G. V. Schiaparelli and A. Secchi on shooting stars

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1. Schiaparelli and Secchi correspondence

In the Archives of the Brera Observatory 69 letters of Angelo Secchi (1818-1878), are kept. All these letters were sent to Giovanni Virginio Schiaparelli (1835-1910): they go from the 14th of May 1861 to the 8th of October 1877. So the letters cover all the time in which the scientific life of both scientists overlapped.

Thanks to the courtesy of the responsable of the *Università Pontificia* Archives in Rome we had the opportunity to consult the letters sent to Secchi by Schiaparelli (74).[4]

Schiaparelli sent to Secchi his first letter in 1861 after the discovery of a new asteroid (Esperia), asking Secchi to observe it. In the same year the milanese astronomer published a paper on the new celestial body he had just discovered.

Schiaparelli had been appointed second astronomer in the Brera Observatory in the 31th of August 1859, but he came to Milan only in the June of 1860. He began his work of astronomer making observations at the Meridian Circle of Starke, an old instrument bought in 1825 thanks to the good offices of the Austrian emperor after he had visited the Observatory. [5]

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[5]For more informations on the instruments of the Observatory see E. Miotto, G. Tagliaferri, P. Tucci, *La strumentazione nella storia dell'Osservatorio astronomico di Brera* (Milano: Unicopli Editore, 1989).

Schiaparelli's first paper was published in the *Effemeridi Astronomiche di Milano* for the year 1861. It dealt with the initial direction of comets tails.

Up to 1860, instead, Secchi had performed astronomical researches in the field of physical astronomy (visual observations of phenomena on the surface of bodies in the solar system, planets, comets, double stars, the Sun, star clusters). It's worth underlining that one of the most important astronomical works of Secchi in that period of 10 years, was the revision of O. Struve double-stars Catalogue, a work that Secchi had begun in 1852 when the Merz refractor arrived in Rome.

It was from the solar eclipse in 1860 that Secchi began to move towards new fields of research: the Sun and the spectroscopy.

Secchi sent his last letter to Schiaparelli a few months before his death (Secchi died on the 26th February of 1878).

Historiography on Secchi, on Schiaparelli, and on the period in which they worked is limited.

Abetti wrote an important book on Secchi's contribution to astrophysics[6].

A general review of Secchi's contribution to science can be found in the "Proceedings" of a meeting organized by the *Accademia dei XL* in occasion of the centenary of Secchi's death.[7].

As regards Schiaparelli only his contributions to the planet Mars have been studied with some accuracy from an historical point of view. Other important issues of Schiaparelli's works in astronomy have been neglected. And it's difficult to find historical works on the connection of astronomy with other important branches of science

[6]Giorgio Abetti, *Padre Angelo Secchi, il pioniere dell'astrofisica* (Milano: Casa editrice Giacomo Agnelli, 1928).

[7]*Padre Angelo Secchi nel Centenario della morte (1878-1978)*, (Roma: Accademia Nazionale delle Scienze detta dei XL, 1979).

(e. g. physics, chemistry) in the 19th century; and, according to us, in the works of both Schiaparelli and Secchi the connection is very strong.

In the light of the previous considerations the analysis of the correspondence between Secchi and Schiaparelli (16 years of letters) can improve greatly our knowledge of the period in which the two scientists lived and operated; besides, of course, they can draw some light to those hidden aspects of scientific undertaking that articles and books can not show.

The topics discussed in their correspondence are as follows: the new asteroid Esperia, longitude difference measured through telegraph, personal equation, stellar, solar and cometary spectroscopy and terrestrial magnetism.

Before entering into some details on the subject of the present communication (shooting stars) we would like to emphasize some aspects of the relationships between the two astronomers. These aspects are not closely related to the scientific undertaking.

The correspondence between the two astronomers shows a warm friendship between them and, above all, that they estimated each other highly.

It's not strange that Secchi, director of the *Collegio Romano* Observatory, professor of Astronomy at the *Collegio Romano*, influential consultant to the pope for scientific problems, wrote to Schiaparelli who was at the beginning of his brilliant career.

In fact Secchi knew about the new asteroid (Esperia), discovered by Schiaparelli, through a letter Schiaparelli sent him with his first observations:

"Le invio le osservazioni del suo pianetino. ... Ella mi farà gran favore se mi potrà mandare qualche altra sua osservazione."

The milanese astronomer had begun his observations of the new asteroid on the 29th of April in 1861 and had published his first paper on this matter in Astronomische Nachrichten[8].

Although it was not so rare, in that period, to find a new asteroid (Cerere was the first asteroid discovered in 1801 by Piazzi, the one discovered by Schiaparelli was the 69th), it was however an important discovery for a young astronomer. It's worth remembering that the new discovery, realized with an Equatorial Sector built by Sisson in London in 1774 - an old instrument whose optics had been changed by Carlini mounting a Plössl objective - allowed Schiaparelli to tell the government that money to buy a new and more powerfull instrument was necessary.

Quintino Sella (an influential *'piemontese'* politician), who was a friend of Schiaparelli and appreciated him very much, managed to satisfy Schiaparelli's request.

Furthermore Secchi might have known that Schiaparelli had studied at Berlin Observatory in 1857 and in 1858 (here he had calculated Vesta's orbit) and at the Pulkowo Observatory, which was one of the most important Observatories in the world, for one year, from about the middle of 1859. At the Pulkowo Observatory Schiaparelli had worked with O. Struve whose double-stars Catalogue Secchi had begun to revise in 1852.

Secchi was very respectful towards Schiaparelli as we can realize from his letter of the 4th of June in 1861:

"Non vorrei essere molesto, ma credo che non le spiacerà avere qualche osservazione del suo pianetino."

So on the one hand Secchi appreciated in Schiaparelli the young astronomer who had studied in one of the best observatories in the

[8]G. V. Schiaparelli, "Entdeckung eines neuen Planeten (68)", *Astronomische Nachrichten*,1861,*55 (1309) (Mai 12)*: 207-208. The number was changed after in (69).

world. But on the other hand Secchi was worried about italian studies in astronomy.

An impending crisis of the old governments and the imminent unification of Italy under the Savoia monarchy, made astronomers feel that human resources and financial support were lacking. It is reasonable to think that Secchi perceived, in the appointment of Schiaparelli, a very clever scholar in astronomy, that something was changing in the field of the astronomy. And indeed he was right.

Moreover Secchi felt that the so-called *"Questione romana"*, that means the sovereignty of the Italian Government over Catholic Church territories, could put him into trouble, as he was a civil servant of the Roman Catholic Government. So Secchi probably foresaw that Schiaparelli could be a valid ally against the interference of new Italian Government into the affairs of the *Collegio Romano* Observatory: also in this case Secchi was right.

From the great deal of issues treated in the correspondence we have chosen to speak about the problem of shooting stars, a problem which Schiaparelli was the first to solve in a convincing way.

2. 19th century hypotheses on shooting stars[9]

Due to the works of Brandes (1823)[10], Coulvier-Gravier (1859) and others, in about 1860 it was known that the frequency of the appearance of shooting stars changed according to observations time, season and their azimuth. Moreover the azimuth of shooting stars was dependent on the time in which they were observed. From

[9] A history of the hypotheses on the origin of shooting stars during the last centuries can be found in David W. Hughes, "The History of Meteors and Meteor showers", *Vistas in Astronomy*, 1982, *26*: 325-345.

[10] As Hughes stresses, Brandes and Benzenberg gave birth to practical meteor astronomy. See Hughes,... pg. 327 quoted in the previous footnote.

Coulvier-Gravier's publication, moreover, an annual variation of the number of shooting stars resulted.

Two contrasting hypotheses had been formulated in order to account for the phenomenon of shooting stars: a *cosmic* hypothesis was sustained by Schiaparelli and an *atmospheric* or meteorological hypothesis was sustained, when Schiaparelli was working on the matter, by Coulvier-Gravier.

According to the *cosmic* hypothesis shooting stars came from interstellar space, and their trajectory could be calculated according to the Newtonian mechanics laws; the influence of the terrestrial atmosphere on shooting stars, one thought, was quite negligible.

The *atmospheric* hypothesis, instead, sustained that the trajectory of shooting stars was only determined by meteorological conditions of the terrestrial atmosphere (temperature, moisture, wind etc.).

Scholars who sustained the *atmospheric* hypothesis were not interested whether shooting stars came from the solar system or from the outer space; even though, after the publication of Schiaparelli's articles, they admitted that shooting stars could come from interstellar space.

What, instead, the supporters of the *atmospheric* hypothesis continued to deny was the existence of the so-called *radiant*, that is a point on the celestial sphere from which shooting stars seemed to originate.[11]

Interested as they were about the atmospheric path of shooting stars, the supporters of the *atmospheric* hypothesis turned their backs to the part of the sky from which shooting stars came; so they could observe the trajectory of shooting stars and not the

[11] More correctly the *radiant* was defined as the intersection between the celestial sphere and a line drawn from an observer's eye and parallel to the trajectory.

spot from which they originated.[12]

The discovery of the yearly and daily variations of the frequency of shooting stars and the discovery of the variation of the *radiants* spatial distribution seemed to support the *atmospheric* hypothesis: it would have been a little difficult to connect a cosmical phenomenon to the local time of each observer. It would be more reasonable to connect the variations of the frequency and the direction of shooting stars to fluctuations of temperature, pressure and so on.

So the problem was the following: either the *cosmic* hypothesis was able to account for the ascertained statistical laws of the frequency and direction of shooting stars, or these statistical laws, according to Schiaparelli, would have caused the defeat of the *cosmic* theory.[13]

3. Schiaparelli and Secchi

H. A. Newton (an astronomer of Yale College) and Schiaparelli, indipendentely, found the key for solving the problem according to the *cosmic* hypothesis: they were able to induce from the law of the variations of the frequency of shooting stars the velocity in their motion around the Sun. This velocity resulted to be 1.45

[12] "Essi [the supporters of the *atmospheric* hypothesis] negano affatto il fenomeno della *radiazione*, ed hanno anche inventato un mezzo assai ingegnoso per non vederlo mai, quello cioè di osservare voltando le spalle a quella plaga del cielo da cui arriva il maggior numero di meteore." in G. V. Schiaparelli, "Note e riflessioni intorno alla teoria astronomica delle stelle cadenti", see n. 5 of Appendix, p. 342.

[13] "Qui era lo scoglio, dove la teoria cosmica dovea necessariamente fare naufragio!" (ibid. p. 356).

times the Earth's velocity, that is the velocity of a celestial body moving along a parabolic trajectory.

But, - Schiaparelli guessed - if the velocity of shooting stars is parabolic, their orbits must be very similar to a comet's orbits. Once that this similarity was proved, the next step was to show the correspondence between the trajectory of a comet and the trajectory of a shower of shooting stars. Shooting stars, then, would be interpreted as low density matter travelling together with the comets, or as matter pulled away from the comets for mechanical reasons.

On this matter Schiaparelli wrote 5 papers which were published in the years 1866 and 1867 on *Bullettino Meteorologico dell'Osservatorio Romano*, whose director was A. Secchi.[14]

The *Bullettino* had already published many articles on shooting stars from the first issue, published in 1862. Secchi, in that period, was seriously involved in studying the Earth's physics. In this frame of mind - he thought - shooting stars could have given some information about the height of the terrestrial atmosphere, as shooting stars became visible at the moment of the contact with the terrestrial atmosphere: so from the observations of their parallax the height of the terrestrial atmosphere could be calculated.

Furthermore in a letter sent to Schiaparelli on the 23rd of November 1866 Secchi claimed that

"L'idea delle comete che possano appartenere alle stelle cadenti mi si era affacciata anche a me, ma non avrei creduto tanta coincidenza negli elementi. Ella ha finito proprio col bôtto, come dicono qui!"[15]

[14]See Appendix for Schiaparelli's paper on the matter.

[15]The letter was written after Secchi had received the *Lettera IV* of Schiaparelli who had found a strict correlation between Perseids and the comet 1862 III).

Secchi observed shooting stars for their possible connection with meteorology, an issue which Secchi was very interested to. In a paper publisbed on the *Bullettino* in September 1862 Secchi reported observations of the shooting stars in August 1861. In that period Secchi was yet undecided whether shooting stars were cosmical bodies or meteorological phenomena.

Again in a paper published in the *Bullettino* in August 1863 Secchi wrote about his observations on the shooting stars of August and referred about the theory of Marsh who had studied the relationship between shooting stars and terrestrial atmosphere.

Secchi, moreover, had devised a system for measuring shooting stars parallax: two observers, one in Rome and another one in Civitavecchia, a little town fifty kilometers from Rome, exchanged informations through a telegraphic line. The telegraph allowed two observers to be sure that they were observing the parallax of the same shooting star.

On the grounds of the complete correspondence between the two astronomers and on the grounds of their published papers we have reconstructed Schiaparelli's path to the solution of the problem of the origin of shooting stars: where they came from, how they were formed, what their trajectory was.

In the *Bullettino*[16] 1863 *17*, a short letter of Schiaparelli sent to Secchi on shooting stars was published. In the letter, although written in an informal way, Schiaparelli outlined a research program on the matter: first of all he was more interested in discovering the law of the motion of shooting stars rather than determining the amount of stars visible with the naked eye:

"Nella notte dal 10 all'11 Agosto ho consacrato due ore alle osservazioni delle stelle cadenti, coll'animo però più intento a

[16]n. 1) of Schiaparelli's papers in Appendix.

scoprire la legge del loro corso, che a determinare il numero di quelle che erano visibili all'occhio nudo."

Some people (among them there were the supporters of the *atmospheric* hypothesis) believed that the path of shooting stars was too irregular to make it to be calculated according to the laws of Mechanics. But Olbers, since 1837, had explained the irregular path of shooting stars as determined by the atmospheric air friction on a non-spherical body which came from the interstellar space.[17]

Certainly Schiaparelli had been struck by the possibility that a so strange and apparently random phenomenon as shooting stars could be subject to the rigorous laws of Mechanics. In fact as Hughes writes:

"Using the data assembled in his 1863 paper Newton concluded that Leonid meteor shower was caused by the Earth passing through a shower of meteoroid particles in November and that the most dense part of the Leonid meteor cloud was only met with at intervals of approximately 33.25 years. Newton thus boldly predicted that there would be a spectacular display of Leonids in 1866. Unknown to Newton, Olbers had indipendentely reached this conclusion some years earlier."[18]

In the letter published in 1863 Schiaparelli moreover realized that it would be very important to know the mean velocity of shooting stars because in this way their absolute velocity and their direction could be deduced.

At the end of the letter Schiaparelli noted that the *radiants* changed as went on. The discovery of this fact, then, was to the credit of *cosmic* origin of shooting stars. As Schiaparelli wrote:

[17]Schiaparelli referred to Olbers's hypothesis "Intorno alla teoria astronomica delle stelle cadenti". See n. 2 of Appendix p. 349.

[18]See Hughes quoted before, p. 330.

"Questo moto del punto di divergenza a seconda della sfera celeste mette poi fuori di dubbio l'origine cosmica delle stelle cadenti, o almeno delle stelle cadenti del 10 Agosto 1863."

In the letter Schiaparelli classified shooting stars in two categories: *systematic* and *occasional*. *Systematic* shooting stars came from the same point of the sky, *occasional* shooting stars, instead, seemed not to obey any law and there were few of them.

In the same year (1863) Secchi published in the *Bullettino* (October 1863) an article in which he sustained the *cosmic* origin of shooting stars after a pubblication in which Quetelet had given strong observational evidence in favour of the *cosmic* hypothesis.

Secchi, moreover, quoted H. A. Newton about the classification of shooting stars as occasional and as convergent to Cassiopea. And again in August and September 1864 Secchi published his observations of shooting stars. As usual, his interest was about the height of terrestrial atmosphere rather than about the origin of shooting stars.

Among the papers Secchi wrote on shooting stars most important is the paper published on the *Bullettino* of November 1865. In it Secchi reported H. A. Newton's opinion about the periodicity (33 years) of the November shooting stars which seemed to come from the Leo constellation. Moreover Secchi reported Newton's prevision that the number of shooting stars on November would be maximum in 1866.

Three years later, in 1866, Schiaparelli observed shooting stars on the 9th, 10th, 11th of August, and again he wrote a letter to Secchi. But this time the communication, although it was sent as a letter, was a real paper.[19]

In a letter sent to Secchi on the 17th of August 1866 (few days

[19] *Lettera I.* See Appendix n. 2).

after his observations and few days before sending the *Lettera I*) Schiaparelli was very outspoken about Coulvier-Gravier:

"Non capisco come mai Coulvier-Gravier si ostini a negare l'origine cosmica e creda di trarre presagi meteorologici."

In the published paper Schiaparelli was more diplomatic.

Also Secchi had observed the shooting stars of August 1866 and had published in the *Bullettino* (August 1866) a paper with his observations. In this paper Secchi forewarded *"un'importante teoria del Sig. Schiaparelli"*.

In his paper Schiaparelli reported some considerations which he had already written in the previous letter, but in addition he was able to deduce, starting from the principles of the celestial Mechanics, the variations laws (in space and through the time) of the number of shooting stars. He showed that the laws he had found were in good agreement with the available observations of Coulvier-Galvier and concluded that the *cosmic* hypothesis of the origin of shooting stars had definitively been found.

Schiaparelli's reasoning started from the following statistical laws he was faced with:

1) The smallest frequency of shooting stars was observed to be in about the period of vernal equinox and the highest frequency was observed to be in about the autumnal equinox. At the period of the solstices the frequency was seen to be practically equal to the main frequency.

2) The smallest frequency was observed to be during the evening and the highest frequency was seen to be during the morning; at midnight the frequency had the mean value.

3) The most frequent direction of shooting stars was observed to be from east to west. Few stars travelled from west to east. The frequency of shooting stars travelling from north to south and

vice-versa was practically equal to the mean value of the frequency. Furthermore the direction was dependent on the time in which observations were made.

Schiaparelli started from the aknowledgment, on the grounds of the available observational evidence, that shooting stars came, with the same absolute velocity, from everywhere in the sky in all seasons of the year. Only the shooting stars of August contradicted this claim, but their percentage in respect to all yearly shooting stars was low.

Moreover statistical considerations led Schiaparelli to hypothize that *radiants* were uniformely distributed on the sky and that also their distribution through the year was uniform.

The uniformity of the spatial distribution over a year was demonstrated by Schiaparelli. In fact Heis, Faye, Greg had shown that, in a night, we see very few *radiants* on the sky; so the uniform spatial distribution over a year had to be proved. And also had to be proved the yearly uniform distribution.

According to Schiaparelli's hypothesis if the rotation was the only terrestrial motion then the Earth would be struck by shooting stars in a uniform way.

But as the Earth travels around the Sun in reality, then the number of shooting stars is different according to the Earth's hemisphere which is turned towards the direction of the Earth's motion.

Schiaparelli demonstrated that adding the instantaneous velocity of the Earth and the instantaneous velocity of shooting stars, an observer standing still on the Earth would see that all shooting stars came from the same spot of the sky.

As Schiaparelli claimed he found the solution following a suggestion that Brandes had given in his book "Vorlesungen über die Astronomie", published in 1827 in Liepzig.

Brandes had noted that, among the infinite directions from which shooting stars could come, there was a direction which was prevailing: the one opposite to the motion of the Earth along its orbit around the Sun. Brandes's interest in shooting stars depended on the possibility to get a direct proof of the Earth's motion around the Sun.

In 1838 Herrich had used Brandes's approach for deducing the daily and azimuthal variation law of frequency.

Schiaparelli demonstrated that the frequency F of the number of shooting stars when they were seen by an observer, was

$$F = 1 + \frac{V}{v} sin\phi$$

where ϕ was the apparent height of the apex, V the Earth's velocity, and v the velocity of shooting stars.

This formula was proposed firstly by A. Herschel.

As regards this formula Schiaparelli expressed ϕ as a function of ϵ (obliquity of the ecliptic), θ (local apparent time), ω (latitude). If K is the mean frequency of shooting stars in any given hour in a year then

$$N = K(1 - \frac{V}{v} cos\omega\, sin\theta(1 - \frac{1}{4} sin^2\epsilon))$$

So Schiaparelli was able to find a formula which established a relation among the parameters which influenced the phenomenon of shooting stars: it was possible to compare this formula with the observational data given by Coulvier-Gravier.

Schiaparelli used Coulvier-Gravier's data and found a little difference between the data calculated according to his formula and the observed data.

Moreover Schiaparelli calculated v/V which resulted to be equal to 1.447, that means practically equal to the ratio between the velocity of a comet and the velocity of the Earth. H. A. Newton had found the same result with a slightly different method.

Schiaparelli knew about Newton's result few days after he had sent his paper to Secchi for publication on the *Bullettino.* It was Secchi that in a letter sent to Schiaparelli on the 13th of September on 1866 spoke about a Newton's paper published in Bruxelles on the velocity of shooting stars.

Schiaparelli answered (the 16th of September 1866) immediately Secchi asking him Newton's article. Schiaparelli did not miss the opportunity for attacking Coulvier-Gravier.

"Io son curioso di sapere che cosa dirà Coulvier-Gravier, (se pure dirà qualche cosa) il quale è così arrabbiato contro le teorie degli astronomi sulle stelle cadenti, quando vedrà che appunto le sue osservazioni han fornito l'argomento più palese contro le sue fantasticherie."

So Schiaparelli got two important results:

1) He used Coulvier-Gravier's data, which seemed to corroborate the *atmospheric* hypothesis, as evidence in favour of the *cosmic* hypothesis.

2) He found that the velocity of shooting stars was the same as the velocity of the comets.

At the same time Erman had found that shooting stars coming from Perseus constellation were very much inclined in respect of the ecliptic and Newton had already shown that the motion of shooting stars was retrograd.

So Schiaparelli conjectured that not only the shape of a comets' orbits and shooting stars was the same, but also that they both came from the same interstellar space where shooting stars were grouped as clusters of very low density matter.

When one of these clusters fell under the influence of the Sun, it was forced by gravitational attraction to scatter its components along a parabolic orbit around the Sun. When the Earth crossed one of this parabolic orbit the components of the cluster became visible as shooting stars.

Many authors criticized Schiaparelli who defended his method in a long paper published in 1871.[20]

The original paper was published in german in the form of book: G. V. Schiaparelli "Entwurf einer astronomischen der Sternschnuppen", Stetti, 1871. But the paper was written in italian and the manuscript is kept in the Brera Observatory Archives; it was translated in german by Georg von Boguslawski. The italian version has been published in the "Opere Complete" (see the previous footnote).

In this paper Schiaparelli defended himself quoting Newton:

"If it shall appear that I use rude processes and inexact data, and reject terms of considerable importance, I must plead that *it is a step forward to do anything in this direction*, and express the hope, that better data will soon warrant the use of more refined processes."

Anyway criticisms were partially accepted by Schiaparelli; he aknowledged that his theory was incomplete and founded on a controversial hypothesis.[21]

In the same paper Schiaparelli claimed:

"Da una teoria affatto incompleta del detto fenomeno ebbi l'ardire od anzi la temerità di concludere che la velocità media assoluta

[20] "Saggio sulle meteore cosmiche." See n. 15) in Appendix.

[21] In fact in the 1871 paper just quoted Schiaparelli proposed another method for finding the value $v/V = 1.45$.

delle stelle cadenti dovesse poco allontanarsi dalla velocità parabolica, e che le orbite delle meteore dovessero quindi esser sezioni coniche molto allungate, come quelle percorse dalle comete."

In this last mentioned paper Schiaparelli demonstrated that daily variations of the frequency of the number of shooting stars depended on so many and complex causes, that it would never be possible to rigorously state mathematical theory of the phenomenon. *"Ne segue che il calcolo da me proposto nella* 1⁰ *lettera al rev. P. Secchi non può riguardarsi come l'espressione dei fatti naturali; e soltanto per fortuita compensazione di circostanze nel medesimo neglette è avvenuto, che i risultati da esso calcolo derivati si trovarono esprimere approssimativamente la verità."*

But the path which would have led to the solution of the problem of the origin of shooting stars had been, by then, traced out.

As we had written previously A. Herschel had already found the relationship between the frequency of the number of the shooting stars and their apex.

H. A. Newton moreover had also found that their velocity was parabolic. So the originality of Schiaparelli's first paper relied on his understanding that the parabolic velocity of shooting stars allowed the astronomers to set up a fertile research program on the matter.

The following step was to find how a cluster coming from interstellar space, under the Sun gravitational action, changed its shape becoming a parabolic stream.

Schiaparelli demonstrated how a parabolic stream could be set up in the second paper published as *Lettera II* in the *Bullettino.*[22]

This paper is, according to us, the original contribution Schiaparelli gave to the solution of the problem of the cosmic origin of

[22] N. 2) of the Appendix.

shooting stars. According to Schiaparelli if shooting stars travelled with a parabolic velocity, their orbit should be a parabola. But the parabola is a feature of comets: Schiaparelli demonstrated, according to the known theories about comets, that comets' parabolic orbit indicated that they came from interstellar space and demonstrated that a cluster of low density matter, subject to the gravitational attraction of the Sun, became a subtle and long stream.

Schiaparelli found that the difference in time of the arrivals to the perihelion of two particles belonging to a cluster was the following:

$$\frac{dt}{t} = \frac{1}{E - e\,sinE}\,\frac{1}{e\,sinE}\,\frac{dr}{r}(\frac{2a}{r} - 1)$$

where E was the eccentric anomaly

e the eccentricity

r the radius vector

a semiaxis of the orbit.

So dt/t was comparable with dr/r; that meant that different particles in the cluster reached the perihelion delayed one in respect of the other. The particles were distributed along a parabolic orbit and they could spend also thousands of years for travelling from one side to the other side of the perihelion.

Schiaparelli gave explicitly the previous formula in the paper "Note e riflessioni intorno alla teoria astronomica delle stelle cadenti" (n. 5 of the Appendix) written and published in 1867. Schiaparelli calculated also the limit of mass density so that the cluster could maintain a stable configuration. This limit was:

$$\delta < \frac{3}{2\pi}\frac{M}{R^3}$$

where R is the mean distance between the Sun and the cluster and M the mass of the Sun.

As R changed rapidly it could happen that the cluster could be completely dissolved during its transit form one side to the other side of the perihelion.

But it could also happen that some cluster could transit from one side to the other side of the perihelion whithout any change in the shape.

In this last case gravitational perturbations of the great Planets would force the cluster to change the parabolic orbit into an elliptic orbit around the Sun. But as perturbation would influence every particle of the cluster in a different way, the single particle would be scattered along the orbit and would form a stream alike a ring.

The shooting stars in November, according to Schiaparelli, belonged to this kind of phenomena. The period was equal to 33.25 years. As years went by the particles in the stream would be scattered along all the trajectory. So the number of the November shooting stars would diminish each year and would be distributed through a greater number of days.

When all particles of the cluster would be regularly distributed along the stream the phenomenon of shooting stars would become periodical as the one in August, but the dynamics of the phenomenon would be different.

The shooting stars in August would come from a parabolic stream which is travelling from one side to the other side of the perihelion. The shooting stars in November, instead, would come from an elliptic stream: as long as the particles belonging to the stream would not be distributed uniformely along the trajectory, there would be a period of time in which the number of shooting stars would be greater than during other periods.

In the last few centuries the November shooting stars have appeared about each 33.25 years. But in 1867 it was possible to note in their passage that the maximum number of shooting stars was smaller than the maximum of shooting stars in the previous transit.

Instead the number of shooting stars in the period of time before and after the day of the maximum, was greater than the previous transit.

Leverrier had identified in Uranus the great Planet which had perturbated the cluster which had originated the November shooting stars, and had forced it in a short period orbit. According to Leverrier the approaching between Uranus and the cluster had happened in about 126 B. C. .

Schiaparelli demonstrated that Leverrier was wrong: he calculated the diameter of a sphere around Uranus, Jupiter and Saturn inside to which the cluster should have passed in order to be forced in a short period orbit. The diameter of the sphere was equal to 12.93 terrestrial radii for Uranus, to 317.42 terrestrial radii for Jupiter, and was equal to 102.00 terrestrial radii for Saturn. So the probability that Uranus could have diverted the cluster into a short period orbit should have been very low.

Schiaparelli's results relied on the hypothesis that reciprocal attractions among the particles which belonged to the cluster and their relative velocity was negligible. But this hypothesis had to be confirmed; and it's what Schiaparelli did in the *Lettera III.*[23]

In the first part of the *Lettera* he firstly demonstrated that the hypothesis was plausible, and in the second part summarized all the results he had obtained:

1) Matter is distributed in the celestial space in the form of stars, which are practically isolated each from the other, in the form of star dust (according to W. Herschel) which forms nebulae; in the form of comets, visible when they approach the Sun; in the form of clusters of little particles.

2) When clusters come into the sphere of attraction of the Sun

[23]See n. 2) of the Appendix.

and their orbit becomes parabolic, they become visible in form of a stream of bright falling bodies (shooting stars).

3) The stream can spend thousands of years for travelling from one side to the other side of the perihelion. When the Earth crosses such a stream bodies become visible as shooting stars.

4) The transit time through the perihelion of a parabolic stream, due to its length, is very long; a short stream is not stable.

5) When a stream crosses the perihelion bodies belonging to the stream are scattered along a line longer than the line along which they were scattered previously; some of these can move from the main stream and can become visible as *sporadic* shooting stars.

6) Perturbations of the great Planets force the parabolic stream, if still compact after its transit from one side to the other side of the perihelion, into an elliptic orbit.

7) There is not a qualitative difference between fixed stars and shooting stars.

In conclusion the difference between shooting stars and comets relies only on the difference of their dimensions.

Up to this point Schiaparelli had demonstrated that comets and shooting stars came from the same interstellar space and was able to demonstrate how the Sun's attraction determined their orbits.

Direct experimental evidence was given to Schiaparelli by the connection he was able to determine between the August Perseids and the comet 1862III and between the comet 1866I and the shooting stars in November 1866.

Schiaparelli exposed these results in the *Lettera IV* and *Lettera V*.[24]

The impact of Schiaparelli's theory on Secchi was considerable. In an article published in August 1871 Secchi claimed:

[24]See n. 2) of the Appendix.

"... la scienza ha fatto già in questo campo eziandio delle luminose conquiste. Basti accennare la scoperta del Sig. Prof. Schiaparelli che questi sciami di corpuscoli seguono la traccia delle orbite paraboliche delle comete. Talchè queste non sono che corpi maggiori facienti parte di una stessa massa nebulosa, la quale entrata dalla profondità dello spazio nella sfera di azione del sole, compie intorno ad esso il suo giro in parabola o in ellisse allungatissima.
Con tale spelendido risultato è rimasta dimostrata per sempre l'origine cosmica di questi corpi e la loro relazione cogli areoliti e con quelle che diconsi pioggie di fuoco."

Some years later the Biela comet was proved to give raise to the shooting stars of the 10th of December and again the comet 1861I was proved to give raise to the shooting stars of the 20th of April.

In the following years Schiaparelli continued to study the correlations between some comet, as they were discovered, and some showers of shooting stars. But the core of his reasoning did not change in the course of the years.

APPENDIX

Schiaparelli's papers on shooting stars

1) "Stelle cadenti del 10 agosto 1863. Lettera al P. Angelo Secchi" *Bullettino Meteorologico dell'Osservatorio del Collegio Romano*, 1863 *II*: 132

2) "Intorno al corso ed all'origine probabile delle stelle meteoriche. Lettere a P. A. Secchi" (1866-1867), published in *Le Opere di G. V. Schiaparelli pubblicate per cura della Reale Specola di Brera*, 11 Tomi, Tomo 3 (Milano: Ulrico Hoepli Editore, 1931), Lettera I p. 261, Lettera II p. 278, Lettera III p. 294, Lettera IV p. 309, Lettera V p. 314.

3) "Dell'influsso che la presenza ed i movimenti dell'atmosfera possono avere sul fenomeno delle stelle cadenti" (1867) ibid. p. 320-327.

4) "Sur la relation qui existe entre les comètes et les étoiles filantes" (1867) ibid. p. 331-333.

5) "Note e riflessioni intorno alla teoria astronomica delle stelle cadenti" (1867) ibid. p. 337-455.

6) "Sulla velocità delle meteore cosmiche nel loro movimento a traverso dell'atmosfera terrestre"(1868) ibid. p. 459-465.

7) "Primo catalogo di stelle osservate in diversi luoghi d'Italia" (1867) in *Le Opere di G. V. Schiaparelli pubblicate per cura della Reale Specola di Brera*, 11 Tomi, Tomo 4 (Milano: Ulrico Hoepli Editore, 1931) p. 3-27.

8) "Alcuni fatti d'osservazione i quali sembrano appoggiare la tesi sostenuta dal Padre G. M. Cavalleri nella Nota: Sulla luce problematica che manifestasi in tutto il cielo nel passaggio delle stelle cadenti in agosto e novembre, e di una proposta diretta a scoprirne l'origine" (1867) ibid. p. 289-290

9) "Secondo catalogo di stelle cadenti, 1867-68 (Osservazioni del sig. G. Zezioli)" (1868) ibid. p. 31-108.

10) "Terzo catalogo di stelle cadenti, 1868-69 (Osservazioni del sig. G. Zezioli)" (1869) ibid. p. 111-188.

11) "Quarto catalogo di stelle cadenti, 1869-70 (Osservazioni del sig. G. Zezioli)" (1870) ibid. p. 191-235.

12) "Alcuni risultati preliminari tratti dalle osservazioni di stelle cadenti pubblicate nelle Effemeridi degli anni 1868, 1869, 1870": Catalogo preliminare di alcune principali radiazioni meteoriche del primo semestre (1^0 gennaio-30 giugno); Catalogo preliminare di alcune principali radiazioni meteoriche del secondo semestre (1^0 luglio-31 dicembre); (1869-1870) ibid. p. 239-276.

13) "Osservazioni generali sulla forma delle radiazioni meteori-

che" (1870) ibid. p. 279-287.

14) "Alcune principali radiazioni meteoriche dedotte dalle osservazioni di stelle cadenti fatte a Bergamo dal sig. Zezioli negli anni 1867-68-69" (1879) ibid. p. 291-302.

15) "Saggio sulle meteore cosmiche" (1871) ibid. p. 305-551.

16) "Sulla relazione fra le comete, le stelle cadenti ed i meteoriti" (1870, 1873) in *Le Opere di G. V. Schiaparelli pubblicate per cura della Reale Specola di Brera*, 11 Tomi, Tomo 5 (Milano: Ulrico Hoepli Editore, 1931), ibid. p. 4-40.

17) "Sulla grande pioggia di stelle cadenti prodotta dalla cometa periodica di Biela e osservata la sera del 27 novembre 1872" (1872) ibid. p. 43-115.

18) "Le stelle cadenti. Tre letture" (1873) ibid. p. 121-167.

19) "Sul calcolo di Laplace intorno alla probabilità delle orbite cometarie iperboliche" (1874) ibid. p. 171-174.

20) "Osservazioni sulla comunicazione di Celso Fornioni dal titolo: "Osservazioni di una pioggia di stelle filanti fatte nella R. Specola di Brera in Milano la sera del 22 giugno 1880" (1880) ibid. p. 177.

21) "La pioggia di stelle cadenti del 27 novembre 1885" (1885) ibid. p. 181-182.

22) "Sulla grande pioggia di stelle cadenti del 27 novembre 1885" (1885) ibid. p. 185-194.

23) "Sternschnuppenfall 1885 November 27" *Astronomische Nachrichten* 1885 *113(2697)*: 137.

24) "La pioggia delle stelle" (1886) in *Le Opere di G. V. Schiaparelli pubblicate per cura della Reale Specola di Brera*, 11 Tomi, Tomo 5 (Milano: Ulrico Hoepli Editore, 1931), ibid. p. 197-214.

25) "Sur la probabilité des orbites hyperboliques. Extrait d'une letter de M. J. V. Schiaparelli à M. Radau" (1890) ibid. p. 217-218.

26) "Norme per le osservazioni delle stelle cadenti e dei bolidi"

(1896) ibid. p. 221-262.
27) "Orbite cometarie, correnti cosmiche, meteoriti" (1908, 1910) ibid. p. 265-285.