The nearly forgotten scientist Ivan Osipovich Yarkovsky

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Recently discovered documents have helped the author to piece together the life of Ivan Osipovich Yarkovsky, an almost unknown Polish Russian engineer, who first described the orbital effect that bears his name.

In 1901 Ivan Osipovich Yarkovsky, a Polish engineer in Russia, described a subtle thermal effect that should act on planets and smaller objects orbiting the Sun. The effect was forgotten, rediscovered in the 1950s and mentioned and studied occasionally since then. In the second part of the 1990s this 'Yarkovsky effect' became a hot topic in studies of the transport of meteorites and asteroids from the main belt to the neighbourhood of the Earth. The man who found it, however, has remained completely unknown. Who was this Polish Russian, how did he find his effect and why is he not mentioned in any textbook or reference work?

The Sun rules the solar system. Its gravitation keeps planets, asteroids, comets and smaller objects in their orbits. However, its radiation plays an important role too. Small bodies are not only illuminated by solar radiation but also pushed away or slowed down by it. The first effect, *radiation pressure*, only acts upon the smallest particles. Its existence was presumed for centuries and in 1899 measured for the first time by the Russian physicist Petr Lebedev. The second effect, the *Poynting–Robertson effect*, was first described in 1903 by the British physicist John Henry Poynting and finally clarified in 1937 by H. P. Robertson. It is a kind of aberration due to the finite velocity of light. Particles with diameters up to about one centimetre are subject to a resistance by this process.

Objects larger than one centimetre are subject to another radiation effect. They absorb solar radiation from one direction and reradiate it as heat in all directions. Because of their rotational motion, thermal inertia and inability to maintain their temperature in equilibrium, the evening hemisphere of such objects is slightly warmer than the morning hemisphere and consequently radiates more strongly. This extra radiation creates a force acting at an angle to the direction of the incoming radiation, causing a slow but steady alteration of the object's orbit. As a result, the object slowly spirals inwards or outwards, depending on its direction and velocity of rotation, its diameter and its thermal properties.

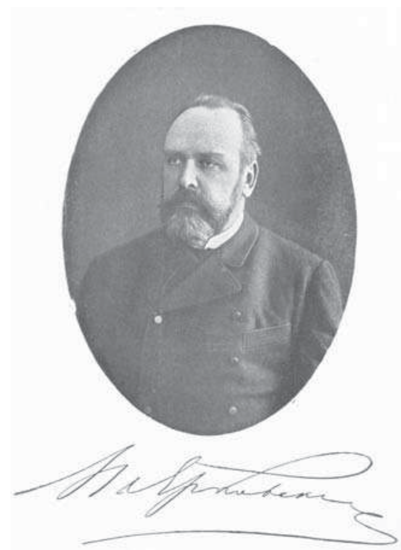

Figure 1. Portrait of Ivan Osipovich Yarkovsky (1844–1902). Place and date of the photograph are unknown. *(Reproduced from ref. 6)*

A rediscovery

In western astronomy this effect was first described in 1951 by Ernst Öpik, from the Armagh Observatory in Northern Ireland, in an article in the *Proceedings of the Royal Irish Academy*.[1] Öpik was studying the motion of small objects orbiting about the Sun and noted that such an effect was already suggested 'by Civil Engineer Yarkovsky, in a pamphlet published in Russian at St. Petersbourg (sic) about 1900'. Öpik had read

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GRB 980425', *Astron. Astrophys. Suppl. Ser.* **138**, 465–466 (1999). See also GRB011121: Bloom *et al.*, *Ap.J. Lett.*, **572**, 45–49 (2002)
6 Narayan *et al.*, *Ap.J.,* **557**, 949–957 (2002)
7 http://cfa.www.harvard.edu/cfa/oir/Research/supernova/HIGHZ.htmp
8 Perlmutter S. *et al.*, 'Measurements of omega and lambda from 42 high-redshift supernovae', *Ap.J.*, **51**(2) (1998)
9 It is very common to represent this equation in the form $\Omega_M - \Omega_\Lambda = -0.4$. Both have the same meaning.
10 These lines would in practice be *almost* parallel, and would show a slight curve similar to that of the boundary line in the top right hand corner enclosing the value of Ω_Λ that is considered to be too high to allow the 'Big Bang' to have taken place.
11 Phillips M., *Ap.J. Lett.*, **413**, 53 (1993)
12 Phillips M. M., 'The reddening-free decline rate versus luminosity relationship for Type Ia supernovae', *Astron. J.* **118**, 1766 (1999)
13 Reiss A. & Filippenko A. V. *et al.,* 'The rise time of nearby type Ia supernovae', *Astron. J.,* **118**, 2675 (1999)
14 Barrow J. D. & Tipler F. J., *The anthropic and cosmological principle*, Oxford University Press, 1986
15 *IAUC* 6899, 6902 and 6905.
16 Some textbooks credit the discovery of SN 1998bu to Chuck Feranda. Although his pre-discovery image is invaluable, the credit of discovery goes to Mirko Villi.
17 Aguirre A. N., 'Dust versus cosmic acceleration', *Ap.J. Lett.*, **512**, 19–22 (1999)
18 http://lambda.gsfc.nasa.gov/product/cobe
19 http://map.gsfc.nasa.gov/
20 http://www.rssd.esa.int/index.php?project=PLANCK

Figure 2. The country seat of count Yan Shadurski in Osveya, where Yarkovsky spent the first three years of his life. Osveya was Polish until 1772, then fell to Russia and in 1919 came to Belorussia. The drawing was made in 1875 or 1876. The property is now a ruin. *(Archive, National Museum of Cracow)*

this pamphlet in 1909, when he was living in Estonia, and could 'refer to it only from memory'. Öpik noted that 'the Yarkovsky effect produces a positive drag opposite to the Poynting–Robertson effect and may counterbalance it; when the sense of rotation is opposite to orbital motion, both effects add, working in the same direction'.

Shortly afterwards it became known in western astronomy that the Soviet astronomer Viktor Vladimir Radzievskii had described the same effect in an article published in 1952 in the *Astronomicheskii Zhurnal*,[2] apparently without knowing of Yarkovsky. In fact he had already described this effect in his 1948 thesis at the university of Gorki (Nizhnii Novgorod). Since the 1970s this thermal effect was treated occasionally in studies of the motion of meteoroids and earth satellites. Sometimes it was called the Yarkovsky effect, sometimes the Yarkovsky–Radzievskii effect and sometimes the Yarkovsky–Rubincam effect (after Dave Rubincam, who in 1987 discovered it in the orbit of the geodetic satellite *Lageos*).[3]

During the last ten years the effect became a hot topic in planetary astronomy. That was due above all to the Italian astronomer Paolo Farinella and his Czech collegue David Vokrouhlický, who bombarded the astronomical world with articles on the importance of the Yarkovsky effect. They showed that this mechanism modifies the rotation rates of asteroids, disperses asteroid families and helps to transport asteroids and meteorites from the main belt to the Earth.[4] Recently the Yarkovsky effect has been detected for the first time in the motion of a natural body, the half-km asteroid 6489 Golevka.[5]

In the meantime, Yarkovsky himself has remained virtually unknown. The only publication about him was a very short – and rather disorderly – biographical sketch published in 1965 by the Soviet geologist Vladimir B. Neiman and his colleagues E. M. Romanov and V. M. Chernov in the Soviet magazine *Zeml'ya Vselennaya* (Earth and Universe).[6] In the western literature this sketch was first mentioned in 1979 by Joseph A. Burns, from Cornell University, in an article in *Icarus*.[7] However, it did not draw any attention, and because Yarkovsky's original pamphlet was thought to be lost by Öpik and all others since, it remained unknown how and when Yarkovsky had found his famous effect.

Five years ago I became interested in this mysterious scientist and started research – at first without much success. In August 2001, however, I discovered in Moscow a detailed unpublished manuscript (in Russian) about Yarkovsky. It was in the possession of Mrs Maria Neiman, the widow of Vladimir B. Neiman. Neiman was the only person who, after the second world war, had made a serious investigation into the life and work of Yarkovsky. His biographical sketch in *Zeml'ya Vselennaya* was just the first fruit of it. On the basis of research in archives and correspondence with some of Yarkovsky's descendants, he had finished (in 1981, together with S. V. Altsuler) a detailed manuscript and worked on a book until his death in 1989. According to his widow, however, 'there was no interest for it, neither in Russia nor in Poland'.

In March 2003, having made inquiries to many institutions in Russia, I also rediscovered Yarkovsky's 'lost pamphlet'. It was in the library of the Sternberg Astronomical Institute in Moscow (Figure 3). So at last it became possible to compose a fairly true picture of the work of this mysterious scientist.

A civil engineer

Ivan Osipovich Yarkovsky was born on 1844 May 24 in Osveya, a small place on the shore of the similar-named lake in the extreme north of the then Russian (now Belorussian) province of Vitebsk. This territory was part of the Kingdom of Poland and Lithuania since the fifteenth century, but fell into the Russian empire during the First Polish Partition in 1772. Yarkovsky's father, Osip Janovic, had participated in the Polish Rising of 1830 in Warsaw, after which his noble title was taken from him. He then emigrated to Russia, where he joined the Polish national minority. In Osveya he became the family doctor to Count Yan Shadurski, an important landowner and dignitary.

After the death of his father in 1847, the young Ivan went with his mother to Moscow, where she became a governess and he received his elementary education at a parochial school. After the death of his mother he attended a military school for orphans. Having completed this training, he served as a cornet (a junior officer rank) in a division of the artillery in the Caucasus. He did not succeed in enrolling in the military technical academy, probably (according to Neiman) because he belonged to the Polish national minority. But he did enrol, in 1868, in the Institute of Practical Technology (now the Technological Institute) in St Petersburg. Already in 1870 he received the title of first-grade technologist and in 1872 he graduated as a civil engineer.

In the meantime Yarkovsky had visited machine building companies in Germany, Belgium and France, was married (to Elena Alexandrovna Sendzikovskaya) and worked for the railroad company Kiev–Brest. In 1873, during the enormous expansion of the Russian railway network, he joined the

Alexandrovsk railway company Moscow–Brest. For more then twenty years he worked as an engineer in various departments of this company, first in Minsk, then in Smolensk, then from 1875 in Moscow. In 1889 he also became president of the imperial Russian Technological Society, an organisation set up to stimulate the development of technology in Russia.

In Moscow Yarkovsky was not only engaged in railway technology but – according to Neiman – in many other technologies too. He measured the aerodynamic forces acting on moving wings and – about the same time as Nikolay Egorovich Zhukovsky (the 'father' of Russian aviation) – demonstrated that it must be possible to fly with craft heavier than air. His interest in this problem passed to his first son, Vitold, who later became an airman and head of the aviation firm 'Ilya Muromec' in St Petersburg. Yarkovsky also designed a ship to be propelled by wave energy and suggested using this principle to generate electricity. Further, he researched into the rotary press, lifting screw, combustion furnace and many other pieces of apparatus.

Radiation and ether

Railways and other technologies, however, were not enough to satisfy Yarkovsky's curiosity. In his spare time he went deeply into the physical sciences. At that time these sciences were in turmoil because of numerous discoveries in the field of electricity, magnetism and radiation. The mechanistic, Newtonian view of the world was transformed into a view that was dominated by electromagnetism. It was a period full of contradictions and uncertainties that offered a lot of space for speculations. One of these was the 'ether', the immaterial, impalpable medium that was supposed to permeate all space in and between ordinary matter. Physicists postulated this medium to explain why things could act on each other without being in contact, such as radiation and gravitation.


ПЛОТНОСТЬ
СВѢТОВОГО ЭѲИРА
И ОКАЗЫВАЕМОЕ ИМЪ
СОПРОТИВЛЕНІЕ ДВИЖЕНІЮ.
И. О. ЯРКОВСКАГО
Инженеръ-Технологъ.
БРЯНСКЪ.
Типографія Юдина.
1901.

Figure 3. The cover of Yarkovsky's pamphlet 'The density of light ether and the resistance it offers to motion' (1901): the source of the Yarkovsky effect. *(Sternberg Astronomical Institute, Moscow)*

Yarkovsky became intrigued by this 'ether' and from the start of his life in Moscow (1875) he used this hypothetical medium to develop a theory on the structure of matter and the workings of radiation and gravity. According to his theory, ether and matter were in fact two manifestations of the same entity that could pass into each other in both directions. 'All that is called ponderable matter is just compacted ether, kinetic energy that has passed into potential energy ... and all the energy in nature emerges from the energy contained in the ether.' Yarkovsky, who was a confirmed Roman Catholic, sought the cause of this compacting of ether in a 'creating power'.

In those days, Yarkovsky was not the only one who thought that matter was transformed ether. He supposed, however, that by increasing the density of ether, matter with increasing complexity would appear. He thought this idea was confirmed by Dmitri Mendeleyev's discovery in 1869 of the periodic law of chemical elements: one of the most important discoveries in chemistry since Dalton's theory of the atom. 'If we have to assume that every element exists in itself, independently of the others, where do we have to find the cause then of the relation which is so clearly demonstrated in Mendeleyev's Periodic Law and which is so brilliantly confirmed by the discovery (as predicted by him) of the elements helium, germanium and scandium?', Yarkovsky wondered.

In Yarkovsky's time many scientists, including Mendeleyev, considered atoms as indivisible and unchangeable entities. Yarkovsky, however, who corresponded intensively with Mendeleyev on this subject, thought that atoms could be divided and changed. The periodic law demonstrated, according to Yarkovsky, that although every atom originated as 'a stable form', the diversity of the atoms must be the result of mutual transitions between atoms – linked with the transition from ether to matter. About 1875 Yarkovsky foresaw in a sense (based on a wrong theory, however) the phenomenon of radioactivity, the transmutation of one element into another in connection with alterations in the internal structure of matter. Radioactivity would be discovered in 1896 by the French physicist Henri Becquerel.

Stars, planets and gravity

Yarkovsky looked to the heavens to find support for his theory of ether and matter. When, in the second half of the ninetienth century, it was discovered that stellar spectra could be subdivided into three or four classes, he was one of the first to suggest that this was caused by the evolution of stars. Stars would steadily become bigger, heavier and hotter because they constantly swept up ether that was 'compacted' to matter in their interior. It was a kind of reverse of the process of radiation at the expense of matter. Yarkovsky referred to Sirius, a white star that should have been red in antiquity. Many astronomers thought at that time – until about 1920 – that stars passed through the same evolution, although not by growth but by contraction.

Not only stars, but also the Earth and other planets would grow by sweeping up ether. To prove that, Yarkovsky looked for a change in the radius of the Earth. He thought he had found a clue in the length of the metre, which was defined in that time as the forty-millionth part of the circumference of the Earth. This standard metre seemed to be 0.1 to 0.2 millimetres shorter in the 1820s than at the end of the 19th century. Yarkovsky saw an expansion of the Earth in this, but later it was found that the difference was caused by measurement errors. In *The Measure of All Things*,[8] Ken Alder shows that the error was made by the French astronomer André Méchain during a survey of the meridian between Barcelona and Dunkerque in 1792–1799.

In Yarkovsky's time there was much discussion on the source of heat in the Earth. Yarkovsky mistakenly insisted that the Earth could not have 'one central fire', as suggested by many geologists. 'If the heat of red-hot iron in a blast furnace is held by a layer of two metres of brick, how hot then would the central fire in the Earth have to be to allow its heat to reach the surface?' Yarkovsky supposed that there were many heat sources in the Earth and that everywhere heat was created by ether swept up by the Earth that was transformed to ponderable matter, resulting in a steady growth of the Earth. Later the German geologist Christopher Otto Hilgenberg would revive the theory of 'Global Expansion', this time prompted by Alfred Wegener's hypothesis of continental drift. In his book *Vom wachsenden Erdball* (On the growing sphere of the earth)[9] Hilgenberg stated, too, that the ether supplied the mass needed for growth. In fact it was this hypothesis that put Vladimir Neiman on the track to Yarkovsky.

Yarkovsky believed that gravitation, also considered by him as a form of ether, could be shielded by matter, so that the Moon could weaken the force of gravity on the Earth. To demonstrate this, Yarkovsky built a 'gravitymeter' and deployed it during the total solar eclipse of 1887 August 19. According to Yarkovsky gravity decreased significantly after the onset of totality and returned to normal after the end. Because no drawing of his instrument has been preserved, we do not know how far Yarkovsky was a victim of wishful thinking. Up till now it was thought that the French researcher Maurice Allais was the first who, in 1959 in *Aero/Space Engineering*, claimed to have observed a strange behaviour of gravity during eclipses.[10]

Figure 4. The famous Great September Comet (1882 II), that grazed the solar surface on 1882 September 17 at a distance of only 465,000km. From the fact that the comet was not decelerated in the solar atmosphere, Yarkovsky concluded that there must be a extra force working on it. *(Drawing by Ernst Hartwig)*

Yarkovsky published his 'Kinetic theory of universal gravity in relation with the generation of ponderable matter within heavenly bodies' in 1888 in French.[11] He probably chose this language because he was aware that his ideas disagreed with current views. Therefore, he did not put the book on sale, but circulated it to a group of about 150 scientists. In 1889 an extended version in Russian appeared and in 1912 a version with more additions would be published posthumously.[12] In 1891 he finished a manuscript called 'A new view of the causes of meteorological phenomena', dealing with the origin of clouds and the interactions between currents in the atmosphere and the oceans, but this has never been published.

In 1894 Yarkovsky left the Alexandrovsk railway company, probably because of his deteoriating health and the need to care for his large family (he had six children). He moved to St Petersburg, where he served for two years as head of the Nevsky mechanical and shipbuilding plant. Because this job was also too strenuous for him, he then moved to Dyatkovo, near Bryansk, where he became assistant manager of the well-known Maltsov locomotive engine plant. In the spring of 1901 he fell ill and was sent abroad by his doctors to find a cure. He first went to Badenweiler (a popular medical resort for Russians) and then to Heidelberg in Germany. On 1902 January 22 he died of sarcoma in the Academic Hospital in Heidelberg.

According to Neiman, one or more of Yarkovky's children later returned to Poland, which had vanished completely from the map of Europe during the period 1795–1918. During the Russian Revolution (1917), Yarkovsky's personal archive was transferred to the re-emerging Poland, where it passed into the hands of his grandson Henryk. This archive was lost, however, during the rising in the Warsaw Ghetto in 1943. That may be one of the reasons that Yarkovsky vanished from history.

The pamphlet of 1901

It was in Bryansk (not St Petersburg, as recalled by Öpik) where in 1901 Yarkovsky's pamphlet appeared in which he described the effect that Öpik named after him. The pamphlet, 'The density of light ether and the resistance it offers to motion' numbers just 17 pages. In this Yarkovsky tried to answer the question of what causes the eternal movements of the planets (and smaller objects) about the Sun. At that time, many scientists thought space was completely imbrued with ether, so it seemed logical that the planets were subjected to a very small ether drag and thus had to spiral very slowly towards the Sun.

Yarkovsky thought that the planets kept their orbits because they were subjected to a force that compensated for this ether drag. He tried to prove this with the famous comet that blazed in the sky in September 1882: the Great September Comet (1882 II). This comet grazed the surface of the Sun at a distance of only 465,000 kilometres and described a similar path to the comets of 1880 and 1843. After perihelion passage, the velocity of this sungrazer or Kreutz-group comet was not decreased appreciably. Some astronomers concluded that the comet had not met any resistance, which could indicate that the ether had no 'material' properties or did not exist at all.

Yarkovsky, however, tried to prove the opposite. He pointed out that the comet passed the Sun at such a short distance (he mentioned 100,000 kilometres), that it surely must have met some resistance from the hydrogen in the solar atmosphere. Because this resistance was not observed in the comet's orbit, this should imply 'that the resistance did exist, but was compensated at the same time by one or another force'. As it was logical to suppose that this force still operated when the comet had left the solar atmosphere, it had to accelerate the comet. Such an acceleration was not observed, however, and that proved that after perihelion passage this force was opposed by a resistance too, that is to say by a space-permeating ether.

The Yarkovsky effect

With this kind of 'logic', reasoning in circles, Yarkovsky tried to show that two forces that counterbalance each other are constantly acting on each object in space: a braking force and a driving force. The latter arose from the radiation of the Sun and varied inversely proportional to the square of the distance. But how could radiation from the Sun push comets and planets in a direction *perpendicular* to that radiation? That was, according to Yarkovsky, a consequence of the rotation of these bodies. The re-radiation took place about a quarter rotation later. This re-radiation should cause a force that compensated for the resistance of the ether at the front side of the planet (in the direction of the orbital motion).

Figure 5. Yarkovsky was buried in Heidelberg, Germany, but the location of his grave cannot now be found in the cemetery registers. Possibly it was on the 'Bergfriedhof', that was situated in the region of the Academic Hospital. *(Photo by G. Beekman)*

Yarkovsky imagined that the ether encountered by a planet at its front side is compressed and 'so to speak being pushed into the pores' of the planet. When this front side has rotated towards the Sun, this 'stored' ether is heated by the Sun. Then this part of the surface rotates further to the backside of the planet, where it meets no ether drag. 'It is clear that the ether, which has accumulated a great amount of energy ... tries to expand and pushes the planet forwards when it escapes from the pores at the surface'. So the radiation of the Sun is transformed by the ether into a force that acts perpendicular to the direction of the Sun, 'something that at first glance should seem impossible'.

Yarkovsky also tried to calculate the maximum density of the ether. Assuming that the ether resembles a gas and using 'the formula derived from observations of the motion of artillery shells'(!), he found a value of 5 to 12×10^{-13} times the density of air: a value much larger than astronomers later found for interplanetary space. Yarkovsky noted that his value for the density was much larger than that found by the British physicist William Thomson (Lord Kelvin), 2×10^{-25} times that of air, but that 'in two of my previous brochures I already pointed out the inaccuracy in the calculations of W. Thomson'.

Yarkovsky formulated his thermal effect in terms of the 'old', Newtonian physics. The 'new' physics was still a bridge too far for him and many others. The ether that he and others needed to reach for this new physics would vanish in the course of the twentieth century, mainly through the theory of general relativity. Yarkovsky therefore found his now famous effect by virtue of a non-existent medium. Since the rediscovery of the effect by Öpik and Radzievskii we know that the radiation of the Sun is not being transformed into a force by the ether, but by re-radiation from atoms and molecules at the surface of the rotating object. The Yarkovsky effect is in fact the photonic equivalent of the 'rocket effect' of evaporating comet ices, as formulated by Fred Lawrence Whipple in 1950. We also now know that the Yarkovsky effect only acts on rather small objects (0.1m to 20km in diameter), that it does not act exactly perpendicular to the radiation, and that it is not the cause of orbital motion but only of small changes to it.

An armchair scientist

How was Yarkovsky's work appreciated during his life? According to Neiman,[6] his ideas found little response in Russia and remained completely unknown abroad. Firstly, Yarkovsky was an engineer and not a physicist and thus did not belong to the circles of scientists in which he tried to move. He could publish his ideas only in little-known Russian journals. Besides, he had no laboratory of his own. He was forced – or maybe just wanted – to remain an 'armchair scientist', who in his spare time mixed discoveries and theories of others with his own ideas to construct a great synthesis of the physical world. His ideas were – with hindsight – sometimes original and sometimes completely beside the truth.

However, Neiman reports that in amateur circles Yarkovsky's originality was appreciated. On 1914 March 14, at the 50th general meeting of the Russian Society of Friends of Knowledge of the World, he was posthumously paid a high tribute. And at a meeting on the occasion of his 125th birthday, held on 1969 May 26 at the university of Moscow, Viktor Radzievskii said that Yarkovsky's research 'in the field of the theory of gravity was just as original and bold as the research of Tsiolkovsky in the field of astronautics'. All these fine words could not avoid, however, the fact that Yarkovsky failed to receive a place in the history of science and that his name lives on only in one effect in astronomy.

Acknowledgments

I owe much to A. M. Cherepashchuk (Moscow), Tamara Djumantaeva (Polotsk), Ela van den Hout (Velp), Ira Kostyuk (Zelenchukskaya), Maria Petrovna Neiman (Moscow), David Vokrouhlický (Prague), Diana Weber (Heidelberg) and Eike Wolgast (Heidelberg).

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Received 2004 April 5; accepted 2004 July 21