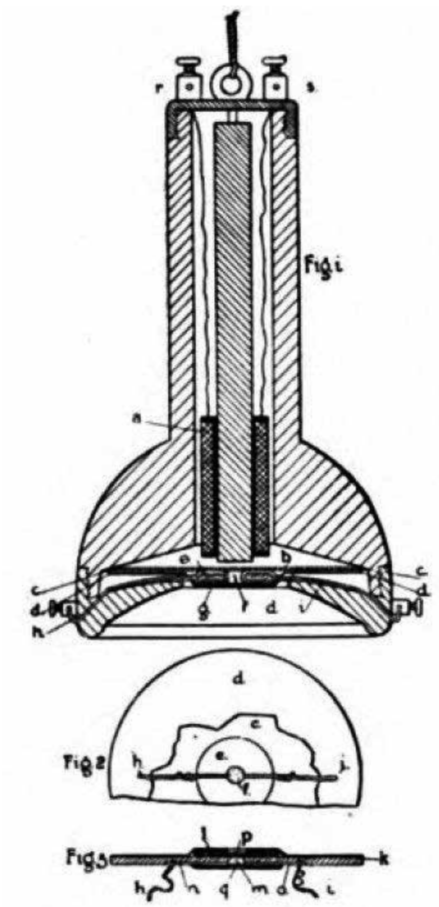


Fig. 13 *This scheme illustrate Tommasina's electro-radiophone with the 'auto de-cohering coherer'. (Tommasina, 1901,* op. cit. *note 37).*

## Schreiber and Fényi Gewitter-Registrator

Lightning recorders seemed to be quite popular in the Austro-Hungarian Empire and various types were proposed by Hungarian scientists and inventors.[39]

During the year 1900, Johann Schreiber (1843–1903), who was assistant of the Jesuit astronomer Gyula Fényj (1847-1927) director of the Haynald Observatory in Kalocsa, conceived a rudimentary thunderstorm recorder (*Gewitter-Registrator*). After various trials and modifications, the definitive instrument was ready in the Autumn, but it was necessary to wait until Spring of next year to test it. The apparatus was quite different from Popov's one, and was described in great detail by Fenyi, who greatly contributed to improving it[40] (Fig. 14 ). Schreiber did not use a metallic powder coherer but an imperfect contact coherer composed by two perpendicular steel needles one laid upon the other[41] The needles were fixed on the box of the electric bell which acted as acoustic alarm as well as de-cohering apparatus. Instead of a telegraphic relay, Schreiber employed a moving needle galvanometer. When, under the action of an atmospheric discharge the coherer became conductive, the current of a battery energised the coil of the galvanometer. Its magnetic needle deviated and one of its pointed ends touched a contact and closed a second circuit. This included a second battery, an electric bell and an electromagnet operating the pen. The bell not only acted as a warning signal but its vibrations de-cohered the two needles. The

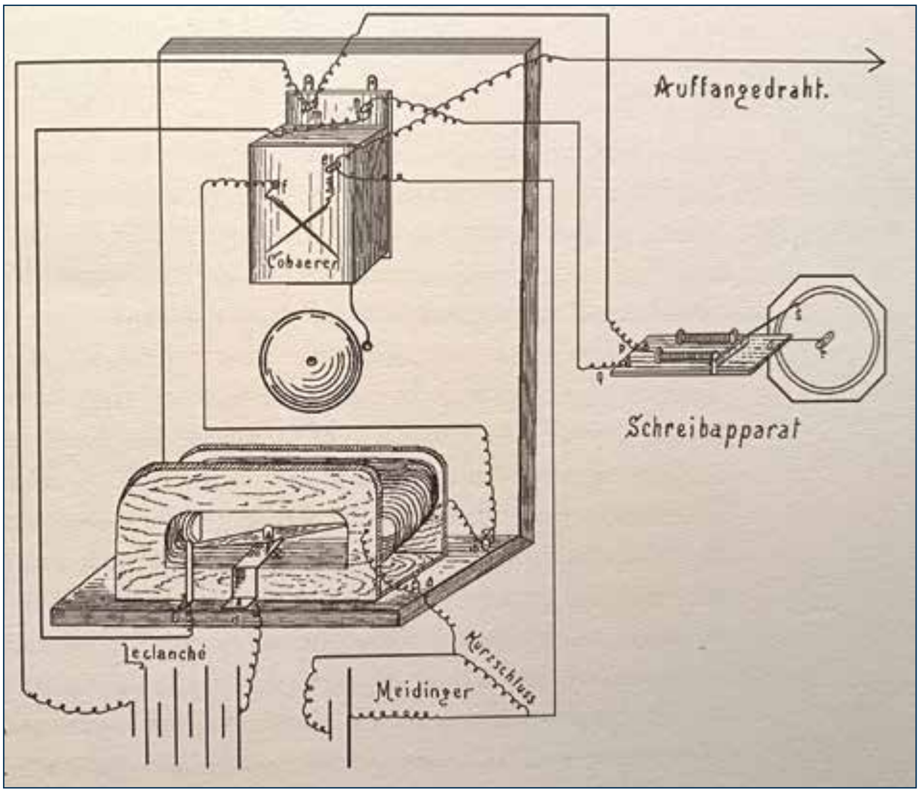


Fig. 14 *Diagram illustrating the Schreiber and Fényi Gewitter-Registrator. The couple of crossed needles acting as coherer was on the box of the electric bell. The galvanometer was used instead of a telegraphic relay. (Tibor Horvát, 2001,* op. cit*. note 39).*

Fig. 16 *One of the disk recorded in 1902 with Palatin's lightning recorder. (Tibor Horvát, 2001*, op. cit. *note 39).*

signals were recorded by the pen on a vertical paper disk which was inserted on the arbour of a clockwork so that every hour it made a complete revolution. A simple contrivance slowly moved the writing mechanism from the periphery to the centre of the disk so that the recordings of a day were not superimposed on a single circle, but drew a spiral.

In the first years of the 20$^{th}$ century, Fenyi modified, simplified and improved the apparatus.[42] One of the problems with the needle coherer was the fact that when the current was too strong the needles stuck together. Initially, he used a Meidinger cell (1 volt) with a kind of shunt in order to reduce the voltage at the coherer to 0.25 volt circa. But in 1902 Fenyi tried a new type of aluminium-zinc battery (0.28 volt). He then experimented with several needles-coherers connected in series (4 to 6) and could use a Meidinger or a Lechanché cell without a shunt. It seems that he also made experiments with metallic powder coherers. He also improved the dimensions of the galvanometer coil, the resistance of the electromagnets, and the length of the antenna, which had to be carefully chosen in order to obtain the highest sensitivity and the best recorded traces. It seems that around 1903 he was using three slightly different recorders.

The large amount of data collected in Kalocsa with the lighting recorders seemed to be in agreement with the observational data previously collected in Hungary. At the beginning of the 20$^{th}$ century, an improved Schreriber-Fenyi recorder was manufactured by the firm Max Kohl of Chemnitz and sold for 180 marks[43] (Fig. 15). This type of recorder was installed in several observatories both in Hungary as well throughout the rest of the world (Pola, Manila, Lisbon, Nürnberg, Potsdam, Kremsmünster, etc.). At least two of them went to Africa: one in Johannesburg and the other in Salisbury (today Harare the capital of Zimbawe). A Schreiber-Fényi apparatus is today preserved in the Museum of the Kremsmünster observatory.[44] This recorder was made in Budapest by the clockmaker and mechanic Victor Hose (1872-1957), who manufactured a number of these apparatus.

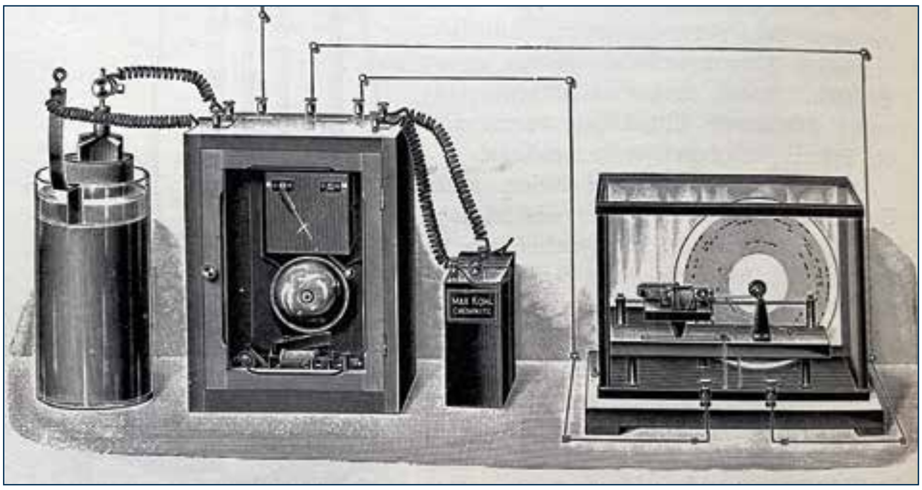

Fig. 15 *The improved version of the Schreiber recording apparatus by the German manufacturer Max Kohl. On the left the detector, on the right the recording apparatus. (Max Kohl, 1905,* op. cit. *note 43).*

## Gergely Palatin Detector

In 1901, another Hungarian physicist Gargely Palatin (1851–1927), who was teaching at the Benedictine college of the Pannonahalma Abbey, became interested in Marconi's experiments and conceived another lightning detector.[45] His coherer was neither one with metallic powder nor a crossed needles version. Palatin used a magnetic steel knitting needle cut in two sections. These were aligned and fixed horizontally leaving a narrow gap between their adjacent ends. Some iron filing were sprinkled on the gap and because of the steel magnetisation formed a kind of bridge. The apparatus included the usual telegraphic relay with an electric bell (acting also as tapper on the coherer) two batteries, and (unusually) a galvanometer (simply used as an indicator).

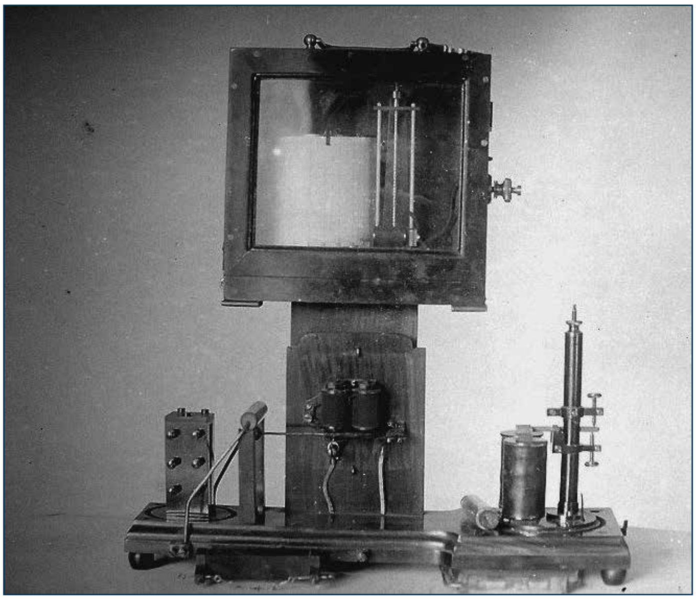

Fig. 17 *An old photograph of the lightning recorder in use at the Gothard Observatorium. On the top of the instrument a Richard recorder. The instrument (without the recorder) is still preserved today. (See: http://www.gothard.hu/gttak/archive-photos/categories/physmisc/physmisc.php).*

In 1902 the detector was also equipped with a recording device. An electromagnetic driven pen inscribed the signals on a rotating disk connected with a clockwork mechanism. The disk made a complete revolution in one hour while the pen slowly moved radially in order to write a spiral. Up to 1907 Palatin made several observations and today 90 recorded disks survive in Pannonahalma[46] (Fig. 16).

Finally, we can mention that in Hungary the engineer, instrument maker and astronomer Jenö Gothard (1857–1909) and his collaborators also made a lightning detector of the Boggio-Lera's type. Jenö and his brothers Sándor and István (1869-1848) founded the Herény Astrophysical Observatory near Szombathely. Their main interest was astronomy, but they also regularly made meteorological observations. Gothard's recorder is today preserved in the Museum of the Gothard Observatory now part of the Loránd Eötvös University[47] (Fig. 17).

## Notes and References

1. For an introduction to the history of these instruments see: Paolo Brenni, ' Prometheus' Tools, Instrument and Apparatus Used in Atmospheric Electricity Research and Experiments', in Peter Heering , Oliver Hochadel, David Rhees Jr, eds, *Playing with Fire Histories of the Lightning Rod* (Philadelphia: American Philosophical Society, 2009: *Transactions of the American Philosophical Society*, Vol 99, part 5, pp. 230-255.

2. Giovanni Battista Beccaria, *Giambattista Beccaria delle Scuole Pie congratulandosi col signor conte Prospero Balbo della sua laurea in giurisprudenza gli appresenta la descrizione di un suo nuovo ordigno disegnatore de' fulmini* (Torino, 1780) and Giovanni Battista Beccaria, *Di un ceraunografo e della ragione de' tremouti* (Torino, 1780). See also Felice Garelli, *Sulle dottrine elettriche nel secolo XVIII* (Mondovì, 1866), pp. 460-470 and Michael Brain Schiffer, *Draw the Lightning Down Benjamin Franklin and Electrical Technology in the Age of Enlightenment* (Berkeley, London, 2006), pp. 179-180.

3. Late 19$^{th}$ century different type of ceraunographs were also called thunderstorm-recorders, lightning-recorders, electrographs, brontometers, brontographs, ceraunometers or electroradiographs. See Charles F. Talman, 'The language of meteorology', *The Popular Science Monthly*, March 1913, pp. 272-279.

4.Beccaria mentioned the conductor, which was a kind of lightning rod, as *filo esploratore della celeste elettricità* ('wire for exploring the electricity of the sky').

5. Beccaria also noted that the number and the sizes of the holes also depended on the length, the insulation and the position of the lighting rod.

6. For obviating this problem, Beccaria proposed to cover the disk with a layer of cinnabar (mercury sulphide). Two sparks passing through the same hole would react with the cinnabar and leave on it two different and separated traces.

7. Francesco Giuseppe Gardini, *De Influxu Electricitati Atmosphaericae in Vegetantia* Augustae Taurinorum, 1784), pp. 28-31.

8. Atanasio Cavalli, 'Lettera II Del Croniometro del Sig. Cavaliere Landriani e del Caraunografo del fu P. Beccaria' and 'Lettera III Del cronio-ceraunometro, dell'elettroforo del saggiatore e dell'atmimetro', *Lettere meteorologiche romane. Tomo primo* ( *Roma,* 1785), pp. 31-42 and 43-66.

9. Marsilio Landriani, 'Descrizione del Chronhyometro ossia di una nuova macchina meteorologica', *Opuscoli fisico-matematici* (Milano, 1781), pp. 21-49.

10. By radially shifting the pencil every day it was possible to have the same disk with records of an entire week.

11. Mario Baratta, 'La specola astronomica e meteorologica Caetani', *La Vita Italiana*, Fascicolo 24 (1897), pp. 915-924.

12. Antonio Vassalli Eandi, 'Notice d'un météorographe', *Mémoires de l'Académie des Sciences littérature et beaux-arts de Turin, Sciences Physiques et Mathématiques*, 1$^{re}$ partie, an XII (1803-4), pp. 426-444.

13. Vassalli Eandi also contemplated the possibility of using a Beccaria ceraunograph of the second type.

14. Pietro Moscati, 'Descrizione dell'Osservatorio meteorologico eretto al fine dell'anno 1780', *Memorie di matematica e fisica della società Italiana*, Tomo V (1790), pp. 365-381 and Edoardo Proverbio, 'Sul Gabinetto meteorologico e sulla Specola meteorologica e astronomica di Pietro Moscati in Milano', *Memorie della Società Astronomia Italiana*, **68** (1997), pp. 543-572.

15. See for example Pierre Bertholon, *De l'électricité des météores*, Tome II (Paris, 1787), p. 306.

16. Geoorg Christoph Lichtenberg, 'De Nova Methodo Naturam ac Motum Fluidi Electrici Investigandi Commentatio prior', *Novi commentarii Societatis Regiae Scientiarum Gottingensis ad a. 1778* (1778), pp. 168-180.

17. Georg Christoph Lichtenberg, 'Commentatio posterior super Nova Methodo Naturam ac Motum Fluidi Electrici Investigandi', *Commentationes Societatis Regiae Scientiarum Gottingensis per annum 1778,* **1** (1779), pp.65-79, (the apparatus is described at the pp. 72-73).

18. Abraham Bennet, *New Experiments on Electricity* (Derby, 1789), pp. 45-55.

19. *Ibid.* pp. 49-50. It is curious that no reference of Landriani mentions such an electricity recorder. It is possible that Bennet confused it with the recording rain gauge or with another apparatus not by Landriani.

20. George John Singer, *Elements of Electricity and Electro-Chemistry* (London, 1814). Singer gave lectures on electricity and among

his audience were Faraday and Ronalds. Did Singer repeat the dubious mention of Landriani made by Bennet? (see note 19).

21. Francis Ronalds, *Descriptions of an Electrical Telegraph and of Some Electrical Apparatus* (London, 1823), pp. 47-52. The instrument was described several years later in *The Encyclopedia Britannica* (eighth edition), Vol. VII, 1855, p. 626 and in Tal. Schaffner, *The Telegraph Manual* (New York), 1867, pp. 153-156.

22. The velocity of the bead on the resin could be varied by connecting the moving system to the hour arbour or the minutes one. Normally with fair weather a slow movement of the bead was ideal, but during thunderstorm the variations of the electric field are more rapid, and it was better to have a faster rotating bead.

23. In 1842, the British Association for the Advancement of Science took the empty building of an observatory which had been completed in 1769 and it became widely known as the Kew Observatory. Francis Ronalds was the inaugural Honorary Director for the next decade and founded the observatory's enduring reputation in the field of meteorology and terrestrial magnetism.

24. Francis Ronalds, 'Report concerning the Observatory of the British Association, at Kew, from August the 1st, 1843, to July the 31st, 1844', in *Report of the fourteenth Meeting of the British Association for the Advancement of Science,* London 1845, pp. 120-142, see especially pp.126-127. See also Beverly F. Ronalds, *Sir Francis Ronalds Father of the Electric Telegraph* (London, 2016), pp. 132-134 and 434-435.

25. The electrograph should not be confused with the photo-electrograph. In the latter the divergence of the straws of Volta's electroscope was projected on a moveable table covered with photographic paper.

26. Édouard Branly, 'Variation de conductibilité sous diverses influences électriques', *Comptes Rendu de l'Académie des Sciences*, **111** (1890), pp. 785-787. Before Branly other scientists such as the Italian Temistocle Calzecchi-Onesti (1853-1922) observed the action of electric sparks on metal filings, however, it was the French physicist that clearly demonstrated that the action happened without any material connection between the spark generators and the filings.

27. The exact mechanism of the coherer behaviour was and still is not very well known. See: *Coherers, A review,* A Thesis Submitted by Thomas Mark Cuff, 1993 https://www.researchgate.net/publication/290446135_Coherers_a_review (accessed 8.1.2020).

28. It seems that the drop in resistance of a metallic powder during a thunderstorm had been noticed since the mid-1850s by the telegraph engineer Cromwell Fleetwood Varley (1828–1883).

29. Vivian J. Phillips, *Early radio wave detectors* (London, 1980).

30. The original article appeared in Russian in the *Journal of the Russian Physical and Chemical* in January,1896. A complete English translation appeared only in 1900: Alexander Popoff, 'Apparatus for the detection and registration of electrical vibrations'; *The Electrical Review*, **47**, 23 November 1900, pp. 845-846 and 882-883.

31. The Parisian firm *Jules Richard (ancienne maison Richard Frères)* was very well known and specialised in registering meteorological, physical and industrial instruments. Most of them were equipped with a revolving drum covered with recording paper and containing a clockwork mechanism.

32. For the role of Popov in the history of wireless see Charles Süsskind, 'Popov and the Beginning of Radiotelegraphy', *Proceedings of the IRE*, **50** (October 1962), pp. 2036-2047.

33. Some of Marconi's biographers mention that around 1892 the very young Italian inventor made an apparatus of this kind when he was doing his first electrical experiments. But we do not know much about his early scientific activity and there is no evidence nor original documents supporting this claim.

34. Enrico Boggio-Lera, 'Sopra un apparecchio registratore delle scariche elettriche dell'atmosfera' *, Atti della Accademia Gioenia di Scienze Naturali in Catania*, *Memoria XIII*, Serie IV, Volume XIII, 1900 and Enrico Boggio-Lera , 'Sui miei apparecchi segnalatori e registratori dei temporali', *ibid*, Serie IV, Volume XIV, 1901. See also: Ladislaus von Szalay 'Elektrische Signalapparate für ferne Gewitter', *Das Wetter Zeitschrift für Angewandte Meteorologie*, **18** (1901), pp. 133-138.

35. Enrico Boggio Lera, 'Un utile modificazione del coherer per gli apparecchi segnalatori e registratori di temporali', *Atti della Accademia Gioenia di Scienze Naturali in Catania, Memoria XII*, Serie IV, Volume XV, 1902.

36. Thomas Tommasina, 'Sur l'auto-décohérisation du charbon…', *Comptes Rendus de l'Académie des Sciences*, **130** (1900), pp. 904-905.

37. Thomas Tommasina, 'Sur l'étude des orages lointaines par l'électro-radiophone', *Comptes Rendus de l'Académie des Sciences*, **131** (1900), pp. 876-878 and Eugene P. Lyle Jr., 'An Electrical Storm Prophet, An account of the Italian Inventor who has Coming Storm Telephone Him of their Approach', *Everybody's Magazine*, **5** (October 1901), pp. 443-447.

38. Tommasina made several observations both in his laboratory in Geneva as well as in his house in Intra on the Lake Maggiore.

39. In 2001 the Hungarian Electrotechnical Museum in Budapest held an exhibition on historical lightning detectors. The booklet accompanying the exhibition gives much information about these kind of apparatus invented and used in Hungary. Tibor Horvát, *100* Éves *Villámjelzők* (100 years old Lightning Detectors), (Budapest, 2001); see also Tibor Horvát, '100 éves Magyar villámjelzők', *Elektrotechnika*, 95 évfolyam, 3. Szám, 2002, pp. 82-85.

40. Julius Fényi, *Gewitter-Registrator construirt von P. Johann Schreiber S.J.* (Kalocsa, 1901).

41. The pressure of one needle on the other could be varied in order to modify the sensitivity of the coherer.

42. Julius Fényi, 'Über den Gewitterregistrator in einer neuer sher einfachen Form', *Meteorologische Zeitschrift*, 1902, pp. 371-372. Julius Fényi, 'Über Konstruktion und Funktion eines einfachen Gewitterregistrators', *Natur und Offenbarung*, **49** (1903), pp. 612-616.

43. Max Kohl, *Preisliste Nr. 21 Physikalische Apparate*, (Chemnitz, Max Kohl, non-dated but 1905), p. 800.

44. See http://www.specula.at/adv/monat_1107.htm (accessed 28 February 2020). This detector has a metallic filing coherer and not the typical Schreiber-Fényi needles coherer.

45. Palatin Gargeli, 'Megfigyelések módositott zivatarjelzővel', *Természettumományi Közlöny*, 5. évfolyam, 8. Szám, 1901, pp. 564-567.

46. Palatin Gargeli, 'Megfigyelések módositott zivatarjelzővelés és új regisztráló készülékkel', *Természettumományi Közlöny*, 35. évfolyam, 409. Szám, 1903, pp. 567-572.

47. Horvát (2001) *op. cit.* note 39. See also: http://www.gothard.hu/gttak/archive-photos/categories/physmisc/images/017.jpg and http://www.gothard.hu/gttak/instruments/meteorological-instruments/meteorological-instruments.php (accessed 30.1. 2020).

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*To be followed in the September issue by Part 2 From Lancetta's electrograph to the teinograph and the kine-klynodograph and the Conclusions.*