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The Phenomenon of Doppler in Modern Science

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The name of Christian Doppler is associated with the widely known physical phenomenon which entered modem science and technology and found numerous applications. In fact, together with the discovery of spectral analysis, Doppler effect started the era of astrophysics. Doppler presented his idea of frequency change of moving wave sources during his lecture at the session of the Royal Bohemian Society of Sciences on May 25, 1842 in Prague Carolinum. It was the topmost of his scientific achievements of his Prague activities and it can be considered the most important physical discovery made in Bohemia during the 19th century.

Doppler spent twelve years in Prague, the same as Kepler did four centuries ago, and we can draw some parallels between these two Prague periods. Both Kepler and Doppler were inspired by Prague atmosphere and its "genius urbis", developed feverish creative activity here and also suffered from material needs and health problems. While Kepler laid foundation of modern astronomy, Doppler contributed to its further development. Nevertheless Doppler's scientific format does not stand the comparison with Kepler's genius.

Christian Andreas Doppler (in some publications we meet erroneous Christian Johann) was born in Salzburg, Austria on November 29, 1803. He came from the family, even dynasty of stonemasous and spent his childhood in the dusty surroundings of family workshop, which marked his feeble health as well. Doppler's father and his predecessors worked out the famous grey marmor of the mountain Untersberg and many monuments and altars in the region bear the sign of Doppler's family name. Young Christian spent much time with his father and elder

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brother Johann in churches and cemeteries, which probably contributed to his sensitive and melancholic nature.

Christian was not strong enough to take over the laborious family business; besides as a rule it went to the hands of the eldest son. That is why his father considerd to assign him the career of an accountant. In the meantime a family friend, well-known Austrian geodet Simon Stampfer detected Christian's mathematical abilities and his interest in study and recommended him be sent to the Vienna Polytechnic founded several years ago. Doppler studied at the Polytechnic in the years 1822–1824, just during the onset of the so-called industrial revolution. The technical applications of mathematics and physics, introducing steam engines and gas illuminations and new discoveries of science and astronomy as well made Doppler enthusiastic. He was eager to work for the benefit of mankind and to follow in the steps of great men of science. On the other hand his abilities to grasp the depths of matematical and physical knowledge were limited and his education one-sided. In contrary of what we often read he never studied at Vienna University and his kowledge of astronomy was fragmentaly and distorted. In the best case he may have attended some lectures of Joseph Litrow and made some observations at his observatory.

With father's death in 1824 financial situation of Doppler's family worsened dramatically. In addition Christian was not able to find any suitable employment. In that period he developed sense of thrift and bitterness so typical for his life attitude. In 1829 Doppler succesfully competed for the position of an assistant at the department of mathematics of Vienna Polytechnic and at the same time he started to publish his first papers in mathematics. They dealt with the theory of parallels and problems of the convergence of some infinite series. His mathematical reasoning however though inventive was not exact enough and his proofs vague and not convincing.

Doppler's employment contract with the Polytechnic was limited to four years and in 1832 his material difficulties arose anew. Doppler had to give up his scientific ambitions and for some time worked as a mechanical engineer (maybe an accountant) in a cotton spinning factory. At the same time he applied for professorship at several universities and academies of the monarchy but in vain. In total desperation he decided to leave for America. In fact his journey ended at the American consulate in Munich, but it does not prevent some American encyclopedias to consider him "American mathematician".

In 1835 Doppler was offered position of professor of mathematics at the newly organised secondary technical school, "Realschule" of the Bohemian Estates in Prague. It was a school of rather low level, sort of preparatory school for further study at Prague Polytechnic. Doppler nevertheless accepted the offer and moved to Prague. He was now able to start his own family life; he married Mathilde Sturm from Salzburg, who became his understanding and devoted wife. All five of Doppler's children were born in Prague.

Teaching elementary mathematics could not of course satisfy Doppler's ambitions and he made efforts to become professor at the Polytechnic. In 1834 the director of Clementinum astronomical observatory in Prague Martin David died and professor of mathematics and astronomy at the Polytechnic Adam Bittner become new director. Doppler immediately applied for vacant position at the Polytechnic, but for several years he had to teach as a supplementary professor with lower salary. Only in 1841 he was promoted to ordinary professorship.

In 1844 Doppler published an extensive textbook of arithmetics and algebra with 450 problems to be solved. He tried to bring mathematics at the Polytechnic to higher level and to introduce some elements of calculus and modern mathematics. His attempt was not too succesful in the result and besides the school authorities were not inclined to admit any innovations. Doppler's teaching activities in Prague were extremely onerous for him. The amount of teaching duties was too high, the number of students was rising rapidly and e. g. some practical exercises in geodesy started as early as at 4 a. m. in the outskirts of the city – something we can hardly imagine in our times. Doppler had to examine several hundreds of students, both orally and in written form, and due to failing to do this he was unjustly accused and admonished.

Doppler's health deteriorated rapidly and his friend, mathematician and philosopher Bernard Bolzano, seriously ill himself, tried his best to help him. He appealed to several influential people not to let Doppler die "as Pegasus under the yoke". Doppler suffered by tuberculosis of larynx and lecturing in large auditoriums was disastrous for him, so that he lost his voice completely at last. In 1847 Doppler with his family left Prague for Banska Stiavnica, now Slovakia to start his new career as Councelor of Mines and professor of the famous Academy of Mines and Forests.

He hoped to find better conditions for quiet scientific work in new surroundings. He got acquainted with long minig tradition in Banska Stiavnica and old mining maps inspired him to study secular variations of Earth magnetism. This promising period of his life did not last too long, however. The stormy events of Hungarian uprising in 1848 forced him to leave for Vienna, where he became professor at the Polytechnic. Two years later a new Institute of Physics was founded at Vienna University and Doppler was appointed its first director. In a sense he started a new era of Austrian physics.

During his stay in Prague Doppler burdened by pedagogical duties, struggling with health and financial problems to support his big family, nevertheless found enough time and energy to continue extensive research work. His enthusiasm and firm decision to bring benefit to mankind grew even stronger and on sleepless nights he conceived more and more new ideas. In the time, when research and publication activity were not at all common for university teachers Doppler prepared and published tens of contributions, booklets and reviews and presented them on sessions of Royal Bohemian Society of Sciences.

It was again his friend Bernard Bolzano who suggested Doppler for membership of the Society already in 1837 and stressed his "exceptional spiritual power combined with an amiable character, genuine unaffected determination and that pure love of science and truth which rises high above narrowminded party-spirit as well as conceited inflexibility." Nevertheless amiable character was not considered sufficient ground for acceptance to the Society and Doppler was elected associate member as late as 1840 and ordinary member in 1843.

The majority of Doppler's contributions concerned constructions and technical improvements of experimental devices and from historical point of view were of marginal importance. So he suggested a cyclograph for the recording of circular arcs of any size of radius without the knowledge of the position of the centre, optical diastermometer for immediate determination of distances, an improvement of catoptric microscope, omatogoniometer for measuring the visual angle, a device to plot out the so-called railway curves, new instrument for the continuous recording of the Cartesian oval lines, modification of stroboscopic method for measuring the velocity of rapidly rotating objects etc. These numerous contributions of Doppler helped to stimulate interest in physics in Prague, but did not help too much to its progress.

In fact Doppler did not really construct his devices nor use them, he just ended at the idea itself while many new ideas occurred to him. As experimentalist he often reached to funny conclusions – e. g. he came to the result that a wire conducting electric current shortened, opposite to the results of other physicists. Also in astronomy he surprised with a few phantastic conceptions. So in 1837 he published an article, where he discussed the possibility to observe fixed stars temporarily hidden by the nucleus of a comet and also the origin of some mysterious bright spots on the Moon. He explained this supposed phenomenon on the ground that the Moon has overdense atmosphere comparable with density of transparent crystals. Astronomers of his time were, of course very sceptical. Another suggestion of Doppler was to measure the diameters of fixed stars by repeatedly enlarging their photographic pictures (1847)!

On 25 May, 1842, however, very important and from the history of physics even curious event happened, which ensured immortality to Doppler and glory to Prague physics. On the session of the section of Natural Sciences of the Royal Bohemian Society in Prague Carolinum Doppler presented his paper "Ueber das farbige Licht der Dopplersterne und einiger anderer Gestirne des Himmels". He formulated general idea, that the motion of sources changes frequency and intensity of emitted waves and radiation. He considered this idea an extension of Bradley's theory of aberration and applied it both to the sound and light waves. According to general meaning Doppler considerd light as longitudnal waves in ether and did not take into account the recent findings of Fresnel about light polarization.

On some 20 lines Doppler derived simple mathematical formula for frequency change, in an awkward and difficult to understand way, with some errors and inconsistencies in notation. Nevertheless the formula was correct and the Doppler principle was born. It may be of interest that already in 1792 George Lichtenberg from Göttingen came to the idea that rapidly moving stars change colours and Friedrich von Hahn, amateur astronomer from Mecklenburg published similar idea in Postdam astronomical yearbook in 1795. It is not known if Doppler was acquainted with these publications.

The Doppler's lecture appeared in the Transactions of the Society and was also published in a separate booklet. There was no experimental proof given to support the Doppler principle and his argumentation was based mainly on astronomical phenomena. Doppler suggested that the components of binaries approaching the Earth and receding shine in complementary colours, bluish and reddish. He also pictured the nice colourful Universe we could observe should our Earth move a little bit faster, with half of the stars, those we approach to, blue and the other, we leave behind, red. He even considered a phantastic situation that new stars shine originally in the invisible part of spectrum and due to sudden motion towards the Earth their whole spectrum shifts and they become visible.

Doppler principle was met with disagreement and embarrasment. Due to happy coincidence it was published just in time when railway transport started to be introduced and fastly moving trumpets or steampipes on locomotives allowed to give some proof of it at least for sound waves. Later on Ernst Mach, excellent experimentalist, arranged laboratory experiments with rotating whistles which were in agreement with Doppler formula. More of that, these experiments brought Mach to investigate supersonic motion of bodies like bullets from military guns, and to open a new era of acoustics. One century later, ultrasound found its application in medicine diagnostics and Doppler sonography became very effective tool to observe motions in human body and blood circulation.

Most of the astronomers at Doppler time could not confirm his arguments and e.g. Johann Mädler from Tartu, well-known specialist on binaries, rejected his theory. Karl Kreil in Prague tried to calculate the velocity a comet should move to demonstrate some change of colour. Doppler principle on the other hand possibly gave impuls to some astronomers to look more closely at the differences in stars colours. Doppler's friend, Italian astronomer Benedetto Sestini, compiled an atlas of stars according to their colours.

The situation changed dramatically after Doppler' s death when Gustav Kirchhoff and Robert Bunsen invented spectral analysis and French physicist Armand Fizeau actually rediscovered Doppler effect and suggested to apply it in astronomy for measuring spectral lines shifts. In 1868 English astronomer William Huggins for the first time measured radial velocity of Sirius that way. Comparison of spectral lines photographs thus opened a new era of astrophysics as described in preceding contribution.

The last period of Doppler's life in Vienna was in the shade of fierce conflict with famous mathematician and optician Jozef Petzval. At several sessions of

Vienna Academy of Sciences Petzval attacked Doppler's work, scornfully observed that his formula expressing frequency change of waves was just "mere fraction," and not a solution of corresponding differential equations, could not represent any physical theory and belonged to "small physics". It is historical irony that Petzval, who contributed so substantially to the development of astrophysics, was so an ardent opponent to Doppler. The discussion between the two scientists was based on misunderstanding and for handicapped Doppler had no way out. His health deteriorated rapidly, Doppler had to give up his position of director of the Institute of Physics and moved to Venezia in hope for some relief. He died in that sunny city several months after the arrival, in 1853.

Doppler was convinced that his principle would provide astronomers powerful tool for exploring distant parts of the Universe, but even in his wildest dreams he could not imagine, how important it would be for the further development of physics and how many technical applications it would find. He estimated correctly that his principle is closely related to aberration formula. In fact in Einstein theory of relativity both of these phenomena are inseparable in the form of Lorentz transformation of the wave four-vector. Since the frequency is closely related to wave energy, it is obvious, that Doppler effect plays important role in modern quantum and relativistic physics. The development of modem physics in 20^{th} century, especially non-linear electronics, gamma spectroscopy, reactor and neutron physics unveiled new and unexpected connections to Doppler principle.

Since all the objects of Nature, from elementary particles to celestial bodies are in permanent motion and emit electromagnetic radiation it is clear that the Doppler effect must be of universal character. It would certainly satisfy Doppler himself and confirm his prophetic visions.