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Ideas of Lomonosov in Auroral Research

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Abstract

This article describes the achievements of the famous Russian scientist Mikhail Lomonosov on the basis of a multi-volume edition of his works in Russian and Latin, and comments to these works published by the Academy of Sciences of the Union of Soviet Socialist Republics (USSR) in 11 volumes. Analysis of Lomonosov's works made from a modern point of view, discusses his discoveries and hypotheses. In the field of atmospheric physics, the most important discovery by Lomonosov, according to the author, was that the aurora is a self-luminescence process of the upper atmosphere, rather than reflected, refracted or scattered light. No direct attention was paid to this discovery in numerous scientific studies before. Lomonosov has interpreted a physical mechanisms of auroras in the Earth's atmosphere based on his numerical experiments and studies. This article compares Lomonosov's work with the work of his contemporaries, eminent scientists from Russia, Europe and USA.

Keywords: Lomonosov, aurora, history of physics, history of geophysics, atmosphere

1. Introduction

The year 2011 was declared by UNESCO as the International Year of Lomonosov in honor of his 300th anniversary. Mikhail Lomonosov's work in science was of an encyclopedic scope (*Menshutkin,* 1952*)*. He was actively engaged in physics, chemistry, astronomy, geology, meteorology and navigation. He also contributed to population studies, political economy, Russian history, rhetoric, and grammar. He brought the most advanced scientific theories to Russia, commented on their strengths and weaknesses, and advanced the original ideas. He published nine papers on the study of the aurora (*Lomonosov,* 1743*; Lomonosov,* 1753(1–3); *Lomonosov,* 1756; *Lomonosov,* 1763(1–2); *Lomonosov,* 1764; *Lomonosov,* 1747–1763), which collected with commentaries in 11 volumes of the complete works of Lomonosov (Fig. 1, http://feb-web.ru/feb/lomonos/default.asp in Russian).

Mikhail Lomonosov (1711–1765), whose portrait is shown in Figure 2, was born and raised in the Arkhangelsk region, near the White Sea. Russian inhabitants of the north, Pomors, consider aurora as usual phenomenon and did not see anything mystic about it. In his youth, Lomonosov often went to the Arctic Sea with his father. According to the current understanding, this is the zone with the maximum probability of

detecting aurora. Therefore, in the future, when he became interested in the physical nature of the northern light, he did not rely on other people's descriptions, often far from reality, but on his own observations.

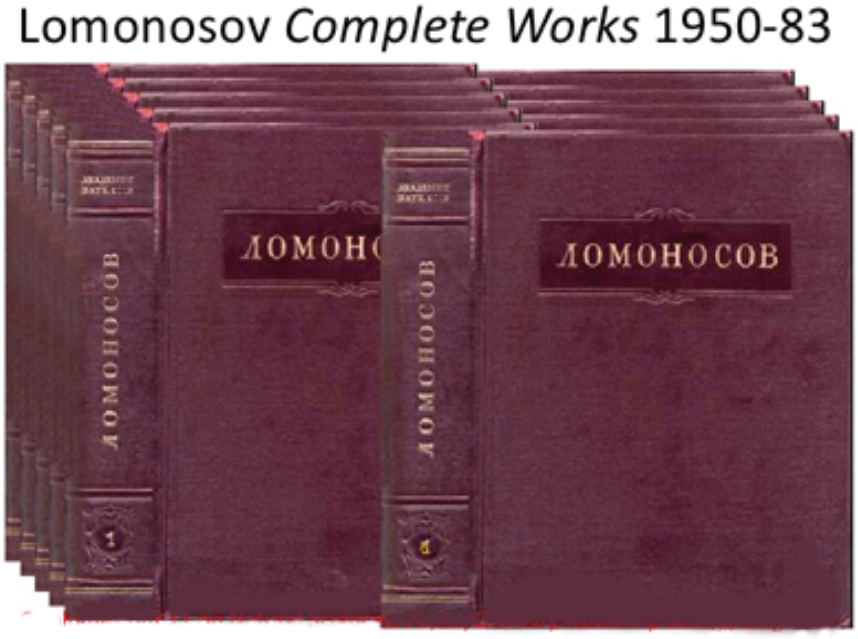

Fig. 1. M.V. Lomonosov, 6 volumes out 11 on Natural Sciences, Physics, Chemistry, Astronomy, Geology and Geography.

Fig. 2. M.V. Lomonosov.

Here is how he described the aurora: "…as much I can imagine, the northern lights, occurred around 64 degrees north, and were variable. I can not remember when I

saw that there is a little regular arc to the north or at noon, but mostly there are flashes of light or highly variable like pillars and beams of light. Secondly, although there are flashes across the sky, they mainly occupy the northern sky. Thirdly, I have seen crimson to cherry-prone colours in the winter sky between the west and noon".[1] For centuries, there were many scientific views on aurora, often associated with mysticism and superstition, religion and subtle analogies. Indeed, the lights might resemble battles in the sky, flying Valkyries, fire-breathing dragon etc. Conception and interpretation of the nature of aurora expressed by famous scientists and philosophers such as Pliny the Elder, Seneca, Galileo and followers (*Eather*, 1980; *Brekke and Egeland*, 1983; *Schröder*, 1984). Academians, such Kraft, Meier and Geynzenus tried to study aurora thoroughly and seriously before Lomonosov in St. Petersburg Academy of Sciences (*Sviatskij*, 1934; *Eather*, 1980; *Yevlashin et al*., 1986).

In 1730 Kraft printed an extensive historical information on aurora by bringing the hypotheses of the optical and cosmic character from the Western Europe. He presented Meyer's point of view, essentially that with the growth of autumn "cold" from the ground upward the contact line between warm and cold air ignites vapors. At that time nobody knew that the aurora occurred during summer and winter, day and night, and the human eye just could not see it, and thus the Meyer hypothesis had the right to exist. Academician Geynzenus was a supporter of the study by De Mairan (*De Mairan,* 1733), which states that the light originate from the matter ejected by the Sun, conjecturing the existence of the solar wind.

2. Ode to an Evening Reflection Upon God's Grandeur Prompted by the Great Northern Lights

This ode (Fig. 3) became one of the first scientific papers Lomonosov wrote on the aurora (*Lomonosov, 1743*). The unique talent of Lomonosov as a poet allowed him to formulate the basic problems of physics and the nature of auroras in verse. Illustrations of the first stanza of the ode is shown as a photograph in Figure 4. In the second stanza Lomonosov is wondering why the aurora (the northern lights were historically called "aurora", since they looked similar to dusk and dawn) does not appear in the east and west, where the sun rises and sets, but appears in the north: "*Dawn breaks from out of northern lands!*" He thus doubts the hypothesis that the auroral light is a reflection or scattering of sunlight: "*Is this the home of our sun's throne? Or are the icy oceans burning?"* And further, in the affirmative: "*Behold, cold fire envelops us!*" Today, cold fire would be called plasma, rarefied ionized gas that is a source of the aurora. So Lomonosov first comes to the conclusion that the aurora is a glow in the atmosphere, these days referred to as luminescence. The third stanza is an appeal to European scientists. Although their names have not been mentioned, they are known for their discoveries in astronomy and celestial mechanics: "*Thou comprehended planets' course, now tell us what disturbs our souls?*" The next stanza is partly criticism of the academician Kraft

[1] Translation of this and other citations of Lomonosov from the old Russian to English has been done by the author.

hypothesis: *"How can it be that frozen steam gives birth to fire from winter's depths?"* His words mean that you can not mindlessly move the phenomena of the lower atmosphere into the upper atmosphere. "*Why does fine flame assault the land? Without a thundercloud can lightning rise from the earth up toward the heavens? How terrible lightning without touch tends to land in the zenith?*" The question of "*Why do these bright rays sparkle in the night?*" is still a subject of scientific research. In fact, Lomonosov brought up scientific issues of auroral physics, which have been partially resolved only recently (*Eather,* 1980*; Yevlashin et al.,* 1986*).*

The day conceals its brilliant face,
And dark night covers up the fields,
Black shadows creep upon the hills,
Light's rays recede from us.
Before us gapes a well of stars -
Stars infinite, well fathomless.

But where, O nature, is your law?
Dawn breaks from out of northern lands!
Is this the home of our sun's throne?
Or are the icy oceans burning?
Behold, cold fire envelops us!
Behold, now day has entered night.

O thou, whose lively gaze can see
Into the book of law eternal,
For whom the smallest part of things
Reveals the code in all of nature,
Thou comprehended planets' course,
Now tell us what disturbs our souls?

Why do these bright rays sparkle in the night?
Why does fine flame assault the land?
Without a thundercloud can lightning
Rise from the earth up toward the heavens?
How can it be that frozen steam
Gives birth to fire from winter's depths?

Fig. 3. Fragments from the "Ode" with illustration (photo: S. Chernouss).[2]

[2] English translation of the "Ode to an Evening Reflection Upon God's Grandeur Prompted by the Great Northern Light" was provided by "From the Ends to Beginning, A Billingual Antology of Russian Verse" – *http://max.mmlc.northwestern.edu/~mdenner/Demo/texts/evening_meds.htm*)

3. *Hypotheses of Lomonosov*

The electrical nature of the aurora

Today it is well known that one of the first who understood the electrical nature of the aurora as a glow of rarefied gas, was M. Lomonosov (*Menshutkin,* 1952). It is even considered to be his main discovery in this area. This hypothesis, unique for its time, was subsequently confirmed. Leonhard Euler reviewed Lomonosov's papers on electric phenomena: "*... delicate matter reveals itself in electric phenomena so clearly that it should not be denied ... ... If we do not propose any hypotheses and fix them by comparing with the phenomena, we will never get to the real explanation .... ".* The main work of Lomonosov, which examines the physical nature of the aurora was the "Oration on aerial phenomena, proceeding from the force of electricity proposed by Mikhail Lomonosov" (*Lomonosov,* 1753(1)), which was presented at the meeting of the Academy in November 26, 1753 (Fig. 4).

Fig. 4. The volume with "Oration on aerial phenomena, proceeding from the force of electricity proposed by Mikhail Lomonosov" (photo: S. Lachinov).

The 18th century was the infancy of physics of electromagnetic phenomena yet there was no concepts of the electric field and the electron. Up to the birth of Michael Faraday, who discovered the common nature of the electric and magnetic fields, electrical phenomena had remained mysteries for scientists. According to Lomonosov, the electric force could be the factor that causes the aurora: *"This thing stopped when a lot of air is presented, as well as electric light was not shown in the glass jar when air was not drawn out of it"* (*Lomonosov,* 1753(1)). Lomonosov used analogy, but his associations could only have risen in the mind of a scientist, who thoroughly and comprehensively understood the topic and the physical picture of the world. *"During excitation of an electric force in the sphere, from which air is drawn out, sudden rays emitted, and instantly disappeared, and at the same time, new ones in their places popped up, so it*

looked like continuous glitter. In the northern lights flashes or beams do not suddenly occur to the extent of the entire space, but behave similarly. The pillars of the northern lights shining as stripes on the surface of the electric atmosphere in subtle or in pure are very nearly perpendicular to the ether, as in the aforementioned electric sphere from a concave circular surface to the center of converging rays" (*Lomonosov,* 1753(1)). The conclusion of Lomonosov was rather categorical: "*So, it is likely that the northern lights were born from the existence of the electric force in the air. It is confirmed by the appearance and disappearance of the phenomenon, movement, color and form, which are shown in the northern lights and the electric light of the third kind ....* ". The same article explains that *"The third type is pale and weak light, which shows in very thin air, or in a place far from having the air above the mercury in the barometer...".* It should be noted that Benjamin Franklin, living in the U.S.A. also expressed the opinion that the aurora was caused by electrical processes (*Eather,* 1980). This fact is mentioned by Lomonosov himself (*Lomonosov,* 1753(2)): *"Franklin's guess about the northern lights, which he refers to by a few words in the same letter of my theory is very different. He attracts electrical matter of the northern lights from the equatorial zone, but I find it in the same place, i.e. in the air and everywhere present. He does not define its place, but I think it is above the atmosphere. In addition, my ode to the northern lights, which was composed in 1743 and published in 1747 in the "Rhetoric", contains my long-standing view that the northern lights arise from the motion of ether."* It is now clear that the electrical force Lomonosov speaks of refers to the physical concept of the electric field. In general, this hypothesis of Lomonorov has been confirmed, namely the existence of a convection electric field in the magnetosphere, particle acceleration by electric fields and penetration of the electric field of magnetospheric origin into the ionosphere and lower atmosphere (*Yevlashin et al.,* 1986).

Colours of aurora

Illustrations in Figure 5 and 6 open this chapter for better understanding of the problem of the colours of the aurora.

Fig. 5. Multi-coloured aurora (photo: V. Zhiganov).

Fig. 6. Multi-coloured aurora (photo: P. Chernouss).

The promising idea of Lomonosov was that the aurora got its luminous colours due to specific substances. At the time of Descartes and Newton many were aware of the fact that the colours of the rainbow were caused by refraction of the sunlight in raindrops, and it seemed that a similar physical mechanism could explain the different colours in the aurora. Lomonosov did not believe this explanation: *"It is convenient to argue about the arc like a rainbow. I could believe that these colours of the night lights owing to refraction occur when three factors are being denied. First, there was not a light source to be refracted. Second, the red pillars were of the same shape and motion as the white ones, so for the refraction the common source would occur very far. Third, there is nowhere proven that all the colours of the refraction were produced, but on the contrary, there are many arguments that the colours look visually different. Furthermore, these were night-shining lights with some clouds. Who is familiar with properties of vapor and clouds, can distinguish them from the northern lights and position the latter outside the atmosphere*" (*Lomonosov,* 1753(1)). It is impossible to explain the colours of the aurora by refraction or reflection of light. In fact, Lomonosov claims that various substances exist in aurora and determine their different colours:"*... the combination of all the primary colours is white, and no air being created, you must not doubt that the aforesaid components separately may be seen*" (*Lomonosov,* 1753(1); *Lomonosov,* 1756). This conjecture was subsequently confirmed by direct instrumental measurements made by Swedish physicist Ångstrøm in 1866–1867 with a visual spectroscope (*Ångstrøm,* 1869).

4. Discoveries of Lomonosov

Upper atmosphere is the location of the aurora

The principal long-term task was to determine the height of the aurora. It has not been fully resolved even at the end of the XIX century. Back in 1621, Pierre Gassendi suggested that the lights have to be at high altitude (*Eather,* 1980). In the XVIII century acceptable measurements of the aurora low border heights with theodolites were obtained by Finnish scientist Anders Hellant (*Tobé,* 1991). His results varied between 50–70 km for the lower edge of auroral arcs and were obtained in Lapland. English scientists Henry Cavendish and John Dalton (*Eather,* 1980) made the first proper measurements of the heights in case studies. Cavendish has measured the heights of lower border at 85–115 km in 1782 and Dalton obtained lower border heights at about 160–240 km in 1786. But earlier, in 1753, Lomonosov showed that auroras were developing at high altitudes above the atmosphere, which according to the ideas of his time extended to the heights of about 40 km. He described an original method of upper auroral edge observations in *Lomonosov,* (1753(3))*:* "*... in our experience visible light can be created in places devoid of air. The position of the northern lights is above the limits of the atmosphere compared to the dusk position. The dusk periphery must be equal to the great circle of the Earth's surface, such as the nature of the Earth's shadow. Positions of the northern lights should be similar circles, co-centric to the big circle, with the width rel-*

ative to the observer's position on the surface of the atmosphere. That can be seen from the regular proportions of the northern light arc height and width "**.** Another Lomonosov's evidence that the aurora is observed in thin air, situated at high altitudes, is based on laboratory experiments (*Lomonosov,* 1753(1,3)). Artificial electric light, which is produced in experiments, demonstrate that different colours depend on kind of matter. Most likely the multi-coloured pillars and lights were born from movements of different gases in the upper atmosphere as Lomonosov proposed.

Detail description on how he made a direct measurement of the height of the upper edge of aurora was presented in *Lomonosov,* 1753(3):" *I noticed rather stable northern lights in October 16 of this year here in St. Petersburg. Since it was possible, I measured height of about 20 degrees, the width of 136 degrees and calculated the upper edge of the arc to be at the height of about 650 km* ". This result corresponded well with the modern measurements of the upper edge of the radiant arc (*Yevlashin et al.,* 1986). Danish teacher Sofus Tromholt also conducted correct and rather systematic measurements of the auroral heights (*Tromholt,* 1885) by the parallax method. The famous Norwegian auroral scientist Carl Størmer made height measurements of the aurora with sufficient accuracy by triangulation photographic observations of the aurora from two points (*Størmer,* 1955). He showed that the height of the aurora usually lies in the range of 100–600 kilometers. Thus, the upper edge of the aurora estimated by Lomonosov nearly one and half centuries before gave more accurate results.

Aurora is self-luminosity of the upper atmosphere of the Earth

Many scientists tried to determine what aurora is: natural luminescence of the atmosphere, or reflected, scattered and refracted rays of light from external sources, both during Lomonosov's time and later. These views can be found in (*Eather,* 1980), which provides information on the main hypotheses of Lomonosov's time.

Galileo Galilei,	1616	Light of comets, reflecting light from the Sun.
Rene Descartes,	1618	Scattering of sunlight by ice crystals.
Edmund Halley,	1716	Expiration of hollow Earth matter along the magnetic field
Vilyam Derham,	1728	Same natural causes as that of earthquakes.
Jean-Jacques De Mairan,	1733	Zodiacal light of matter ejected from the Sun.
Pieter Musschshenbrok,	1744	Luminescence of sulfur vapour in the air.
Leonhard Euler,	1746	Zodiacal light due to emanation of the Earth
Reverend Eric Pontopiddian	1750	Electricity appearing due to friction of humid air on the Earth's surface.
Christian Wolff,	1745	Glow of substance, which is a precursor of a lightning.
Benjamin Franklin,	~ 1750	Circulation of atmospheric electric charges, sedimented in the polar regions.

None of them answered the question of what the nature of the aurora in the atmosphere is or proved their views with experiments. Even Lomonosov himself was mistaken when he thought that the aurora may be caused due to the friction of ascending and descending air flows. Nobody knew at Lomonosov's time that luminous atoms and molecules exist in the atmosphere because of the impact of precipitating charged particles of the magnetospheric origin. Lomonosov did not know that, but as a well experienced scientist, who observed the aurora many times, he noticed that the stars could be seen through the lights, based on this he made the correct conclusion: *"All northern lights pictures show that the lights may not be vapour or clouds shining under some lighting. They almost always have a regular figure, and stars are clearly seen through the northern lights"* (*Lomonosov,* 1753(1)). It was an evidence that the aurora itself is luminescence of the atmosphere, rather than reflected, refracted or scattered light from a remote source. He confirmed this by describing his own observations of the aurora, and presented them in drawings (Fig. 7), from which engravings have been made. Figure 7 shows Lomonosov's sketch of the aurora, in which the Big Dipper (Ursa Major) constellation is visible. Thus, he definitely answered the questions: "What is the aurora?" and "Where is the aurora?"

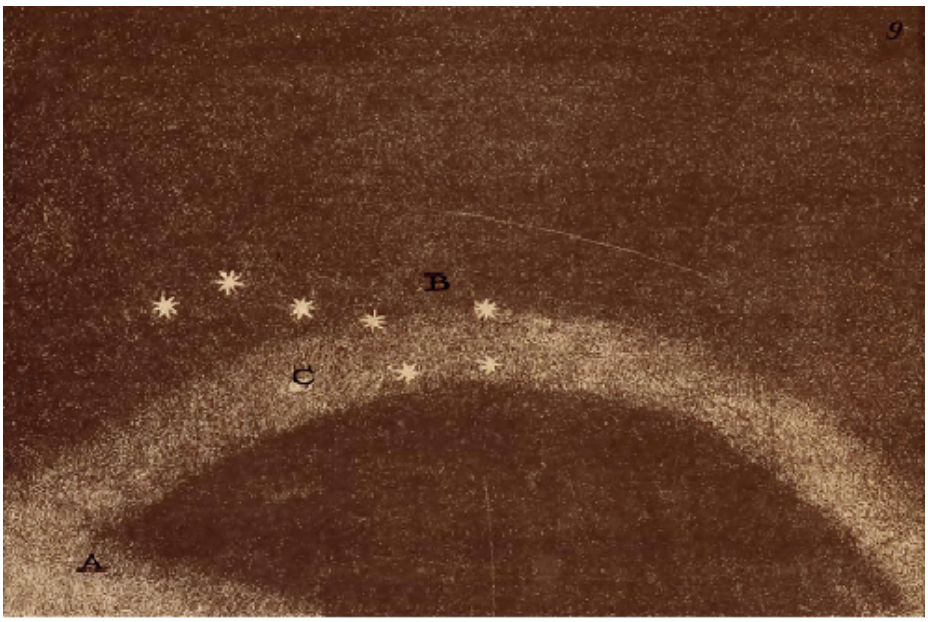

Fig. 7. Aurora. The Big Dipper constallation is visible through aurora (engraving of Lomonosov).

Eather (*Eather,* 1980) considered the problem whether the glow of aurora itself is luminous, or due to the transformation of light from remote sources. He decided that Ångstrøm was the first, who discovered that by spectroscopic observation of auroral spectrum in 1867 (*Ångstrøm,* 1869). In fact, Lomonosov was using a method of simultaneous observations of stars through the aurora and solved this problem hundred years before Ångstrøm.

5. Lomonosov engravings

Engravings, sketches and descriptions of the aurora made by Lomonosov are of great interest (*Lomonosov,* 1764). Forty-seven drawings were engraved on eleven copper engraving (Fig. 8) and kept in the Lomonosov museum in Saint-Petersburg (*Lomonosov,* 1764). One can see them in the typical forms of auroras, which are now associated with a variety of plasma phenomena in the magnetosphere and ionosphere physics.

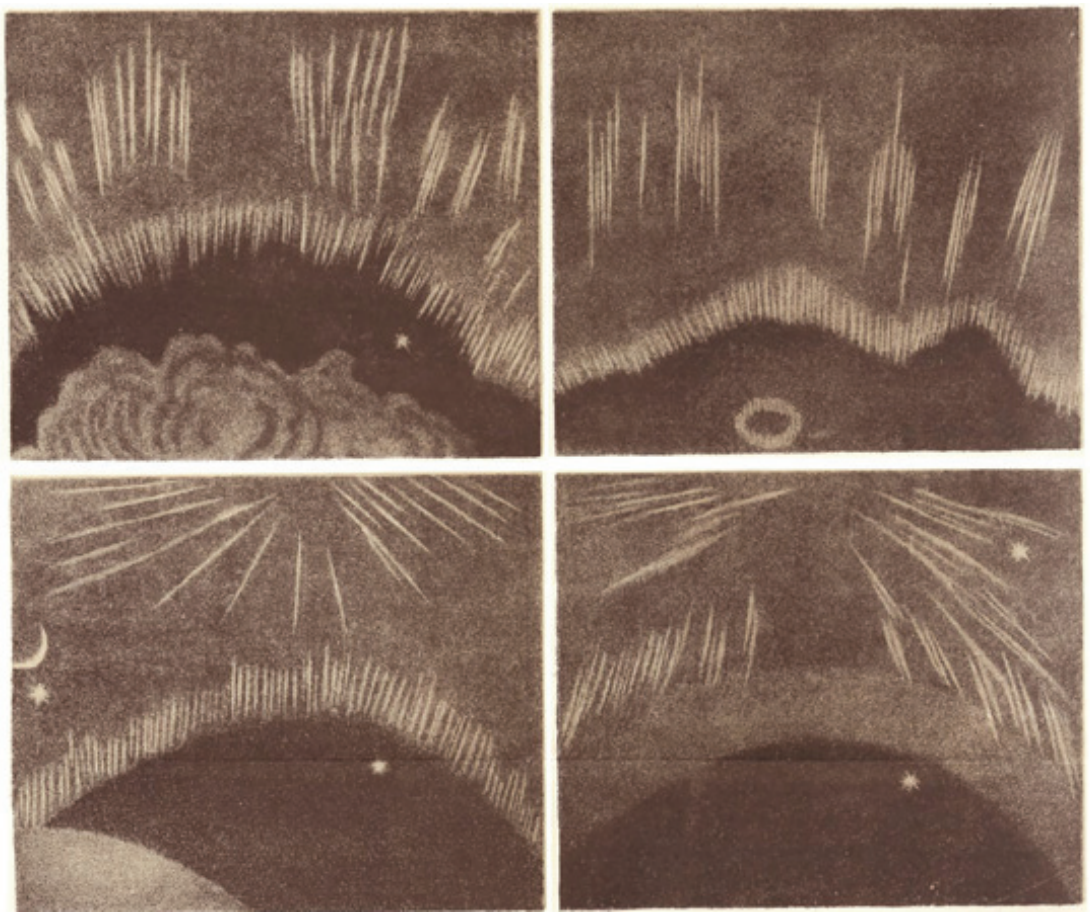

Fig. 8. Engravings of Lomonosov.

Lomonosov correctly noted the main features of auroras and their variability in space and time. Figure 9 shows the radiant of auroral arc rays, observed by Lomonosov, with the notation: h - bright arc, g - green, f – scarlet, showing the different colours of the aurora. In the sketch, we see red light at the top of the aurora, the bright light at the lower part of the arc and green light in the part of the arc between them. The red glow has later been classified as type "A" red aurora. The slope of the rays of the aurora, as in the figure lie along the lines of the Earth's magnetic field. The similarity of Lomonosov's sketches and more modern images of aurora can be seen in other auroral forms as well. Obviously, the aurora has changed very little in 300 years.

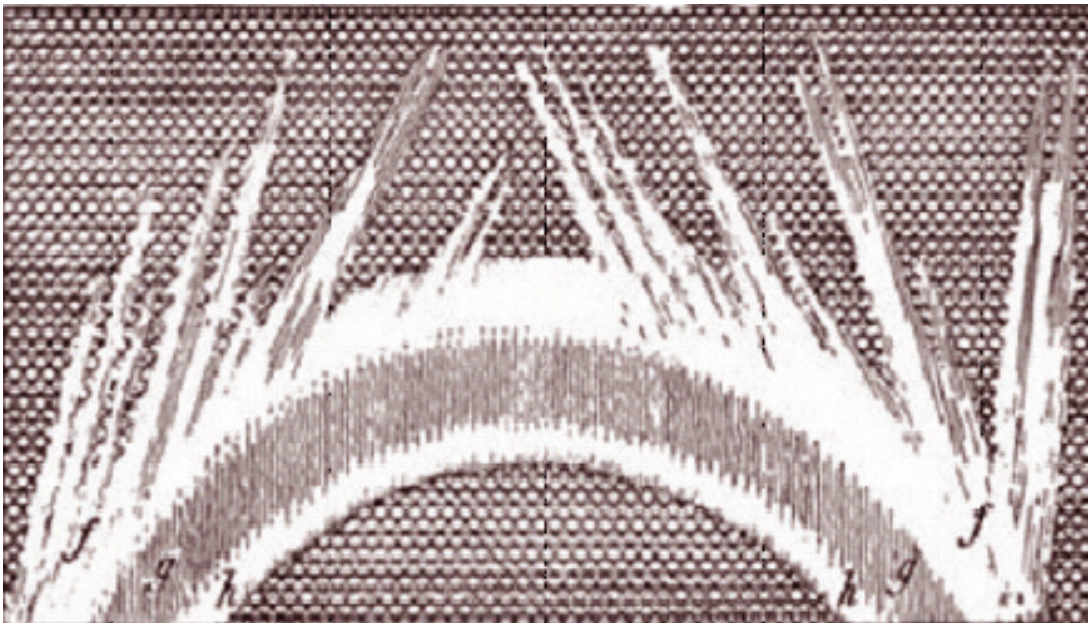

Fig. 9. Aurora over St. Petersburg (engraving of Lomonosov).

6. Conclusion

The data presented do not illustrate all auroral studies done by Lomonosov. His discoveries (if we consider that discovery is hypothesis proved by experiment) associated with the definition of the aurora as a natural luminescence of the atmosphere and the determination of the upper atmosphere as their location. He published a work plan (*Lomonosov,* 1763), which had the intention to comprehensively, both theoretically and experimentally, investigate the phenomenon. He planned to deep study the work of De Mairan and Pontoppidian, continue complex experimental study of the aurora, continue laboratory testings on electricity and systematize Siberian observations and observations of pomor Amos Kornilov (*Lomonosov*, 1747–1765), who had wintered on Spitsbergen during several years. Unfortunately, Lomonosov "went to the stars" too early, in the age of only 54 years.

The scientific research of Lomonosov enriched many branches of out knowledge. One can only wonder the brilliant foresight, with which the famous Russian scientist Mikhail Lomonosov anticipated the true nature of the aurora, which only became available to us in the space age.

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Referenses

Brekke, A. and A. Egeland, 1983. The northern light: *from mythology to space research,* Springer-Verlag, p. 170.Mairan, J.J., 1733. Traite Physique et Historique de l`Aurorae Boreale, L`Imprimerie Royale, Paris.

Eather, R.H. 1980. "Majestic lights: the aurora in science, history, and the arts", AGU special publications, Vol. 18, p. 323.

Lomonosov, M.V., 1959. Ode to An Evening Reflection Upon God's Grandeur Prompted by the Great Northern Lights. In: The Lomonosov Complete Works. Vol. 8. Moscow-Leningrad. USSR Academy of Sciences, p. 120–123.

Lomonosov, M.V., 1952. In: Oration on aerial phenomena, proceeding from the force of electricity proposed by Mikhail Lomonosov", 1753. In: Lomonosov Complete

Works. Vol. 3. Moscow-Leningrad. USSR Academy of Sciences, p. 15–99.

Lomonosov, M.V., 1952. Discussion proceedings on the "Oration on aerial phenomena, proceeding from the force of electricity", 1753. In: Lomonosov Complete Works. Vol. 3. Moscow-Leningrad. USSR Academy of Sciences, p. 145–179.

Lomonosov, M.V., 1952. Necessary explanations to the oration on the electrical aerial phenomena, 1753. In: Lomonosov Complete Works. Vol. 3. Moscow-Leningrad. USSR, Academy of Sciences, p. 103–133.

Lomonosov, M.V., 1952. Oration on the origin of light, presenting a new theory of colours was reading at public meeting of the St-Petersburg academy of sciences, 1756. In: Lomonosov Complete Works. Vol. 3. Moscow-Leningrad.USSR, Academy of Sciences, p. 315–345.

Lomonosov, M.V., 1952. Test of the causes of the aurora borealis and other similar events, 1763. In: Lomonosov Complete Works. Vol.3. Moscow-Leningrad. USSR, Academy of Sciences, p. 481–487.

Lomonosov, M.V., 1952. Report on observations that confirm the electrical nature of the Northern Lights, 1763. In: Lomonosov Complete Works. Vol. 3, Moscow-Leningrad. USSR, Academy of Sciences, p. 477–479.

Lomonosov, M.V., 1952. Engravings of the Northern Lights, performed by M.V. Lomonosov, 1764. In: Lomonosov Complete Works. Appendix to Vol. 3, Moscow–Leningrad, USSR, Academy of Sciences, p. 13.

Lomonosov M. V., 1952. A brief description of the various trips to the northern seas, and the indication of possible passage of the Siberian Ocean to the East Indies, 1747–1765. In: Lomonosov Complete Works. Vol. 6, Moscow-Leningrad, USSR, Academy of Sciences, p. 461.

Menshutkin, B.N., 1952. "Russia's Lomonosov" (English translation by W.S. Hamilton). Princeton Univ. Press, Princeton, New Jersey, p. 214.

Schröder, W., 1984. Das Phänomen des Polarlichts. Erträge der Forschung, Band 218, Darmstadt, p. 156.

Størmer, C., 1955. The Polar Aurora, Clarendon Press, Oxford, p. 403.

Sviatskij, D.O., 1934. The evolution of the northern lights in the Russian literature and science from X to XVIII century, *Archive the history of science and technology*. **4**. LA, p. 479.

Tobé, E., 1991. Anders Hellant - en krönika om sjuttonhundratalets märkligaste tornedaling. Tornedalica, Luleå, p. 224.

Tromholt, S., 1885. Under the Rays of the aurora borealis: In the land of the Lapps and Kvæns, ed. by Carl Siewers, (original edition), London.

Yevlashin, L.S., G.V. Starkov and S.A. Chernouss, 1986. Mikhail Lomonosov and the study of aurora. *Geomagnetism and Aeronomy*, **6**. p. 881–886

Ångstrøm, A.J., 1869. Spektrum des Nordlichts, *Annales der physik und chemie*., **137**, 161–163.