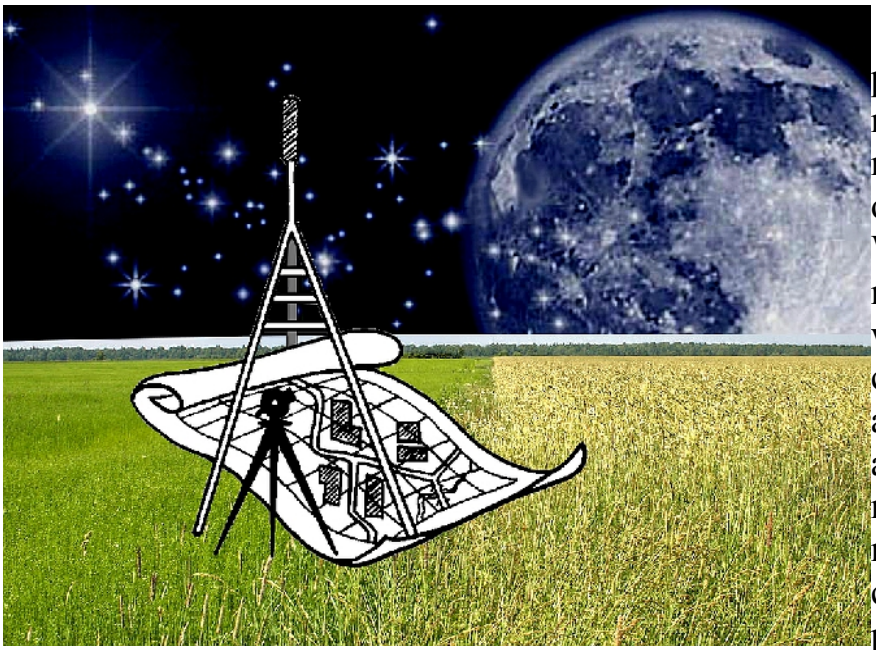
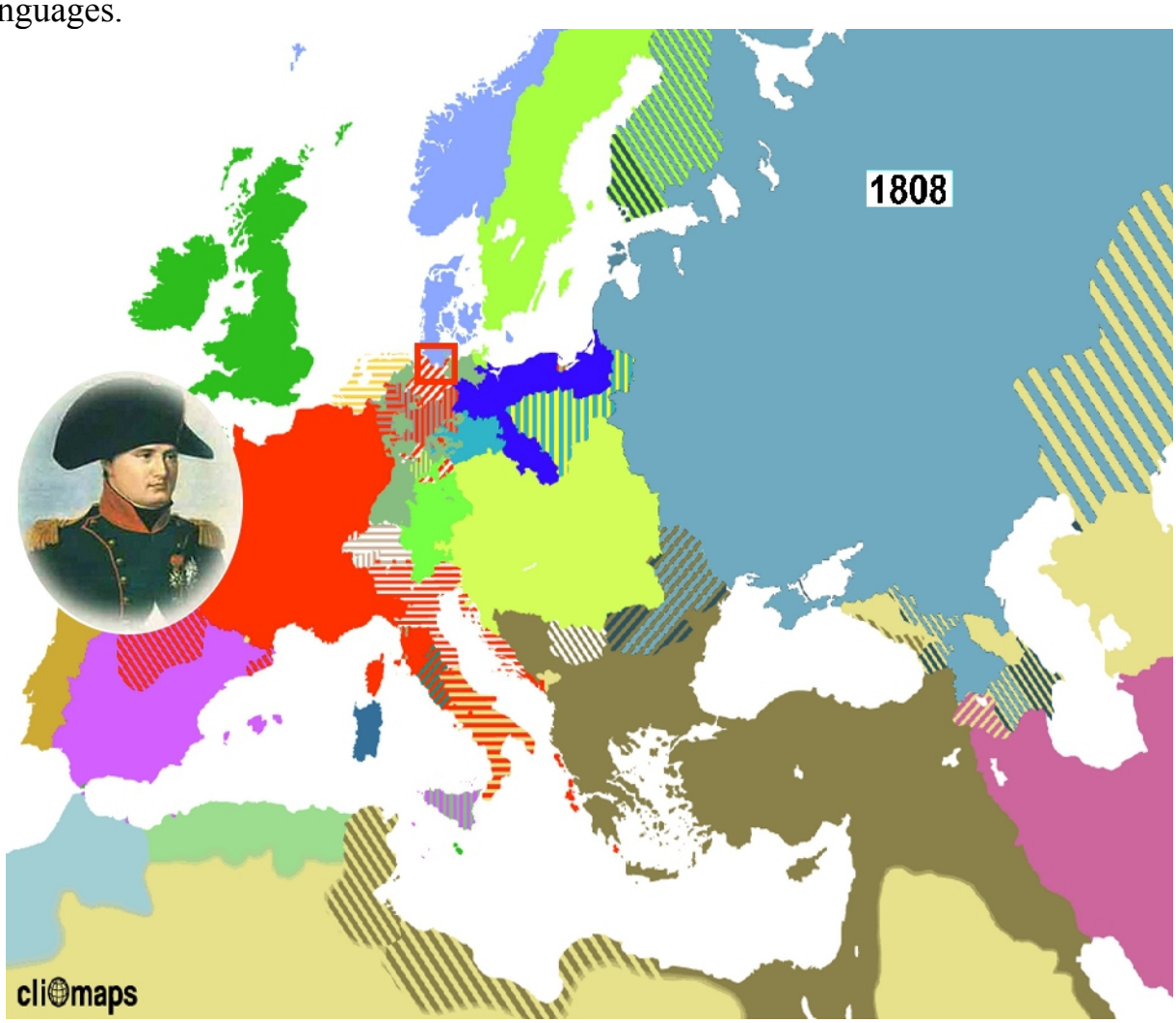
Life and activities of the outstanding scientist Wilhelm Struve (1793 - 1864) progressed in the early and mid-19th century. He inherited thoughts and traditions of more than two millennia of development of science, progress in mechanics and optics. The 15-year-old boy from Holstein, he came to Russia, here finished the university, became a Russian scientist and worked in science for his entire life. His biographers note a ***conscious loyalty*** of Struve to Russia where he worked tirelessly, realizing the need to bring, in his own words, ***"honour to our homeland"*** .

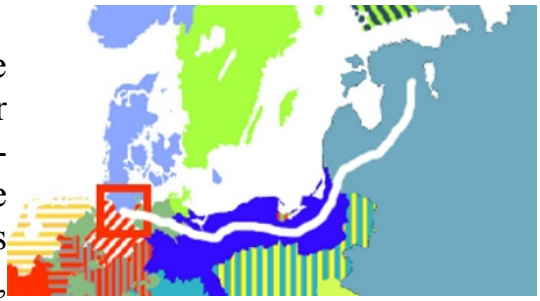


Classical surveying provided technical means and moral satisfaction with making *direct measurements* of sizes, distances and angles. With the help of measurements objects of the world could be placed in some clear and geometrically accurate order, and that allowed to make accurate maps too. Anyone who knew mathematics was able to calculate his geographic position by means of

observing stars. He could even calculate the size of the vast planet Earth. Mathematics had similar techniques to study either the celestial sphere or a convex geographic space. Omnipotence and progress of mathematics was evident. Still in his early years mathematics captured imagination of Willie Struve. His father also loved mathematics, although by his profession he was a teacher of theology and classical languages.



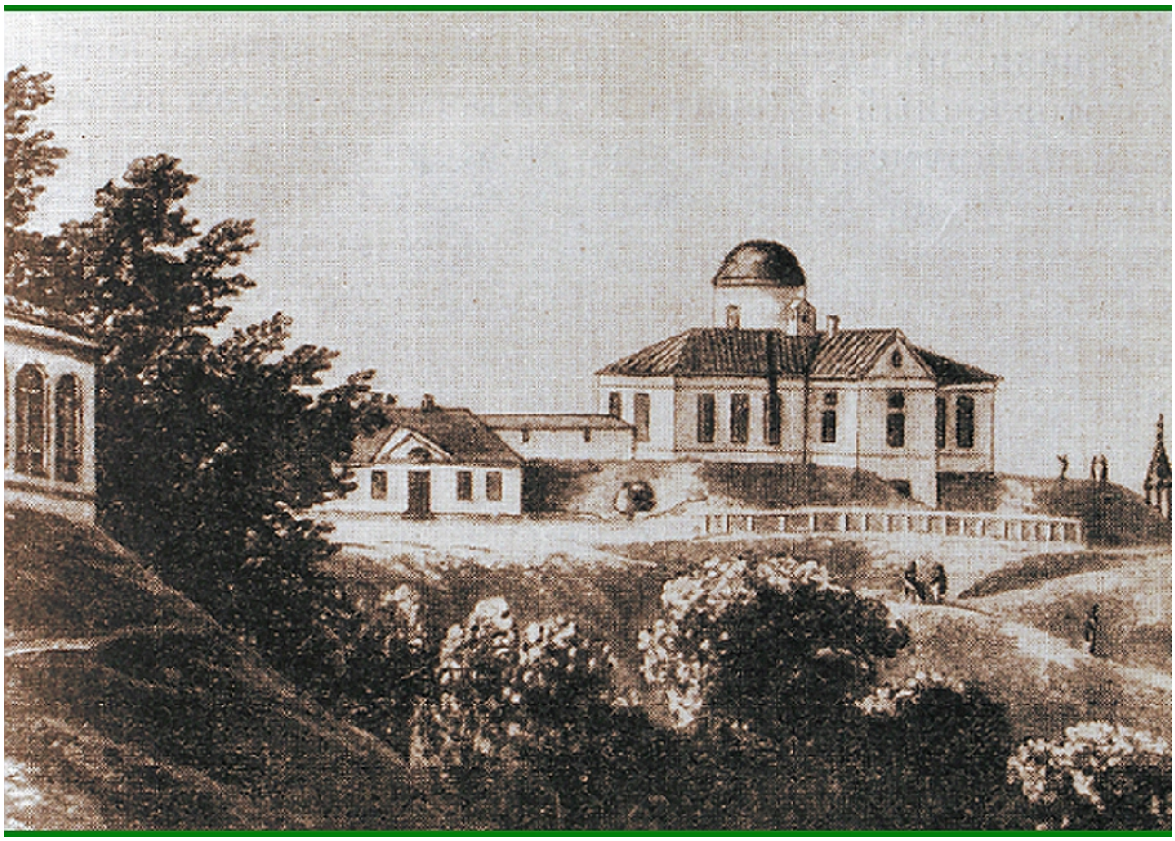
Apart from mathematics, the future career of young Struve was affected by social and political events in his native Holstein. He had nearly graduated from high school, but his further education was under question. His hometown Altona was between the territory seized by Napoleonic troops, and Denmark which declared neutrality. Altona was not occupied but "*the winners of Europe"* were very close - in the city of Hamburg. One day, having come to this big city, the tall and physically strong Willie was captured by Napoleon's recruiters who opened the door to his becoming a brave guardsman of the invincible army. Young Struve chose running home instead. He thus escaped having to fight Russians in a bloody "draw" at Borodino.



In summer of 1808 15-year-old Willie Struve went to the country where his elder brother lived: the Livland Province in the German-speaking Russian Baltic, to its cultural centre the town of Dorpat (now Tartu in Estonia). With his excellent certificates and the Danish passport,

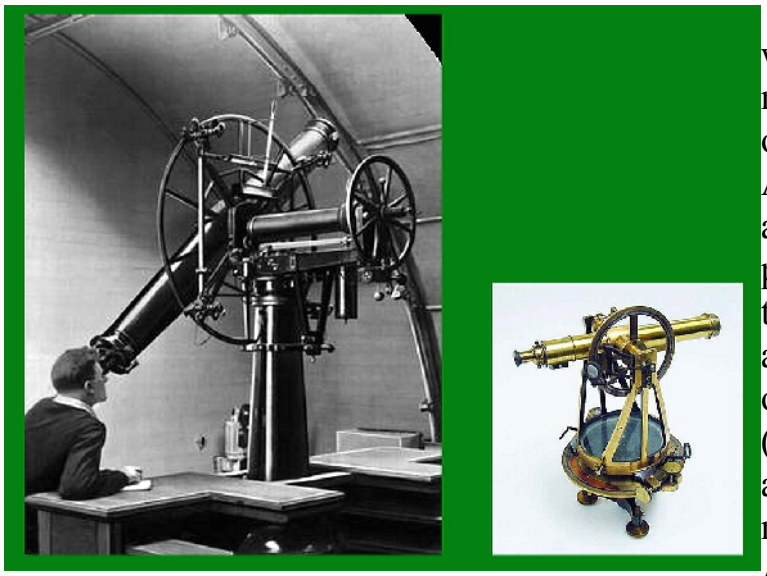
Struve was enrolled university student.

Following his father's advice he chose philology and graduated in two years, received a remunerative offer to the post of a teacher of classical languages. But he rejected it, and went fully deep in the study of his favorite mathematics and astronomy. Such a decision was much influenced by the lectures and individualities of Wilhelm Pfaff - professor of mathematics and astronomy, and Friedrich Parrot, physics professor. Besides, just at that time, in early 1811, a new building of the university observatory was finished.



Soon Struve became almost the only worker in the observatory, because there was nobody else capable to work there as much as Struve did. He himself has mounted a new upscale astronomical tube, thus started as master in instrumentation matters. Mainly from his own observations he derives the accurate values of the coordinates of the observatory. His independent learning (three years of hard work) ended in the autumn of 1813 when he was awarded the degree of Doctor of *"philosophy"* (mathematics and astronomy). He was then 20 years old.

Struve became distinguished astronomer whose name is inseparable of the glory of the old Dorpat and then new Pulkovo observatories. His merits in the field of astronomy are widely recognized, but we will outline ***Struve's activities in geodesy and surveying***.



Surveying as *practical geometry* was a branch of applied mathematics, it was similar to the observational astronomy of the time. As masters in measurements, astronomers were often requested to perform geodetic surveys. Besides, they knew geodesy because they admired the outstanding experiment of the Paris Academy of Sciences (1736-1739). Through laborious astronomical and geodetic measurements at the Equator and Arctic Circle, the Newton theoretical proof that the Earth was flattened at the poles came true. Since then, astronomers of the world were actively engaged in scientific geodetic measurements, aiming at establishing yet more accurate shape of the Earth.

On the other hand, a major shift in cartography was under way. Governments and military headquarters of the world's more advanced countries grew interested in trigonometric surveys of their territories. Trigonometric survey, or triangulation,

was a new efficient method of determination of coordinates of many linked control points to create more accurate maps. Due to the fact that France was then the first in this kind of surveys, French geodetic instruments and important treatises acquired wide credibility. French military maps were in fact the best in the world.

In Russia, first governement-sponsored experiments in triangulation began in the first decade of the 19th century in the Provinces of Moscow and St. Petersburg,

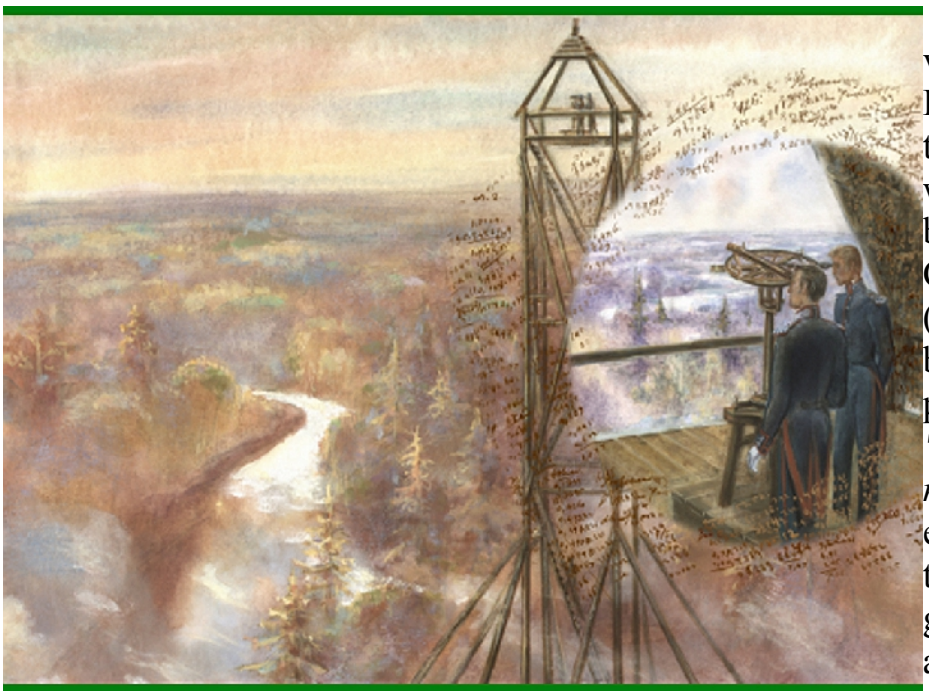
but they did not progress because of the 1812-14 war with Napoleon.

At this very time the young adherent of mathematics, Struve bought a sextant for himself, got a base-measuring device and started training in triangulation on his own. Portable sextant can measure not only heights of stars, but angles in any arbitrary plane, between terrestrial objects too. This is a small "universal instrument" for many purposes.

Once, in summer of 1812, while Struve was conducting a field measurement, he was arrested by a Russian army patrol on suspicion of espionage. There was wartime, and he has been on trial. Fortunately, the mistake was realized and he was released.

In autumn next year Struve has defended his doctoral thesis and was soon appointed director of the university observatory. Since early 1814 he started reading lectures in mathematics, astronomy and practical geometry - that is, surveying and topography.

We note the year ***1814 as the beginning of Struve's professorship in geodesy and surveying.***

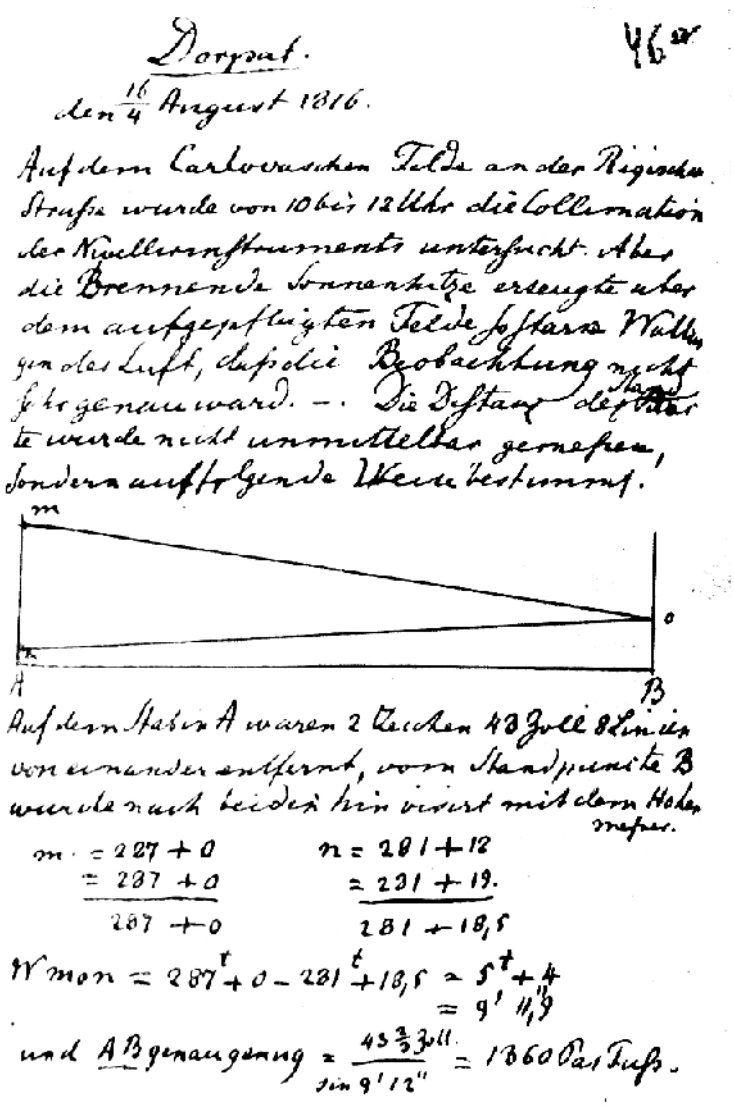


Immediately after the victory over Napoleon, Russian state (military) trigonometric surveys were organized and soon began under Colonel C.Tenner's command (afterwards Tenner became Struve's principal partner in measuring the *"Russian arc of the meridian"*). Meantime, the educated community of the Livland Province also grew interested in the advanced technology of map-making. An idea was accepted of a new map of the Province which would embrace land- and cadastral

surveys over previous years. Budgets for the project was found, but the technology was yet to be think over. The offer was made to the talented and energetic Professor Struve. He took it.

For three summers of 1816-1818 Struve performed extensive geodetic and astronomical survey resulting in coordinates of 325 stations and heights of 280 ones. His observation points were manor buildings, churches, windmills and he established more than 60 wooden landmarks in places where there were no sighting targets. According to experts, ***the astronomical and trigonometric survey of Livland*** made by Struve was notable for the art of observation, witty overcoming local obstacles, careful exclusion of instrument errors. All that job of coordinating the vast province Struve fulfilled almost alone, using assistance of his two students in few cases only.

He measured the angles with a 10-inch sextant, whose errors had been thoroughly determined. The accuracy


Dorpat. 46a

den 16/4 August 1816.

Auf dem Carlowaschen Felde an der Rigischen Strasse wurde von 10 bis 12 Uhr die Collimation des Kreisinstruments untersucht. Aber die Brennende Sonnenhitze erzeugte über dem aufgepflügten Felde so starke Wallungen der Luft, daß die Beobachtung nicht sehr genau ward. – Die Distanz des Standpunkts wurde nicht unmittelbar gemessen, sondern auf folgende Weise bestimmt.

Auf dem Stabe A waren 2 Zeichen 43 Zoll 8 Linien von einander entfernt, vom Standpunkte B wurde nach beiden hin visirt mit dem Höhenmesser.

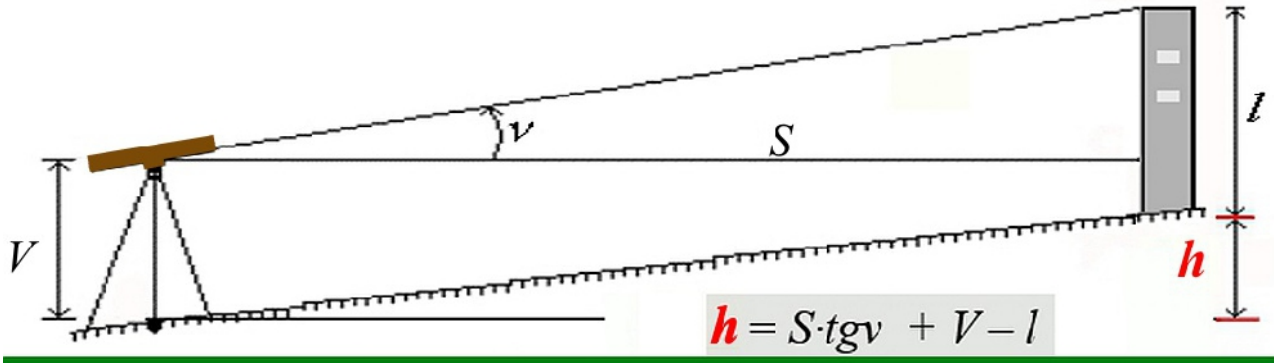
m = 287 + 0 = 287 + 0 = 287 + 0

n = 281 + 12 = 281 + 19 = 281 + 18,5

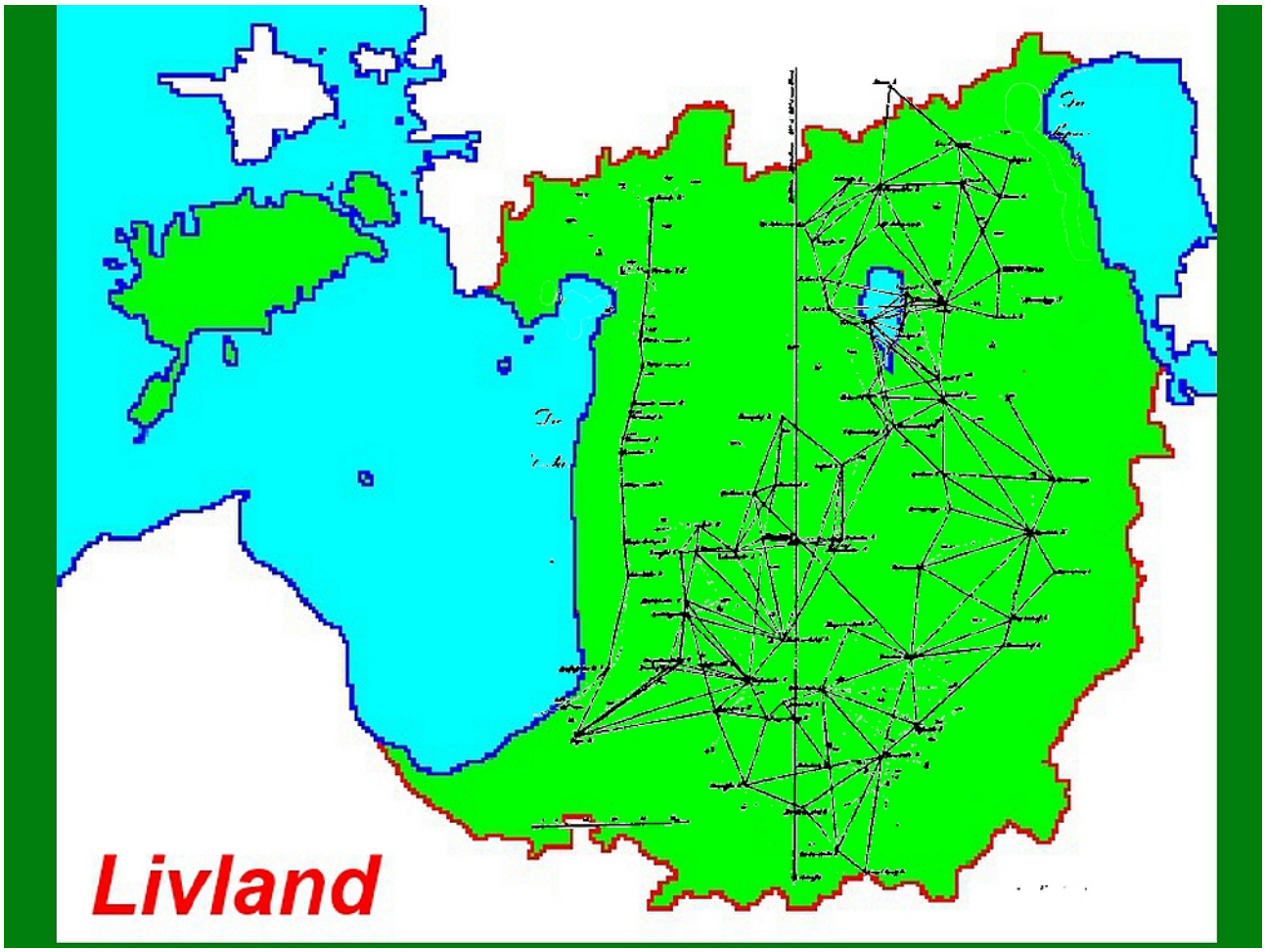
W mon = 287t + 0 − 281t + 18,5 = 5t + 4 = 9' 11,3"

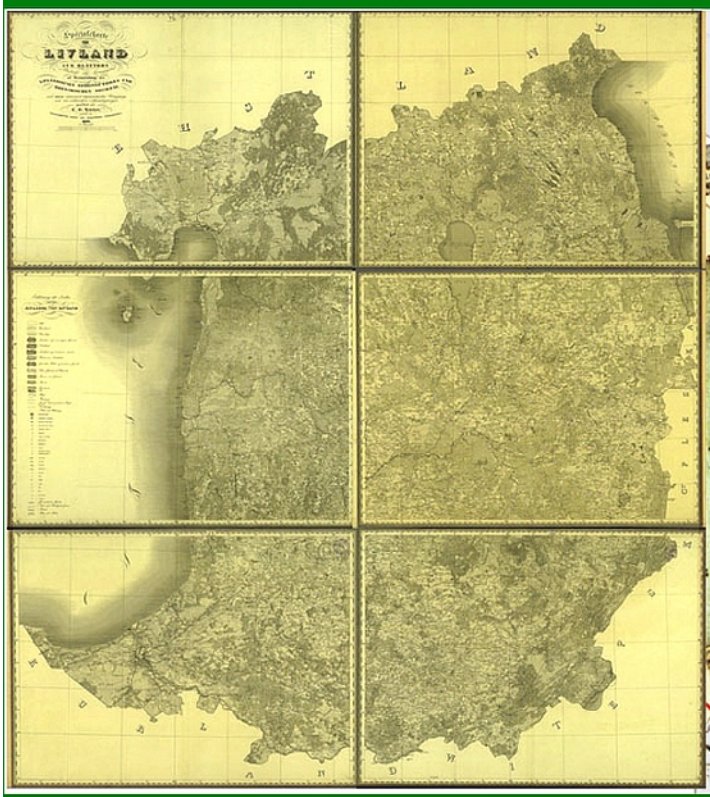
und AB genaugenug = 43 2/3 Zoll / sin 9' 12" = 1860 Par. Fuß.

of the angular measurements was about 15 arcseconds; stations with lacking visibility were determined astronomically; azimuth values were either computed via measured angles starting from the initial direction established at the Dorpat observatory, or by observing stars with the same sextant. Heights were determined trigonometrically, their reference being the level of the Baltic Gulf of Riga. Struve's sextant, even stable on its tripod, was not accurate enough for trigonometric leveling; Struve used a device of his own design, made under his supervision by the university mechanician. This so called *"sector"* allowed to measure small angles of elevation with the accuracy of ± 4 arcseconds. Struve's base-measuring device was just a chain of five jointed wooden bars with two attached accurate scales at its outer ends.



Struve's principal horizontal reference framework of Livland:



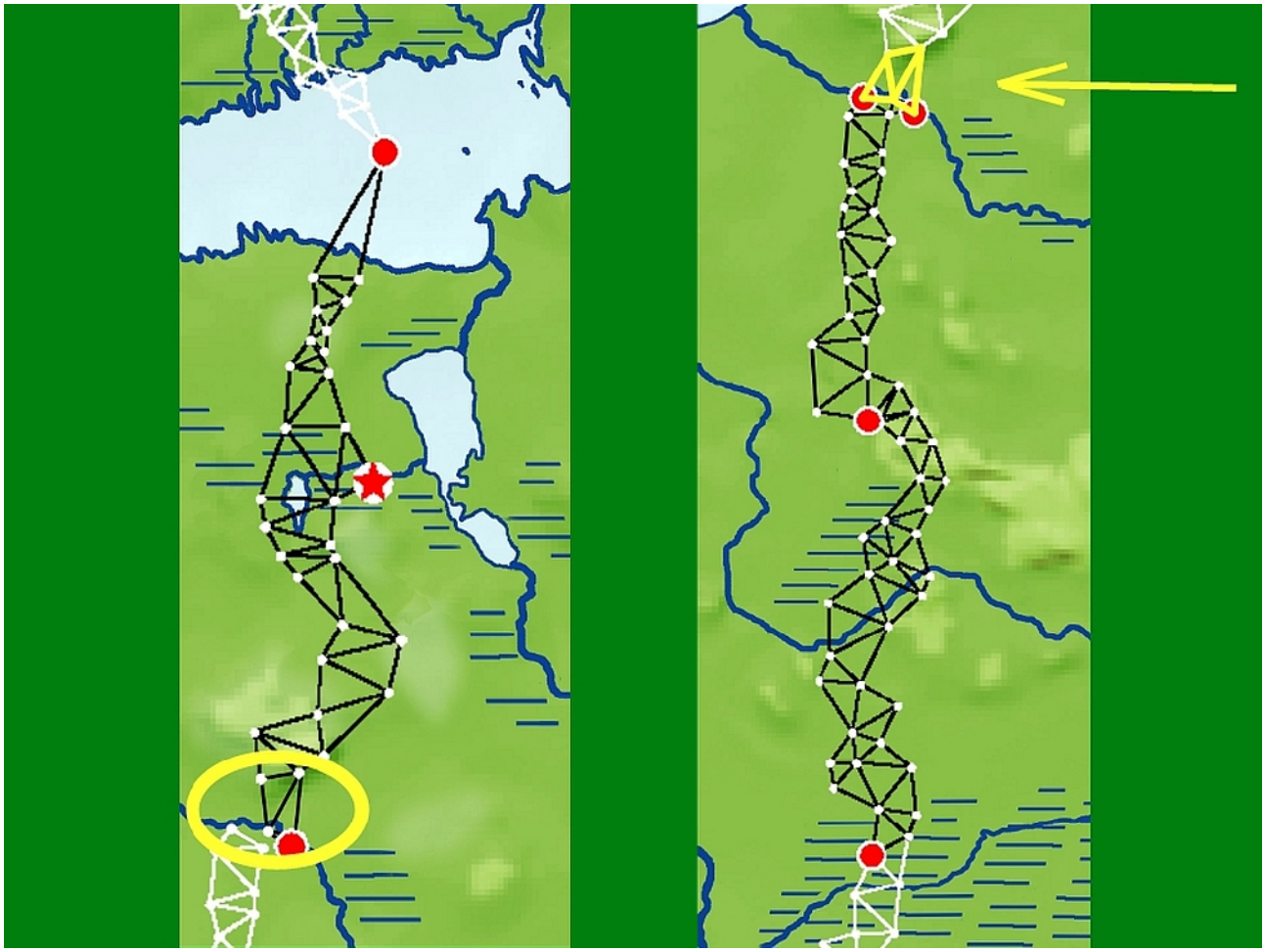


Here one can see two general maps compiled after the Struve survey. They testify that he was the first who has established the exact horizontal and vertical reference frameworks in the contemporary Livland.

Due to his surveying work, Struve got to know the country well enough to measure arcs of the meridian and parallel there. The idea of new measurements along geographical arcs was popular at the time. More and more accurate determination of the Earth's figure was important to astronomers. Why so?

- The Earth's radius served as the length standard and key to calculate the motions of celestial bodies in the Solar system. Therefore Struve also thought about ***precise measuring of the shape of the Earth***. Immediately after the completion of his field works in Livland, Struve advances with a proposal to measure the meridian and parallel arcs in the Russian Baltic provinces. Interesting enough, that Emperor Alexander I approved Struve's proposal and allocated funds to perform new measurements in just the same Province! Inspired Struve went to Europe to order best equipment and consult colleagues there. ***An unprecedented enterprise in Russia was about to begin - a measurement of the meridian arc.***

It should be noted that the length of a meridian arc was just the computed result, whereas a triangulation built along the arc served as a method of measurement.



During the next 8 years Struve and his military students measured the meridian arc from the island of Hogland in the Gulf of Finland to the city of Jakobstadt on the Western Dvina river. In 1828 there was a junction with another meridian arc measurement performed by military surveyors of General Carl Tenner south of the Western Dvina to the Pripyat' marshland. The operation was unique: the two triangulations to be linked had been observed with different instruments and were scaled in absolutely different length units: toises and sazhens.

After success of the junction Struve applies to the then (next) Russian Emperor Nicholas I about the northerly extension of the measurements. Emperor consulted the Army Headquarters and allocated funds for a 15-year measurement of the meridian arc through the Russian Finland, up to the northern coast of the Gulf of Bothnia at Tornea. The measurements in Finland were performed under Struve's general guidance by his former military students, C. Oberg and C.F.G. Melan, followed in 1835 by astronomer of Helsingfors observatory Fr. Woldstedt.

Struve realized that to measure the *"Russian arc"* yet further north would be a problem - far and expensive; there was no staff available for that; the Russian Army Headquarters didn't show any interest in the northern extention.

Then a question arises: measuring further north - what for? maybe, one should stop at Tornea?

- Yes, of course, the arc measurements might be less extensive and expensive. But they would not then be of a scientific value. The matter was that only measurements of a considerable extent could neutralize the influence of local irregularities in the Earth's figure as well as various inevitable errors of measurements. Struve and his colleagues well knew that. Moreover, all measurements should be carried out as accurately as possible, with the best technical means, with careful examinination and elimination of the instrument errors, rechecking written certificates of the instrument makers. Otherwise one would deal with a crucial loss of accuracy and transformation of scientific value into utilitarian cartographers' benefit.

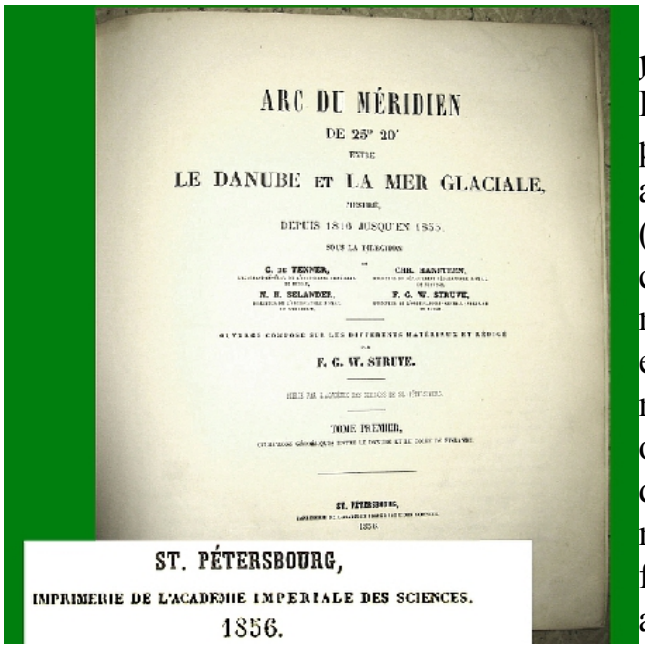
In order to ensure continuation of the measurements further north, Struve went to Stockholm to discuss the mattter with the Swedish scientists and surveyors. He himself presented the matter to Oscar I - the new King of Sweden and Norway, and it

C.F. Tenner

N.H. Selander

Chr. Hansteen

was a success. By King Oscar's decree the Swedish and Norwegian surveyors, mainly the military, guided by N.H. Selander and Chr. Hansteen extended the meridian arc measurements in 8 years up to the Arctic coast of Europe. At about the same time, General Tenner's surveyors brought their triangles to the upper Dniester, and then, further south to Bessarabia, to the mouth of the Danube. Astronomical observations and base-measuring works in Norway and Bessarabia were fulfilled by astronomers with Struve's Pulkovo observatory. Eventually, ***the most extended and precise astronomical and geodetic measurements of the Earth's figure*** came to the end.

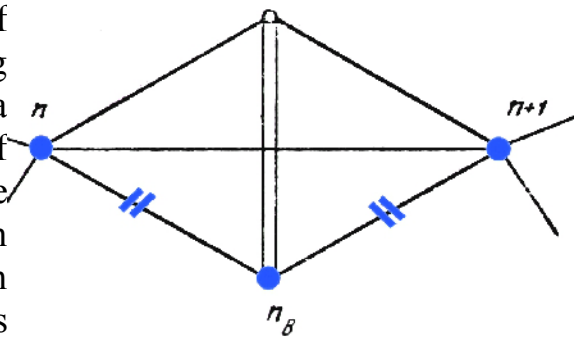

ARC DU MÉRIDIEN
DE 25° 20'
ENTRE
LE DANUBE ET LA MER GLACIALE,
DEPUIS 1816 JUSQU'EN 1855.
F. G. W. STRUVE.
TOME PREMIER.
ST. PÉTERSBOURG,
IMPRIMERIE DE L'ACADÉMIE IMPÉRIALE DES SCIENCES.
1856.

They lasted from 1816 to 1855, ***40 years***, from Struve's youth to his old age. During all this vast time Struve was preparing, participating, providing advice, managing field work (immediately and then by correspondence), carrying out necessary metrological research and instrument error investigations, inventing new methods and measurement techniques, organizing, instructing and supervising, directing and doing himself hard mathematical processing, preparing the final publication. All that was going along with his other duties and interests, especially in the field of astronomy. His colleagues helped him. Each of the astronomers and temporary trainees in Pulkovo observatory had to perform a part of the huge computational work.

The arc of the meridian, which is reasonably called the ***"Struve Arc"*** - is Struve's most famous geodetic work, it has received universal recognition and respect of the scientific world. In our century it has been recognized by UNESCO as the ***cultural object of "outstanding universal value"***.

Struve's merits in geodesy and mapping do not only refer to this outstanding measuring of the figure of the Earth.

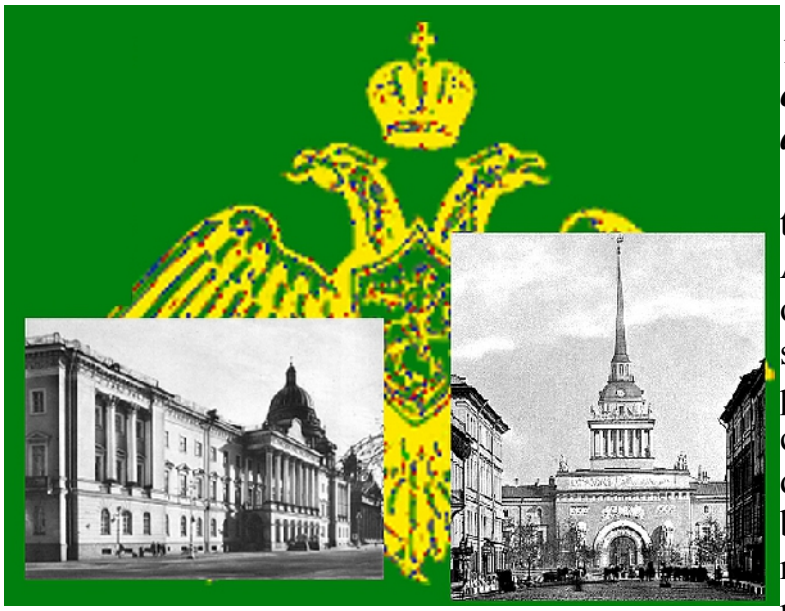
Russian scientific hypsography was then at its young age: collecting the data. Struve, as well as General Tenner, performed trigonometric leveling while carrying out measurements of the arc of the meridian. Apart from that, Struve organized another major leveling work, that is, ***determination of the difference in height between the Azov and Caspian seas***, also by trigonometric leveling. The work was done in two years by Struve's disciples - Georg Sabler, Alexey Savich and Yegor Fus. The length of the surveyed route was about 880 km.



Struve developed a special method of leveling under conditions of heat and strong refraction. An elementary leveling section had a small length: 7 to 8 kilometres. In the middle of it a baseline was measured. Heights of the adjacent stations were determined from simultaneous measurements of the zenith distances from three stations. Also coordinates of all the stations were calculated from elements of the inner triangles. The results of this expedition served Struve to investigate the influence of refraction: he invented the procedure to account for it through measuring temperature and pressure.

Struve was one of the ***founders of the Russian Geographical Society*** (RGS, 1845). Here he led the work on mathematical geography. The first RGS expedition went to the Polar Urals, followed by an expedition to Siberia and others. Struve was responsible for astronomical parts of those expeditions. He compiled routes and wrote instructions to expedition astronomers, analized field materials as to correct astronomical positioning.

It was Struve who suggested (and the RGS contributed to) introduction of the Gauss map projection into map-making in Russia. Society also supervised the process of compiling precise maps of the central Russian provinces using boundary and cadastral survey materials accumulated over the years: this project reminds of the similar Livland survey by Struve. He also gave expertize in teaching geodesy within higher education programs, as well as conducted cartographic measurements of areas of Russia's provinces.

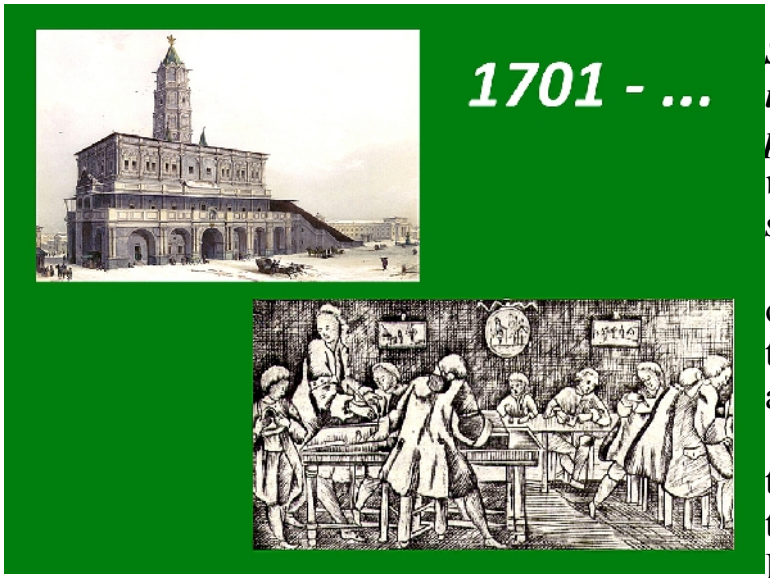


Yet in the very beginning of 1825 Struve was nominated to ***collaborate with Russian Military and Naval ministries***.

He was engaged in practical training of young officers of the Army and Navy, checking works of military astronomers and surveyors; he organized and participated himself in chronometric expeditions to determine differences in longitude between principal cities of Russia, reviewed on new topographic maps, promoted manufacture and organized research into instrumentation for military geodetic surveys, gave expertize as to junctions of Russian, Prussian and Austrian triangulations. Those junctions

testified that Russian geodetic surveys were getting across the national borders, and Russian geodesy was capable to new international continent-wide projects.

Now, the principal thing.



The most important Struve's merit in Russian geodesy is this: he has established a permanent practical training which educated plenty of young surveyors for their careers.

The art of Surveying can only be transferred from Teacher to his student - it was before, and always will be so.

It is known, that in Russia the basics of surveying were first taught in Moscow by Professors Farhwarson, Gwyn and Grace invited by Peter I from *"England"*. Eventually the Russian geodesy started with astronomical positioning and vast geographic surveys. The epoch of *"Peter's surveyors"* began. The name was applied first to graduates of the Moscow Navigation school, then - to those of the Petersburg Naval Academy, as well as to alumni of few engineering and land-surveying schools. Those who managed to live up to the reign of Empress Elizabeth (1840-ies), received *hereditary nobility* for their immense and mainly dangerous work of surveying.

The Struve epoch was that of mathematically correct mapping, the epoch of triangulation and leveling. Thanks to Struve's energy, knowledge and experience, Dorpat observatory first, then - for decades - Pulkovo observatory became ***leading centers of practical training of Russian surveyors***.

"Struve's surveyors" met requirements of their times. They possessed skills in defining latitudes and longitudes like their predecessors in the previous century. They were, moreover, able to build trigonometric networks, conduct mathematical treatment of measurements on convex spheroidal surfaces, determine heights of stations in different ways, investigate instruments and chronometers; they knew how to measure the force of gravity. Almost all Struve's disciples headed regional geodetic and hydrographic surveys. Some of them: Alexei Savich, Wilhelm Doellen and Struve's son Otto Struve became professors and advisors to the next generation of surveyors. High level of readiness for the profession and excellent practical results of former students of the "Struve school" earned international recognition and brought Russian geodesy to the forefront of science and practice.

At the end of his active and extremely fruitful activities Struve advanced the idea of a ***trans-European measurement of the arc of the parallel***. Russia's high international prestige in surveying and mapping became a key factor of future implementation of this idea. The project was headed by Struve's son and successor Otto Struve, and German military surveyor Baeyer, who had previously worked with Bessel. The trans-European measurements of the arc of the parallel gave origin to the modern ***International Association of Geodesy*** (IAG).

Thus, not only Struve was among the founders of the *Russian* Geographical Society, but he also contributed to establishing of the ***international community of geodesists and surveyors.***

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Compiled by Vitali Kaptüg

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