



# The Man behind "Degrees Celsius"

A Pioneer in Investigating the Earth and its Changes

Martin Ekman

Summer Institute for Historical Geophysics • Åland Islands





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## Contents

Preface	7
1. The unknown man with the well-known name: An introduction	10
2. Where and when: Official and personal background	12
2.1 University and science: From clerical control to academic freedom	12
2.2 Father's parents: The quarrelling astronomer and his wife	17
2.3 Mother's parents: The quiet astronomer and his wife	19
2.4 Father and mother: The unhappy astronomer and his wife	26
3. Curiosity and unpaid work: Student and young scientist	32
3.1 Growing up	32
3.2 A novelty	33
3.3 Up in the church tower, down in the silver mine	36
3.4 Waiting in Uppsala	39
4. Out in the world: For or against Newton?	41
4.1 A safe position	41
4.2 Via Berlin to Rome	43
4.3 In Paris: A turning point	47
4.4 In London: Preparing for the north	51
4.5 To the Arctic Circle: Stars and ice	53
4.6 Was Newton right?	62
5. At home again: Investigating the unknown Earth	69
5.1 An observatory for investigating the Earth	69
5.2 Latitude, longitude and mapping	79
5.3 Gravity and the Earth's shape	91
5.4 Land uplift / water decrease and history	94
5.5 Sea level and the atmosphere	101
5.6 Temperature, air pressure and climate change	103

5.7	Magnetism and magnetic changes	111
5.8	Northern lights and a big surprise	115
5.9	Science, family and friendship - and love?	118
6.	After Celsius: An unusual heritage	120
6.1	The sudden end of life	120
6.2	The decline of the observatory	122
6.3	A new observatory in Stockholm	125
6.4	The unknown man with the well-known name: Looking back	131
	Appendix: A dramatic love story	133
	References	136
	Illustrations	151
	Index	153

## Preface

This is a book about Anders Celsius, his life and his works. It is, thereby, also a book about the beginning of systematically investigating the Earth and its changes.

Up till now there has been no book at all about Celsius and his scientific works for an international audience. Even for Swedish-speaking people there has been (apart from smaller publications) only one book, published nearly a century ago. In my own scientific work within different geophysical fields I repeatedly came across Celsius' name when searching for the roots of the sciences I dealt with. And as there is hardly any relevant book about Celsius and his works to read, I finally decided that I should write one myself. This is the result.

The book attempts to give a wide perspective on Celsius without going too much into details. It is a book about science, about history, about people and about a life. I have tried to put these aspects together into something that hopefully will give a faithful picture of Celsius and what he did.

In order to give a reasonably complete picture of Celsius one should include also the works of his assistants. Considerable parts of their work were directly inspired by Celsius. Therefore, I have taken relevant parts of their work into account as well.

I have also attempted to analyze some of the methods and results of Celsius and his assistants by using modern scientific methods and by comparing with findings based on later data. This has led to an improved understanding of the quality of his methods and results. These investigations have earlier been published separately but the main conclusions from all of them are now included here.

There are official paintings of Celsius and his male ancestors, but in addition to these there are two private paintings, one of Celsius himself and one of his mother. I have managed to trace these two portraits and include them in the book; they have not been shown to the outer world before.



The book is intended for reading by a wide range of people who are curious to know what the person with the well-known name actually did and who he was, but it is also intended for people generally interested in the early development of Earth sciences. It requires an elementary background in natural sciences. I have, however, avoided formulae in order to make the book readable for people irrespective of their mathematical knowledge. Those who wish for more of such things are referred to publications in the reference list.

There are a number of quotations in the text, giving Celsius the possibility to speak for himself now and then. Their translations into English are due to the present author. Some parts of the quotations have, due to their considerable age, had to be translated somewhat freely to make them understandable; however, great care has always been taken to convey the original message in a correct way.

Translations into English of the names of universities cause a special problem. There are three possibilities to use: A. University of Something. B. Something University. C. The present official translation. Alternative A will disturb those people whose own university now uses translation B. Alternative B will disturb those people whose own university now uses translation A. Alternative C is difficult to handle because of the variety of present translations, including a few that do not function very well in a text like this one. I have here used alternative A in the main text as the least bad solution. That is why the English name of the university at which Celsius spent most of his life is here given as the University of Uppsala in the main text; in the lists of references and illustrations, on the other hand, the present version Uppsala University is used.

A number of people have been helpful during the work with this book. I would first of all like to thank the persons who have read the whole manuscript and given constructive comments on it, all of them at the same university as Celsius: Sven Widmalm, Eric Stempels and Hans Bergström. I would also like to thank a few colleagues at other institutes who have read parts of the manuscript: Per-Anders Olsson and Birna Olafsdóttir. In addition I would like to thank a British colleague for having contributed several improvements of the English language as well as other improvements: Philip Woodworth.

To get access to Celsius' hand-written and printed documents I have had the great benefit of the helpful staff at the Uppsala University Library as well as at the Center for History of Science at the Royal Swedish Academy of Sciences; this also applies to the Linköping Diocese Library. Concerning portraits, Riko Eklundh and Anita Nystén, descendants of a cousin of Celsius, have kindly allowed me to arrange to photograph the paintings of Celsius and his mother in their private homes, whereby Yehia Eweis undertook the professional photographic work. Görel Cavalli-Björkman has shared her expertise to figure out the probable artist behind the paintings. Mikael Ahlund at the Museum Gustavianum has on my account kindly arranged re-photographing the paintings of Celsius and his ancestors belonging to the University, whereby Mikael Wallerstedt made the professional photographic work. My thanks to all of you.

Åland Islands, at the vernal equinox 2016

*Martin Ekman*

## 1. The unknown man with the well-known name: An introduction

“The temperature is 25°C.” This is a quite normal statement giving information on how warm it is somewhere, outdoors or indoors, or in a substance of some kind. The international temperature unit °C contains the symbol ° standing for “degrees” and the letter C standing for the name “Celsius”. The book you have now started to read is a book about the man behind the letter C, about his life and works.

The person behind the letter C is Anders Celsius. He lived in the early 1700s, from 1701 to 1744, in what was then a tiny northern university city called Uppsala, to the north of Stockholm in Sweden. As a young student Celsius started performing systematic measurements of air temperature, and twenty years later he introduced a well-defined temperature scale based on accurate definitions of two fixed points on the scale, the freezing point and the boiling point of water. Today the name of Celsius is known all over the world because of the international temperature unit he invented through this scale of his. Also the absolute Kelvin scale uses this unit. However, Celsius himself is surprisingly unknown, as are most of the many other topics he studied. Who was he? What did he do? The temperature unit that has made his name so wellknown is hardly the most important thing he did in his life.

Celsius may be characterized as a pioneer in investigating the Earth by means of systematic observations and by collecting long series of numerical data. He partly started with this work in 1722. During his active years he, and his assistants, measured and studied latitudes, longitudes, gravity, magnetism, heights, sea level, air pressure, temperature and northern lights. By collecting series of such data he and his assistants could find patterns and draw conclusions about various aspects of the Earth, and also of changes of the Earth on various time scales (days to centuries). This was a novel way of working at that time.

Formally a professor of astronomy, Celsius may be described, in modern terminology, as a pioneer in geophysics. He and his assistants

worked within what today would be termed astronomy, geodesy, solid geophysics, oceanography and meteorology. Celsius' driving force was not only his scientific interest in the Earth but also his wish to create science useful for practical applications in society. Such applications were mapping and navigation, time keeping and almanacs, weather and climate, and even history.

Much of Celsius' inspiration for his works came from his participation in an international expedition to the Arctic Circle, the purpose of which was nothing less than trying to confirm the theories of Newton. In many respects Celsius concentrated on utilizing Sweden's northerly position on the Earth, promoting such investigations that could not easily be made in more southerly countries.

Celsius did not work alone. He gradually created a loose group of assistants and disciples around him, some of them coming and going, some of them more permanent. A few of them developed into more independent scientists, but they all worked in the spirit of Celsius. In order to understand the impact of Celsius, one has to deal also with those works by his assistants that were clearly inspired by Celsius himself.

Celsius was of a well-known family at the University of Uppsala (concerning English names of universities see Preface), but he nevertheless lived in rather poor circumstances. As a professor Celsius stayed with his mother, by then a widow, who ran an eating-house for students and teachers. His father had had an unsuccessful time at the University with periods of unemployment, leading to difficulties for the family. On the other hand, the considerable political freedom in Sweden during Celsius' time, together with the approaching Enlightenment, created a favourable basis for Celsius to work as he wished.

This book is the story of the life and works of a man who started from meagre circumstances in an isolated northern university but developed into a pioneering Earth scientist with international contacts. It is also the story of a scientist who was engaged in creating an observatory and supporting an academy for the benefit of society but who died in the middle of his activities. And it is also the story of a person who made friends easily everywhere but never found someone with whom to share a common life.

## **2. Where and when: Official and personal background**

### **2.1 University and science: From clerical control to academic freedom**

When a human being is born, she or he is born into a context which depends on where and when the person is born. Life starts against a certain background given by this where and when, whether we like it or not. This background may be said to be partly an official one, partly a personal one, although these are by necessity more or less interrelated. The official background is shaped by the country and its institutions at the time, the personal background by the family and its circumstances at the time. In the case of Anders Celsius these two were closely interwoven: His ancestors were connected to an important state institution in Sweden in the 1600s and the early 1700s, the University of Uppsala. Let us look into the more official background in the present section and then turn to the more personal background in the following sections.

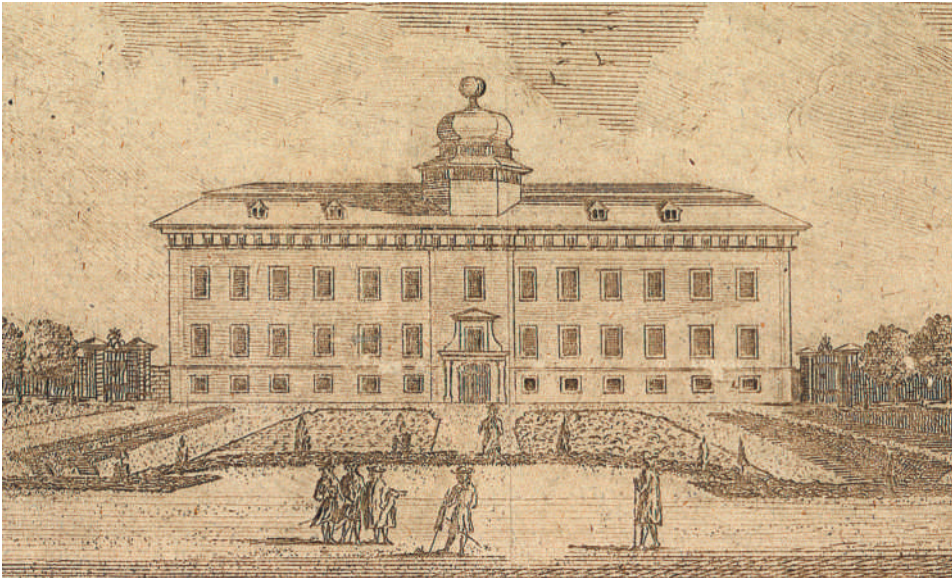
The University of Uppsala in Sweden was founded in 1477. This occurred partly as a consequence of information reaching the Swedish Government that a university was planned in the neighbouring country of Denmark. Should Sweden accept in silence being inferior to the Danes? Certainly not. The Swedes hastened to create a university of their own and, thereby, managed to become the first Nordic country to establish a university. The University of Copenhagen in Denmark was founded two years later.

The man behind the University of Uppsala was the archbishop of Sweden, Jacob Ulfsson, residing in Uppsala. He was a highly educated person and became the head of the University. The University had close relations to the Catholic Church not only because of the role of the archbishop; the decision of the Swedish Government to found the University was confirmed by the Pope in Rome. The University aimed at giving education in a variety of fields; right from the beginning there were courses given in astronomy.

After the initial ambitious decades, the University started to decline. The situation worsened after half a century when the King of Sweden broke with the Pope and the Catholic Church, and replaced it by the Church of Sweden, a protestant church. As a consequence of that, the University faced a period of what might almost be called a coma. But in 1593 the University was restored, in order to serve the Swedish Church as well as the State. In connection with the restoration a professorship in astronomy was introduced.

A big step forward for the University of Uppsala was taken in 1620 and the next few years. It was a consequence of a series of long-range decisions by King Gustaf II Adolf (Gustavus Adolphus) and his prime minister, Axel Oxenstierna. These decisions included new professorships, scholarships for poor students, a university library, well worked-out statutes, and a special university chancellor, the first chancellor being the King's teacher Johan Skytte. A university building was erected close to the Uppsala cathedral; it is still there, see Figures 2-1 and 2-2. The most remarkable decision, however, was the one made by the King in 1624. He then gave away no less than 300 productive farms in eastern Sweden, owned by himself, to the University, in order to secure its economic independence and stability. The total income from these farms was more than sufficient to keep the University going. In fact, this was the only income for the University for more than 200 years! An odd consequence of this, however, was that the salaries of the professors became partly dependent on harvest results and grain prices. Today the University still enjoys the income from these farms, some of them including forests, as an additional income to the more important money from the State.

The number of students increased to between 500 and 1000 after the reforms. This was a considerable number in a place like Uppsala, which only had some 3000 inhabitants. Most of the students were sons of priests or peasants. Education was on a level considered reasonable to supply the growing State authorities as well as the Church with skilled people. Discussions and disputations were lively. Scientific research of any importance, however, hardly existed at this early stage, as it rarely did at universities in other countries. There was but one exception to that at Uppsala during this century: the discovery of the lymphatic system in the human body by Olof Rudbeck the elder, later professor in medicine.



*Figure 2-1. The old University building in Uppsala, "Gustavianum", founded by King Gustaf II Adolf (Gustavus Adolphus) in the 1620s. Engraving by Fredrik Akrel 1769.*

He demonstrated this discovery to the scientifically interested Queen Christina at her visit to the University in 1652. Rudbeck also built an anatomical theatre, to demonstrate the interior of dead bodies, on the top of the University building; it is still there.

The improving quality of education at the University led to increasing fear by the Church of losing its power over the way of thinking among the university teachers. A tension built up between theologians on one hand, and medics, astronomers and the like on the other hand. The most sensitive point was the scientific idea of the Earth not being in the centre of the Universe, an idea rejected by the Church. In 1679 a young student, Nils Celsius, closely related to Anders Celsius as we shall soon see, presented a thesis in astronomy in which he claimed the supremacy of science over the Bible. This struck the theologians with horror; they managed to have the thesis cancelled. This, in its turn, triggered furious reactions from people on the other side. For several years the two sides quarrelled, until they decided to put this principally



*Figure 2-2.* The old University building “Gustavianum” today.

important matter before the King. Should the University obey the Church or should it be allowed to seek knowledge freely?

The King, Carl XI, set up a committee with people from both sides to give him arguments and advice. After having hesitated for a long time, the King made a diplomatic decision of great importance, in 1689: The University was granted the right to seek and spread knowledge freely, provided it paid sufficient respect to the Church. This opened up a future for science; in practice anything could be said and published as long as you also put in a few polite words about the Church.

From 1690 onwards several text books with applied scientific contents were published. And in 1695 the first scientific expedition in the Nordic countries was carried out. It went to the Arctic Circle. Two of the three people taking part in the expedition were astronomers: Johan Bilberg (former professor in mathematics) and Anders Spole (professor in astronomy). Bilberg and Spole studied most of the time the midnight sun, especially the refraction of the sun light in the atmosphere. This was



an interesting subject, but their results were too inaccurate to be useful. Associated with the expedition was the botanist and zoologist Olof Rudbeck the younger (professor in medicine), son of Rudbeck the elder, who studied and painted plants and birds in the north.

Two of the persons involved above were closely related to Anders Celsius: Nils Celsius was the father of Anders Celsius, and Anders Spole was his grandfather (his mother's father)! Nils Celsius' fight for the right to speak and write freely as well as Anders Spole's scientific expedition to the Arctic Circle – both rather unsuccessful in their own context – were to be important from the perspective of influencing the life of Anders Celsius.

In 1702 a great fire struck Uppsala. Almost the whole city burnt down. The University building itself was saved from the flames but almost all professors lost their homes and everything they owned. Rudbeck's botanical garden as well as Spole's astronomical observatory on top of his house were also lost in the fire.

After recovering from this disaster, another one threatened. In 1710 the plague hit Uppsala. The University was closed, and people moved to the countryside. To some of them this gave a possibility for scientific reflection. One of them was Eric Benzelius, the university librarian. Inspired by the scientific academies established in London, Paris and Berlin he initiated a scientific society in Uppsala the same year as the plague. After some shaky years in the beginning, the society was revived and soon became known as the Royal Society of Sciences. In this forum people from different sciences could meet, discuss and cooperate, irrespective of their positions at the University, or outside it. The Society also started offering a possibility to publish scientific findings in a publication series of theirs, "*Acta literaria et scientiarum Sveciae*".

Politically, the situation in Sweden had for a long time been characterized by a powerful king governing the country with more or less influence from a government and sometimes a parliament. This changed drastically in 1720, after lost wars and economic decline. That year the political power was transferred to the Parliament, while the King was made a symbolic head of the state. This is known in Swedish history as the "Age of Freedom"; it somewhat resembles the situation of

today. Also freedom of speech and freedom of the press was gradually introduced. This would contribute further to creating scientific freedom at the University.

So, because of a long series of events and decisions described above the situation for the University of Uppsala at the beginning of the 1720s may be said to be promising. There was still hardly any scientific research but the possibilities for such activities had opened up. And the Enlightenment was approaching. It was at this moment that Anders Celsius entered the university life.

## **2.2 Father's parents: The quarrelling astronomer and his wife**

Anders Celsius' ancestors were more or less prominent persons at the University of Uppsala, and all of them devoted themselves to astronomy. Nevertheless, they were quite different personalities, and their lives developed quite differently.

Anders Celsius' grandfather on his father's side was Magnus Celsius, the first in a long row of university teachers in the Celsius family. A painting of him is shown in Figure 2-3.

Magnus Celsius was born in 1621 in a village some 200 km north of Uppsala. The name of his home as a child, the vicarage of Högen [The Hill], inspired him to adopt the family name of Celsius, from the Latin word for hill. In 1641 he became a student at the University of Uppsala. His interests were wide, including both astronomy and history.

In 1665 Magnus Celsius was appointed temporary professor of astronomy at the University of Uppsala, and three years later professor of mathematics. At that time these subjects were overlapping to a certain extent. In parallel he held a position at the National Board of Antiquities, where he studied rune stones. He also acted as an instrument maker, copper engraver and architect. Thus Magnus Celsius was a many-sided person. In this respect he was similar to his contemporary professor of medicine, Olof Rudbeck the elder, for whom he engraved several figures of the human body for publishing. Rudbeck, too, among other things, had astronomical interests; on the top of his anatomical theatre on the



*Figure 2-3. Magnus Celsius, university teacher, grandfather (father's father) of Anders Celsius. Painting by unknown artist 1661.*

roof of the University building he built a remarkable sun dial, still to be seen.

One of the teachers of Magnus Celsius, Bengt Hedraeus, had a small astronomical observatory built on the roof of his house, but died just before it was ready for use. Inspired by him, Magnus Celsius built a small observatory on the roof of his own house, but he does not seem to have used it very much. Magnus Celsius' main astronomical work was an instructive textbook on chronology and calendars, for which he was awarded a sum of money by the King. He also issued a few almanacs for the public.

Magnus Celsius seems to have been a person who did not easily give up. According to one of his children he always tried again and again

to solve a task he had taken upon himself, even if it seemed too difficult. Being stubborn like that might be an advantage when you want to solve a problem. But it might be a disadvantage in relations with people, and he was repeatedly involved in conflicts with persons at the University. Also in this respect he resembled Rudbeck. Apparently both Rudbeck and Magnus Celsius were strong personalities that had a limited understanding of other people and who lacked diplomatic qualities. Through the years they had a large number of clashes and quarrels with each other.

In 1677 Magnus Celsius was made vicar of the parish of Gamla Uppsala [Ancient Uppsala]. The church there was (and is) part of the original cathedral of Uppsala, erected in the 1100s close to three mighty pre-Christian burial mounds. However, because of the continuing land uplift after the Ice Age this place could no longer be easily reached by boat. Hence a new Uppsala was founded in the 1200s further south at a better harbour locality, and a new cathedral, the present one, erected there. Magnus Celsius' time at Gamla Uppsala was short; he died in 1679. He is buried there and his grave became the Celsius family grave.

Magnus Celsius' wife, and Anders Celsius' grandmother on his father's side, was Sara Figrelius. She was born in 1638. Magnus Celsius and Sara Figrelius married in 1657, when he was 36 years old and she was 19. She was a younger sister of Edmund Figrelius (later Gripenhielm), a professor of history in Uppsala, a teacher of King Carl XI, and a poet. Unfortunately, as is usual at this time, not very much is known about Sara Figrelius herself. She lived a long life and died in 1720; she survived her husband by no less than 41 years.

Sara Figrelius and Magnus Celsius had four children who became adults, one daughter and three sons. The oldest of them was Nils Celsius, Anders Celsius' father.

### **2.3 Mother's parents: The quiet astronomer and his wife**

Anders Celsius' grandfather on his mother's side was Anders Spole, also a university teacher, but a completely different personality. A painting of him is shown in Figure 2-4.



*Figure 2-4.* Anders Spole, university teacher, grandfather (mother's father) of Anders Celsius. Painting by Georg Burghard 1697.

Anders Spole was born in 1630 in a small village in southern Sweden. In 1652 he became a student at the University of Greifswald on the German Baltic coast, at that time belonging to the Swedish realm. Three years later, in 1655, he moved to the University of Uppsala, studying mathematics, astronomy and other subjects. He also studied navigation and fortification some time in Stockholm.

While in Uppsala, Anders Spole was employed as a teacher for the sons of a noble-man south of Stockholm. After some years he was given the opportunity to make an international study tour together with the sons. This was an opportunity of decisive importance for him. He started his study tour in 1664. A private report of his allows us to follow him on his tour.

Anders Spole first sailed across the North Sea to the Netherlands. There he visited Amsterdam and the university city of Leiden. He met the famous physicist and astronomer Christiaan Huygens and the leading cartographer Joan Blaeu. Spole then left for England, crossing the English Channel. Arriving on the coast there he stopped. He spent one week with the people at the coast trying to learn the English language reasonably, an ambitiously rapid course of learning indeed. He then proceeded to London and the university city of Oxford. Here he met the famous physicists Robert Boyle and Robert Hooke. Probably he spoke Latin with them rather than English.

From England Anders Spole crossed the English Channel again to go to France. Arriving on the coast he started walking to Paris. He arrived after one week and a half. In Paris Spole stayed for nearly three years, from 1664 to 1667. He spent these years giving private lectures in navigation and fortification for a large number of students from different countries. Obviously his teaching was too popular, because the French tried to prevent him from doing it. However, one of Spole's pupils was a member of the French Parliament, and he persuaded the King of France, Louis XIV, to grant Spole the right to continue his lecturing!

After his long stay in France Anders Spole left for Italy, this time probably by horse. There he visited Rome and the university city of Bologna. He met, among others, the astronomer of Queen Christina, the scientifically interested Swedish queen who had abdicated and moved to Rome. A voyage to Sicily was included to allow a look at the volcano of Etna. The plan then was to meet the Dutch ambassador and his wife to continue with them to Constantinople. This, however, was prevented by an earthquake killing both the ambassador and his wife. Instead Spole went back to Paris, from where he returned to Sweden. In his luggage he brought books which he had acquired during his long tour; some of them are still to be found in the University's collections in Uppsala. Two generations later his grandson, Anders Celsius, would make a similar study tour.

While Anders Spole was abroad, the King had decided to establish a university in the south of Sweden, in the part of the country that had recently been conquered from Denmark. This was the University of

Lund. It was inaugurated in 1668, soon after Spole had returned. Spole was now appointed its first professor in astronomy, largely on the basis of his merits following from his teaching in Paris. However, as a matter of fact, he had never formally completed his own studies!

While in Lund, Spole received a special commission, in 1671. Together with Ole Rømer from the University of Copenhagen, he assisted Jean Picard from the Observatory of Paris when making a scientific visit to the small island of Ven (Hven) at the entrance to the Baltic Sea. The intention was to visit the ruins of the once important observatory known as Uranienborg, founded by the Danish astronomer Tycho Brahe. Using observations of stars and of Jupiter's moons, Picard together with Rømer and Spole determined as accurately as possible the differences in latitude and longitude between the ruins of Uranienborg and the Observatory of Paris. The same year, perhaps in connection with this, Spole made himself a special wooden box to keep documents and other things in, beautifully carved and painted, showing his name and the year. It is still preserved; see Figure 2-5.



*Figure 2-5.* The decorated wooden box made by Anders Celsius' grandfather Anders Spole in 1671.

Some years later a war between Denmark and Sweden forced the University of Lund to close for a time. However, Anders Spole got an opportunity to move back to Uppsala: In 1679 he was appointed professor of astronomy of the University there. He was now married, and moving a long way to Uppsala by horse and carriage was probably not easy for the family. He and his wife had recently lost their home and almost everything they owned in the war, they had several small children and the youngest child was but a baby. Moreover, soon after arrival the baby died. In Uppsala, where he had lived as a student, he now settled with his family for the rest of his life.

Like Magnus Celsius, Anders Spole built a small observatory on the roof of his house in Uppsala. Being a skilled glass cutter he also made astronomical instruments for use in his observatory, where he trained his students. Spole's main astronomical work was a comprehensive textbook in two parts for use among the students, dealing with practical as well as theoretical aspects of astronomy. His teaching, like elsewhere, concentrated on practical applications like positioning and timing, and their use in mapping, navigation and chronology.

During Anders Spole's first year in Uppsala he was, as mentioned in Section 2.1, approached by a young student who wanted to submit a dissertation in astronomy for oral defence. The young student was Nils Celsius, son of Magnus Celsius and later father of Anders Celsius. Spole approved, but it turned out that the Church did not; the student had openly questioned the distribution of power between religion and science. A sharp conflict with wide implications arose; we will deal with this drama in the next section, when meeting Anders Celsius' parents.

The most sensitive matter in relation to the Church was the position of the Earth in the Universe. The Bible, like astronomers during Antiquity, placed the Earth in the centre of the Universe, while a steadily increasing number of astronomers since the days of Copernicus placed the Earth in an orbit around the sun. Anders Spole watched his words and showed a talent for diplomacy. In his written works he carefully avoided any conflict with the Church by expressing himself vaguely. In his private lectures, on the other hand, he spoke freely in favour of the scientific view. But science could appear doubtful also to scientists



themselves. When Newton's theory of gravitation appeared later, Spole found it too strange to accept it.

Every year during his professorship Anders Spole calculated and issued an almanac for the public. These almanacs were quite popular. But there were competitors, translated almanacs issued by foreign astronomers. Spole was irritated by errors he detected in such almanacs. One year a solar eclipse was predicted that never occurred, another year Easter day was calculated to occur one week too early. This caused confusion among people. Spole's complaints led the King to decide, in 1686, that henceforth all Swedish almanacs had to be approved by the astronomy professor at the University of Uppsala. So from now on the contents of the almanacs lay firmly in the hands of Spole himself.

Towards the end of his professorship, in 1695, Anders Spole received a special commission, as mentioned in Section 2.1. Together with his colleague Johan Bilberg, former professor of mathematics, he was ordered by the King to carry out a scientific expedition to the Arctic Circle, a novelty at that time. The original purpose was to investigate the midnight sun; other purposes like positioning, gravity and magnetism were added later. The expedition started at the end of May. Bilberg gives an illustrative account of their travelling problems:

"In the north we were hindered by snow and ice, and had several rivers and sounds to cross, some of them quite wide. Since there were mostly no ferries one was compelled to put horses and coaches into two boats tied together, two wheels in each boat. ... The bays of the sea were still covered by thick ice, and the spruce branches showing the winter road were still there, but since the ice no longer was connected to the land nobody dared to cross the bays."

After two weeks they reached Torneå (Tornio) at the northern end of the Gulf of Bothnia, close to the Arctic Circle.

The main purpose of the expedition was to investigate the refraction of sun light in the atmosphere. It had been noted that the midnight sun could be observed even south of the Arctic Circle, at Torneå, because of this phenomenon. However, the scientific results of the expedition must

be considered a failure. The instruments were not accurate enough, and the time spent there was too short. On the other hand, this was the first scientific expedition in the Nordic countries. As such it was of importance, its aim was relevant, and you learn from your mistakes. Two generations later Anders Spole's grandson, Anders Celsius, would perform another and more successful expedition to the same area.

Anders Spole, in contrast to Magnus Celsius, seems to have been a quiet person. One gets the impression of someone who tries to be diplomatic, without abandoning his convictions or cutting himself off from those who are close to him. This can be seen in his way of handling his dealings with the Church and in his relations with Nils Celsius through the years (see further next section). According to the university librarian, Anders Spole was good-natured, open-minded and humorous. On the other hand he could react strongly when he felt hurt. The librarian probably knew him well because of a common interest: books. Anders Spole had a private library containing more than 1200 books in a variety of subjects.

During his last years Anders Spole lost his hearing. According to his own account this originated from an accident twenty years earlier, when he and his horse had fallen into a small lake and his ears were filled with cold water. Since that day his ears were buzzing and his hearing gradually diminished. In the end he became completely deaf. Anders Spole died in 1699; he is buried in the Uppsala cathedral.

Anders Spole's wife, and Anders Celsius' grandmother on his mother's side, was Marta Lindelius. She was born in 1650. Anders Spole and Marta Lindelius married in 1669, when he was 39 years old and she was 19. Unfortunately, as with Anders Celsius' other grandmother, not very much is known about Marta Lindelius herself. She lived a long life and died in 1726; she survived her husband by 27 years.

Marta Lindelius and Anders Spole had nine children, six daughters and three sons. As mentioned above, one of them died as a baby. The oldest of the children was Gunilla Spole, Anders Celsius' mother. The youngest one was born more than 20 years later.

## 2.4 Father and mother: The unhappy astronomer and his wife

Anders Celsius' father was Nils Celsius, also a university astronomer, but one without much success in his life. A painting of him is shown in Figure 2-6.

Nils Celsius was born in 1658 in Uppsala. He studied mathematics and astronomy at the University, with his father Magnus Celsius as his main teacher. In 1679 he had a dissertation in astronomy completed and wanted to defend it orally. Up to now things had apparently worked well, but at this moment his life turned in a direction that he had not anticipated.

Nils Celsius' dissertation had the title "De principiis astronomicis propriis" ("On the proper principles of astronomy"). Just before he was able to defend it his father died. He then turned to the new professor in astronomy, Anders Spole, to get permission to put it up for public defence. Spole approved, and the dissertation was printed. By this time, as stated in the preceding sections, a tension had gradually built up between the Church and the University. The relation between religion and science had become a sensitive matter, especially concerning the question whether the Earth was in the centre of the Universe or not. In this situation Nils Celsius' dissertation came like a bombshell.

The dissertation stated that astronomical science is based on observations, hypotheses and theories. The observations form the foundations of the science; from these, conclusions must be drawn without prejudice and preconceived ideas. In his dissertation Nils Celsius points out that such prejudice is frequent due to clerical people interpreting the Holy Bible literally. He frankly states that this literal interpretation of the Bible "puts a mask of pretended piety over the truth". This was too much for the theologians. A storm broke out.

The theologians at the University managed to have the oral defence of Nils Celsius' dissertation postponed. Nils Celsius himself was summoned to an interrogation. So was Anders Spole, the responsible professor, but he managed to avoid it by claiming that he had broken his foot! Nils Celsius was ordered to give a written explanation. So he did. Its contents shocked the theologians even more. They stated in an



*Figure 2-6.* Nils Celsius, university teacher, father of Anders Celsius.  
Painting by Jan Klopper 1718.

official document that his explanation was much worse than the dissertation itself! They now required that either the oral defence should be cancelled, or the two most unacceptable pages in the dissertation had to be ripped out; in the latter case the pages ripped out were to be shown to them. Nils Celsius refused, and the public defence was cancelled. This triggered a long-lasting quarrel between different parts of the University, which led the King ten years later to make his important diplomatic decision concerning freedom of knowledge combined with respect for the Church (Section 2.1).

After this battle Nils Celsius was partly frozen out from the University for a long time. Nevertheless, Anders Spole continued to support him, although he avoided questioning the views of the

theologians too much. Already the year after, Spole strongly recommended the university chancellor to award Nils Celsius a royal scholarship he had applied for; he also got it. Otherwise Nils Celsius had difficulties in finding a job. For some years he worked as a temporary land surveyor, partly in the Baltic provinces belonging to Sweden, and later on now and then as part-time lecturer in mathematics, astronomy or Latin at the University.

When in 1699 Anders Spole felt that he was too old and unhealthy to continue his professorship in astronomy, he wrote to the King to inform him about this. At the same time he recommended Nils Celsius, who by then also had married his daughter Gunilla, as his successor. And now even the archbishop supported Nils Celsius! However, in the University Senate (consisting of professors) Olof Rudbeck the elder was still an influential person. Being an old antagonist of Nils Celsius' father he worked against Nils Celsius. At the voting in the Senate another candidate, Pehr Elvius the elder, got one vote more than Nils Celsius, and so the King appointed Pehr Elvius as professor of astronomy. Pehr Elvius later married another daughter of Spole, so Nils Celsius and Pehr Elvius became related by their marriages. But Nils Celsius still had no permanent position and no regular salary. It was by this critical time that Nils Celsius and his wife had two children, one of them being Anders Celsius.

Three years later, in 1702, came the next blow: the great fire of Uppsala. The Celsius family, like many others, lost their home. Nils Celsius faced increasing economic problems, and the family appears to have lived in rather poor conditions.

For many years, Nils Celsius now earned some money by issuing almanacs. In 1705 he happened to make a mistake when calculating Easter day, and got the day one week too late. This to some extent further damaged his reputation. The year after, when he tried to obtain the position of university librarian, he was rejected because of the strange argument that he was too old.

At the same time, Nils Celsius' two younger brothers were more successful. One of them, Johan, was an expert in law and worked as a

judge; he also spent time on writing plays as well as acting. The other one, Olof, was an expert in languages and became professor in Greek and Oriental languages.

After Pehr Elvius had died, Nils Celsius once again applied for the professorship in astronomy, in 1719. This time he was appointed; it was his first permanent position. By then, however, he was more than 60 years old and a tired man. The appointment came too late. After five years, in 1724, he died.

Nils Celsius gives the impression of originally having been a fighter for his freedom but also, to some extent like his father, of having been quite undiplomatic. With the years, all the set-backs in his life, together with the contrast to his more successful brothers, appear to have made him a rather sad person. His life probably turned out quite different from what he had hoped.

Nils Celsius' wife, and Anders Celsius' mother, was Gunilla Spole. She seems to have been a quite independent woman. A painting of her, fortunately existing, is shown in Figure 2-7.

Gunilla Spole was born in 1672 in Lund in southern Sweden. She moved to Uppsala when her father Anders Spole became astronomy professor there. As stated above, her father supported Nils Celsius. Gunilla Spole and Nils Celsius married in 1691, when she was 19 years and he was 33. Together they had two children who became adults: one daughter, Sara Märta, and one son, Anders. In 1702, as mentioned, when the children were quite small, the family lost their home and nearly everything they owned in the great fire of Uppsala. For Gunilla Spole this was the second time; as a young girl she had lost her home in the war with Denmark.

In 1709 two special events must have stirred the feelings of Gunilla Spole. One of her sisters, Anna, married the then astronomy professor, Pehr Elvius. Thus a fourth astronomer was included in the family. And one of her brothers, Andreas, was taken as a prisoner of war in Russia. He managed to flee disguised in sailor's clothes on a ship from the Arctic coast and returned home three years later.



*Figure 2-7. Gunilla Spole, manager of an eating-house, mother of Anders Celsius. Painting probably by Johan Henrik Scheffel c. 1740. (In private possession, see Preface.)*

After the children had grown up Gunilla Spole and her daughter Sara Märta Celsius, Anders Celsius' sister, together ran some kind of restaurant or dining-rooms in Uppsala. This eating-house was located in the small group of houses in Uppsala belonging to Gunilla Spole. They probably acquired raw materials for the food from some of the many university farms around Uppsala. The information about their eating-house is sparse. We know that Anders Celsius himself as a professor had his dinners there. We know that an assistant of his regularly dined there. And we know of a student, not connected to Celsius, who used to eat there. Probably this was a place where both university teachers and students could eat and meet in an informal way. And for the Spole-Celsius family, this might have provided an excellent opportunity to obtain the latest news of happiness and sorrow in the university families as well as news on the university institutions.

Gunilla Spole also gives the impression of being quite well-acquainted with astronomical matters. Remember that she grew up as a daughter of one astronomer, later married another, and finally became the mother of a third! When Anders Celsius as a professor wrote to his mother he could inform her about astronomical instruments without further explanations. And when he built his first observatory it was located in her garden.

Gunilla Spole became very old. She survived her husband by 32 years, but sadly enough also her son by 12 years. She died in 1756, at the age of 84 years.

Looking back we note that Anders Celsius' ancestors were strongly connected to astronomy at the University of Uppsala: His father, his father's father and his mother's father, as well as his mother's brother-in-law, had all been astronomy professors there. On the other hand, they were very different personalities. In addition he had close relatives working in such varied fields as languages, history and law. Moreover, his ancestors showed a considerable mixture of success and failure. All this formed the background to the life of Anders Celsius. And last but not least: His mother was there all his life, sharing with him her knowledge and experiences from her life together with all these astronomers.



### 3. Curiosity and unpaid work: Student and young scientist

#### 3.1 Growing up

Anders Celsius was born in Uppsala in 1701, November 27. As mentioned in the preceding chapter the situation for his family was not very easy at this time. His father was partly frozen out from the University and faced economic problems. Their house burnt down in the great fire of Uppsala when he was one year old. Thereby they lost nearly everything they owned. Apparently much of his grandfather's book collection was saved, however; it was put up for sale the year after, bringing in some money for the moment to the family. As a whole, it seems that Anders Celsius grew up in rather poor circumstances.

Otherwise very little is known about Celsius' childhood. He lived with his family in a re-built house probably similar to those in Figure 3-1. When he was a teenager his parents persuaded him to start studying law rather than mathematics. His parents made it clear to him that it was essential to have a safe income and pointed out to him the sad fate of his father. He obeyed but was not convinced.

During his law studies Celsius met a young man, Samuel Klingenstierna, who also attended the lectures. Klingenstierna, who was three years older, soon found that mathematics was much more interesting and left the law studies for mathematics. Celsius, who felt the same way, followed this example. Obviously he no longer wanted to obey his parents, but succeeded in persuading them to let him go his own way. The two men would later on have a lot to do with each other.

Celsius started his mathematical studies around 1717 with a private teacher, Anders Gabriel Duhre. Duhre gave lectures in applied mathematics at his farm outside Uppsala as well as at the Fortification Office in Stockholm. Celsius visited Duhre at his farm; the mathematical education there was of a comparatively high standard, although Duhre's teaching was hampered by him being very absent-minded. In addition,



Figure 3-1. Typical wooden dwelling-houses in Uppsala built after the great fire; as a young boy Celsius probably lived in a house of this kind. Most houses will have had a backyard with a cow and a pig. Drawing by Johan Gustaf Härstedt around 1780.

Celsius was educated by his father as well as his mother's brother-in-law.

Some lecture notes by Celsius are left from this time. The main ones form a thick manuscript in geometry, neatly written and with a lot of figures beautifully drawn by Celsius; an example is shown in Figure 3-2. Celsius made these lecture notes when he was 16 years old. These are the first documents by Celsius' hand that we know of.

### 3.2 A novelty

After his mathematical studies Celsius turned to astronomy. Around 1719 he started attending astronomical lectures at the University given by his father Nils Celsius as well as by his father's successor, Eric Burman. The mathematical lectures at the University were at a low level so Celsius did not bother much about them. Neither were the astronomical lectures of a very high standard, but they gave additional insight into mathematics.

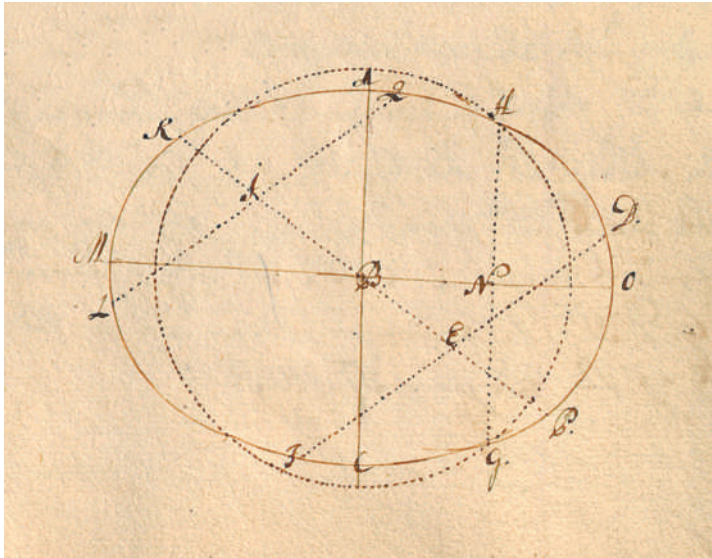


Figure 3-2. A geometrical figure of a circle and an ellipse constructed by Celsius as a teenager 1717.

While Celsius was studying astronomy, in 1722, he started doing some special work as an astronomical assistant at the University. He did not earn any money, but his work was a novelty: He was charged with performing daily measurements of temperature and air pressure, a pioneering work for a young assistant. These kinds of measurements were here introduced for the first time in the Nordic countries. Also winds, cloudiness and precipitation were recorded. Astronomy at that time thus came to include also the study of the Earth, what we today would call geophysics in a wide sense.

Right from the beginning, at New Year 1722, the temperature observations were performed by Celsius himself, sometimes together with Burman. Temperature was not read from one thermometer only but from several different ones, thereby allowing comparison between different instruments and scales. This was an inspiring work for Celsius; see further next section. Celsius' signature from this year is shown in Figure 3-3. From now on scientific weather data were systematically collected, creating one of the longest temperature series in the world.

Also the air pressure observations were right from the beginning made by Celsius, sometimes together with Burman. As with temperature, air pressure was read from a number of barometers. But air pressure did not only change with time as temperature did, it also changed with height. This phenomenon interested Celsius and led him to make his first scientific investigations, starting already during his first year as an assistant. For these investigations he used two nearby vertical constructions of considerable dimensions: a high tower of the cathedral and a deep shaft of a silver mine; see further next section.

Celsius' first scientific findings were reported the same year in the newly founded Royal Society of Sciences. Two years later, in 1724, he was appointed assistant in the Society, and the year after its secretary. As such he, again, did not earn any money, but he was made responsible for issuing their scientific publication series. He spent a lot of effort on this job without any salary. To improve his ability as secretary to correspond with foreign institutions he also spent time practicing French and English.

In 1728, soon after Celsius had completed his astronomical studies, his old friend Samuel Klingenstierna was appointed professor of mathematics. Klingenstierna, however, had already disappeared on an international study tour to learn the more advanced mathematics recently developed in Germany, England and France. Klingenstierna

A photograph of a piece of aged, yellowish paper with a handwritten signature in dark ink. The signature is written in a cursive style and reads 'A. Celsius'. Below the signature, the date 'Ups. d. 20 Dec. 1722' is written in a similar cursive hand. The paper shows signs of age, including some foxing and discoloration.

Figure 3-3. Celsius' signature written in 1722, the first year of his temperature and air pressure measurements.

was, therefore, granted leave of absence to continue his study tour. A stand-in was needed to do the ordinary mathematical lecturing. Who would be able to do that? Celsius! So Celsius was suddenly appointed deputy professor of mathematics. However, once again he did not earn any money. There was simply no salary for the stand-in; the salary went to the ordinary professor!

Celsius by this time was in need of a job where he could obtain some money. It so happened that his old mathematics teacher, Duhre, had started a kind of technical and agricultural institute in Uppsala. Celsius now managed, in 1728, to get a paid job there as a mathematics teacher. He had a lot of pupils, and he also wrote an elementary text-book for his educational courses there.

So, at the end of the 1720s Celsius worked as an assistant in astronomy at the University, a stand-in lecturer in mathematics at the University, and a secretary in the Society of Sciences, all of the positions without any salary. His modest money came from his fourth job, that as a teacher in mathematics at Duhre's private institute. In fact, Celsius lectured in mathematics 7 hours every day. No wonder he was tired and unable to fully do his job as secretary in the Society. In a letter to the former university librarian and the founder of the Society, Eric Benzelius, he writes, in 1729: "I hope that, when Prof. Klingenstierna returns home, which is said to occur this autumn, he will take away half my burden."

In autumn there was still no sign of Klingenstierna returning. Instead something unexpected happened. The fairly young professor of astronomy, Burman, known as a great music lover, suddenly died of a heart attack. Again a stand-in was immediately needed to do the lecturing. Who would be able to do that? Celsius! So Celsius was appointed also deputy professor of astronomy, in this case with a salary. Now Celsius had got a fifth job! When would Klingenstierna return?

### **3.3 Up in the church tower, down in the silver mine**

During most of the 1720s, in addition to the lecturing, Celsius was engaged in the new meteorological observations. He collected data: temperature, air pressure, wind direction and wind force, cloudiness, and precipitation. He compared thermometers, and he compared barometers.

The thermometers used were of different constructions with different scales, such as Hawksbee, Fahrenheit, Réaumur, and later Delisle. When a new thermometer was introduced, it was read together with old ones during a sufficient time span. As a consequence, there was always overlapping between different thermometers, allowing all temperature readings to be reduced to one and the same scale. However, not only did the various scales differ from each other, but also the individual thermometers using the same scale sometimes differed considerably from each other. So, which was the correct temperature? This was a problem that Celsius would return to later in his life.

The barometers also behaved interestingly, but from another point of view. In an almanac which Celsius bought at the end of 1722, we find a special annotation on the first page: "From the observations I have hitherto performed in the tower of the Uppsala cathedral I have found that for one line of mercury falling in the barometer there corresponds 96 feet in height." (For modern units, see below.) Uppsala cathedral, inaugurated in the 1400s, has two impressive towers as shown in Figure 3-4, at Celsius' time slightly lower than those of today. Inside each tower there is a medieval spiral stair case. Celsius thus ascended and descended this stair case with his barometers, reaching a height between 50 and 100 m above the ground, to find out how air pressure decreased with increasing height. This may be said to be Celsius' first scientific investigation; similar investigations along these lines had, however, been made before by others.

Two years later, in 1724, Celsius went to the Sala silver mine, a very deep mine not far from Uppsala, almost as old as the cathedral, to undertake a wider investigation. Here he descended and ascended a mine shaft with his barometers, using a mine hoist (barrel) reaching a depth of nearly 200 m. He found that an increase of 1 line for the barometer corresponded to 106 feet of increasing depth. Thus his result from the silver mine agreed reasonably well with that from the church tower. Transformed into modern units he found that 1 hPa of air pressure would correspond to approximately 10 m in height. Later he made a similar investigation in the huge Falun copper mine, yielding 1 hPa corresponding to 8 m in height, close to the correct value.



*Figure 3-4.* The towers of Uppsala cathedral in which Celsius made his first scientific investigation, of air pressure versus height, in 1722.

Celsius' investigation in the church tower, partly made together with Burman, was, as mentioned earlier, reported in the Royal Society of Sciences. Celsius' investigation in the deep silver mine was published in the Society's publication series, and also in the publication series of the Royal Society of London. This was Celsius' first published paper; he was 23 years old and we can imagine that he was proud of it.

Celsius' studies of air pressure versus height had a possible application, mentioned by him in his paper. Knowing the ratio between

air pressure difference and height difference, air pressure can be measured at both the foot and the top of a hill or mountain and then the height of the hill or mountain can be approximately calculated. Thus air pressure measurements could be used to learn about the topography of a country.

Otherwise, the weather observations in which Celsius took part were published in the form of annual overviews by Burman, until his sudden death. Immediately after that, Celsius took over the responsibility for publishing them; his first meteorological report was for the year 1730. They contained maximum and minimum temperatures for each month, maximum and minimum air pressures for each month, and other remarkable weather characteristics during the year.

### 3.4 Waiting in Uppsala

So, Burman had now died and there was going to be a new professor in astronomy. Who would that be? And when would Klingenstierna return to ease Celsius' burden in lecturing mathematics?

When the professorship in astronomy was advertised as vacant there were five people applying for it. One of them was Celsius, who, as we know, already acted as stand-in. Celsius was probably the most qualified, although his qualifications cannot be said to be very impressive overall. But Celsius had ambitions: He planned to make an international study tour, just like his mother's father had made, and just like his friend Klingenstierna was presently making.

Celsius first had to await the decision of the University Senate. When it came it was unanimously in favour of Celsius. His planned study tour was seen as an advantage. Then he had to await the confirmation of the King. It took some time. In the end, however, it came. In 1730, half a year after Burman's death, Celsius was appointed professor of astronomy at the University of Uppsala. As a consequence of that he left his teaching job at Duhre's institute.

The next thing to do would be to start the international study tour. But this could not be done as long as Klingenstierna had not returned from the study tour he was making. Celsius was still acting as stand-in



for Klingenstierna. If Celsius would leave now there would be neither a professor in mathematics nor in astronomy. That could not be accepted by the University. So Celsius had to wait.

While waiting for Klingenstierna to return Celsius made a new acquaintance. Celsius' uncle, Olof Celsius, the language expert, had met a young man in the remains of the botanical garden. The garden had grown rather wild since the great fire, but Celsius' uncle, who was interested in plants, sometimes took a walk there. The young man he met was a student with a remarkable knowledge of plants but with no money to buy food and clothes; his name was Carl Linnaeus. Celsius' uncle took care of Linnaeus and let him stay with the family. Thus Celsius got to know Linnaeus, who was six years younger. They would have a lot to do with each other later on.

But the main question remained: When would Klingenstierna return? No one seemed to know.

## 4. Out in the world: For or against Newton?

### 4.1 A safe position

Anders Celsius held his inauguration lecture as professor of astronomy at the University of Uppsala in 1730, June 2; he was then 28 years old. A portrait of him as a young professor is shown in Figure 4-1. The title of his lecture was “Astronomiae usus in vita civili”, i.e. “The use of astronomy in civil life”. This reveals an application-oriented attitude that would be characteristic of much of Celsius’ work in the future. Celsius now had a safe position with a permanent salary.



*Figure 4-1.* Anders Celsius as a young professor. Painting probably by Olof Arenius c. 1730.



*Figure 4-2.* Symbolic sculpture (by Knut Erik Lindberg) of Celsius making temperature measurements, and observing the sun in order to find the latitude, in central Uppsala.

Celsius had to stay in Uppsala for another two years before he could carry out his international study tour. During these years he gave lectures on astronomical observations as well as on astronomical mathematics. Especially he taught spherical trigonometry, the kind of mathematics necessary to use for curved triangles on the celestial sphere (the sky) as well as on the globe of the Earth.

Celsius also started on a few scientific works but did not achieve much during these first years. He determined the latitude of Uppsala using the sun, a rather approximate method. He started investigating the apparent fall of sea level occurring in the Baltic Sea. He continued his observations of temperature and air pressure, and he got interested in the northern lights. On the whole, we here notice his tendency to focus on the Earth rather than the Universe, a tendency that would only become stronger with the years. A symbolic statue of Celsius, measuring temperature as well as latitude, can be seen in the centre of Uppsala; see Figure 4-2.

Finally Klingenstierna actually returned from his long tour abroad. This meant that Celsius could stop acting as stand-in lecturer in mathematics and concentrate on his own business. In particular, he would be able to start on his own tour abroad. Before that he still had some duties to fulfil as secretary of the Royal Society of Sciences, among other things arranging a scientific journey by Linnaeus to Lapland in northernmost Sweden. At last, however, in 1732, Celsius was ready to leave.

## 4.2 Via Berlin to Rome

Celsius left Uppsala, probably by horse and carriage, in summer 1732. He was accompanied by two young assistants, Jonas Meldercreutz and Georg Biurman. After two weeks he reached the southern coast of Sweden, according to his private notes written during his journey. From there he was going to take the mail boat across the Baltic Sea to Germany. It turned out, however, that a Prussian prince, the brother of the King of Prussia, was on his way back from Stockholm to take the mail boat across the Baltic. Because of that no mail boat was allowed to leave until the prince had arrived. Celsius had to wait for five weeks! When the ship finally left, the wind blew from an unfavourable direction and the ship landed on the coast of Denmark. After two days at anchor there the voyage continued. Eventually Celsius arrived on the coast of Germany.

When Celsius reached the German coast he arrived in Pomerania (Pommern). In a sense he was still in Sweden because western Pomerania since the Thirty Years War had been a part of the Swedish realm, but linguistically and culturally it was German. Celsius noted that the Low German spoken there was fairly close to Danish and Swedish. In a letter to the former university librarian Eric Benzelius he explains that "I made myself reasonably acquainted with the Low German; I constructed a few rules and then I could easily exchange Swedish for Low German." After a brief visit to the small Swedish-German University of Greifswald he continued southwards. In the autumn Celsius arrived in Berlin, the capital of Prussia.

The journey to Berlin had taken between two and three months, much longer than anticipated. As winter was approaching, Celsius decided to stay in Berlin over the winter. In Berlin he met members of the remarkable family of Kirch. Christfried Kirch was astronomer at the

Royal Prussian Academy of Sciences and head of the Berlin Observatory. His sisters Christine and Margaretha Kirch were active astronomers at the same institute. Both their parents had also worked as astronomers: Their father Gottfried Kirch had been the first head of the Berlin Observatory, and their mother Maria Winkelmann had been an active astronomer there. Thus within the family there were two male and three female scientists! Celsius stayed with a neighbour to the Kirch family, an artist, close to the Observatory.

Celsius was not very impressed by the Berlin Observatory; its scientific equipment was of a modest quality. On the other hand he was impressed by the way it was financed. The Academy of Sciences had been given the exclusive right to issue almanacs (which were calculated by Christine Kirch), and the income from the almanacs contributed to financing scientists, books and instruments at the Academy and its Observatory. Celsius expressed a wish, in his letter to the former university librarian, that "when I, God permitting, come home from my travels, one could obtain the privilege to issue almanacs; in that way I hope that our Society of Sciences could obtain money for a secretary and in addition I could obtain money for building an observatory". He did engage himself strongly in these things when he later returned home.

Celsius found Kirch a pleasant man, "in his character not too much German". They discussed not only science but also science fiction. Celsius had earlier, in his inauguration lecture, speculated about planets around other stars than our sun and about living creatures on such planets. He now found Kirch speculating in somewhat the same direction, imagining that in the future one would be able to travel from the Earth to Mars and other planets, resulting in both commerce and war between the planets.

In spring 1733, after having observed a solar eclipse, Celsius left Berlin to continue his travel southwards. He went via Leipzig to Nürnberg, where he stayed during the summer. In Nürnberg he found nothing of interest, but he spent his time there publishing a special document.

The document Celsius worked on in Nürnberg was a collection of observations of the northern lights (aurora borealis). Celsius had collected more than 300 such observations made by different people,

including himself, during the last two decades. He now had these printed in a publication. His main interest was to encourage others to do the same and, thereby, to find out where in relation to the Earth the northern lights occurred. This was unknown; Celsius in a private note suspected that they might be caused by volcanoes throwing fire into the atmosphere close to the pole. In his publication Celsius makes a general statement revealing his scientific philosophy:

“It will bestow on our century a greater honour to have left true observations to later generations, rather than false hypotheses which can easily be refuted.”

Celsius would spend much of his life producing consistent series of observations useful for future generations of various quantities related to the Earth. This was something that was a novelty at that time.

In summer 1733 Celsius left Germany and continued southwards to Italy. He travelled via Venezia to Bologna, where he stayed over the whole winter season.

In Bologna Celsius met the astronomical family of Manfredi. Eustachio Manfredi was professor of astronomy at the University of Bologna, and his two sisters Teresa and Maddalena Manfredi were also both learned and interested in astronomy. Once again Celsius met female astronomers! And Eustachio Manfredi was in fact not only an astronomer, he was also a well-known poet; he inspired Celsius to take an interest in Italian poetry as well. Astronomically, Celsius took part in Manfredi's determination of the obliquity of the ecliptic, i.e. the inclination of the Earth's orbit to the equator. Celsius also spent some time on an unsuccessful study of the intensity of star light.

But mostly Celsius enjoyed the spirit and culture of Italy. He easily made friends, both among men and women. We get a glimpse of Celsius' private life in Italy through a letter of his to his mother that happens to be preserved. Celsius writes:

“Now I am here in Bologna and I am feeling quite well, much better than I often did in Sweden. This place appeals to me quite a lot and there are many things to buy. I live here, as far as food is concerned, as if every day

were a wedding day. My room, food twice a day, lights and firewood and bed etc. altogether do not cost more than 10 ducats per month. ... The Italians are very polite people towards foreigners. I wish I could exchange Uppsala for this city; in that case I would never leave this place."

Celsius also noted that people there knew nothing about Sweden; "they ask if we have such houses as they have or if we live in tents".

Celsius first stayed with an artist close to one of the churches; that is the room referred to above. Later he rented a room from a Signora Barbara. The latter hostess apparently appreciated the company of Celsius; after he had left she sent him several letters.

While in Bologna Celsius was fascinated by a mysterious text on an old Roman tombstone, commemorating two persons. The text is enigmatic, like a riddle. Inspired by this unusual tombstone Celsius wrote a short and tragic love story as a possible solution to the riddle. This dramatic love story is still preserved among Celsius' papers left at his death; see Appendix.

In spring 1734 Celsius left Bologna and continued to the southernmost point of his long tour. This was Rome, the capital of the Papal States, where he stayed during the summer.

In Rome Celsius was welcomed and taken care of by Giannantonio Da Via, one of the Pope's cardinals. Da Via had a profound astronomical interest. He lent Celsius two fundamental instruments, a quadrant for measuring angles and a pendulum clock for measuring time. At Da Via's home Celsius had the opportunity to observe a solar eclipse. Da Via also presented Celsius to the Pope, Clemens XII, then 82 years old. The Pope let Celsius use one of his palaces for observations, and even had some of the windows there expanded to facilitate these observations.

A glimpse of Celsius' impression of Rome is given in a private letter from him to a cousin of his, Magnus Beronius:

"I have now been here in Rome for a month, and plan to stay here over the summer. The present Pope is very polite towards foreigners and likes

speaking to them. ... I now use a part of my time to study the Roman antiquities which I originally had never intended to do. ... This Italian climate is fully according to my temperament. If things were different I would like to stay here for several years. ... But carriage and horses are here expensive; every time I use a carriage I have to pay 12 pauli, and without a carriage you cannot manage since this city is enormously large."

But Celsius had a negative impression of many clerical people; "monks and abbots are useless people, walking about in the streets, flirting, talking news at the coffee houses."

Celsius had now been away from home for two years. He had experienced other cultures, and he had met a lot of people. However, neither in Germany nor in Italy had he come into very much contact with scientific research; astronomy there turned out to be on the same low level as in the Sweden he had left two years ago. The scientific benefit of the tour so far was hardly noticeable. Something had to be done. But what?

### **4.3 In Paris: A turning point**

Celsius now decided to leave Italy for France. At the same time he wrote to the University of Uppsala to get extra money and extra time for extending his study tour. In summer 1734 he left Rome together with his young assistants Meldercreutz and Buirman, as well as Francesco Algarotti, later a well-known Italian author of books in popular science. They went to Genova on the Italian west coast, from where they took the boat to Antibes on the south coast of France. From there they travelled by horse and carriage to Paris. Here Celsius stayed for nearly one year. Several decades later, Algarotti still told about his memories of the scientific discussions with Celsius.

In Paris Celsius stayed with the mother and sister of Joseph Nicolas Delisle, a French astronomer who some years earlier had moved to St. Petersburg. The interesting point here is that both Delisle's mother and sister were scientifically minded and interested in astronomy. Thus Celsius once again had come across female astronomers! In a letter to Kirch in Berlin he writes: "I begin to believe that it is my destiny that all



astronomers I have the honour to know during my travel have their learned sisters." One generation later another Uppsala astronomer, Bengt Ferner, travelled in Europe and came to visit Delisle and his sister; Ferner, thereby, writes in his diary:

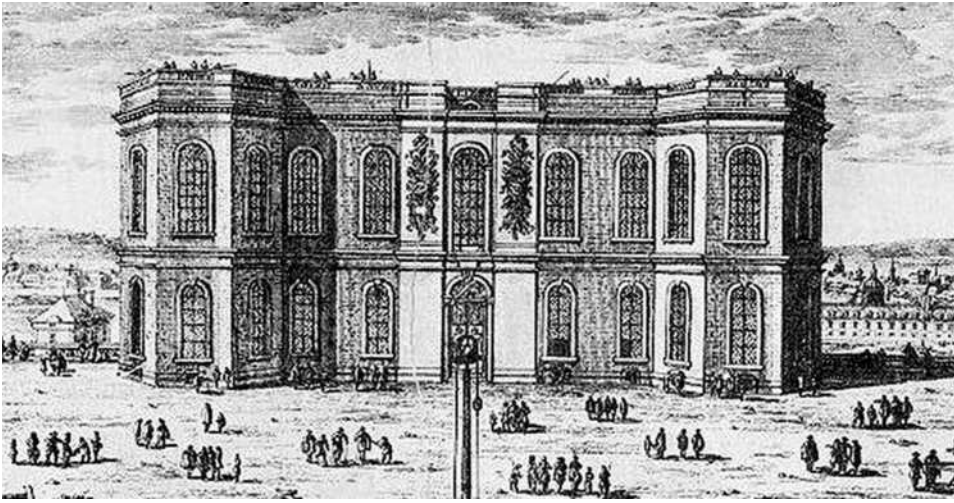
"I there met his sister, who had been acquainted with the late Prof. Celsius. The old woman talked about him with ecstasy ... It is extraordinary how Celsius has been able to just fascinate people into loving him."

On the whole, one gets the impression that Celsius was a person who easily made friends with other people, both men and women.

Celsius' arrival in Paris turned out to be a turning point in his life. Not only were there the Royal French Academy of Sciences and the associated Paris Observatory, both having scientists far ahead of anything he had encountered in the rest of Europe, but also Celsius happened to arrive at the right moment, jumping into a scientific debate with far-reaching consequences.

The situation was the following. In England the famous mathematician and physicist Isaac Newton had, based on his theories of gravitational and centrifugal forces, arrived at the conclusion that the Earth must be a body somewhat flattened at the poles. In France the head of the Paris Observatory, Jacques Cassini, had, based on measurements along the Earth's surface across the country, arrived at the conclusion that the Earth must be a body somewhat flattened at the equator, thus contradicting Newton's theories. The shape of the Earth seemed to be a key to accepting or rejecting the theories of Newton. Who was right?

Newton's theories were still questioned, or at least not understood, by many scientists. Jacques Cassini as an astronomer and geodesist relied more on his own measurements, forming the basis of a planned map of France, than on Newton's abstract theories. Cassini's father Jean Dominique Cassini had been the founder of the Paris Observatory, Jacques Cassini himself was now its head, and Cassini's son, César Francois Cassini, was just about to start his career at the Observatory, later also becoming its head. The Cassini family was an important astronomy family in France. However, within the Academy of Sciences



*Figure 4-3. The Paris Observatory during the time of Celsius.*

there had recently grown an opposition against the Cassinis, in favour of Newton. This group was led by Pierre Louis Moreau de Maupertuis, a free-thinking physicist of a somewhat similar kind as Celsius.

After Celsius had arrived in Paris he was invited to visit the meetings of the Academy of Sciences, and he did so regularly. He also visited the Paris Observatory which made a great impression on him; the building itself was similar to a palace, as shown in Figure 4-3. In the Academy meetings the controversy on Newton's theories was a frequent subject, to which Celsius listened with interest. A method to settle the question would be to make measurements on the Earth at maximally separated latitudes, instead of only within France. In February 1735 the Academy decided, after approval of the King, Louis XV, to send a scientific expedition to the equator, to Peru (today's Ecuador) in South America. The data from there could then be compared with those already obtained in France, thereby hopefully bringing a solution to the problem. Three months later the expedition left.

After that things happened quickly for Celsius. The following month, in June, Maupertuis proposed that a similar expedition should be sent as far north as possible. Celsius, remembering the attempt of his mother's father, immediately suggested that the expedition should go to

northern Sweden, to the northern end of the Gulf of Bothnia, close to the Arctic Circle. Maupertuis agreed, and the Academy once again, after the approval of King Louis XV, decided to send a scientific expedition to solve the problem, this time to the Arctic Circle, to Sweden (today's Sweden and Finland). The expedition would be headed by Maupertuis. And Celsius would become a member of the expedition!

According to the plans the expedition would leave for Sweden the next summer. New high-quality instruments were needed for this purpose. Celsius was now charged with the task of ordering some of these instruments in London. After they had been built there he would bring them to Sweden.

So, suddenly Celsius found himself engaged in a French scientific project of international interest, to be carried out in his own country! One can imagine that his self-confidence grew considerably through this.

By now it was also time for Celsius to start thinking about his own work in Uppsala after the expedition. Inspired by what he had seen and heard in Paris, Celsius had asked the University of Uppsala for money to buy a high-quality quadrant and some other instruments in Paris for use at home on his return there. The quadrant was an instrument for accurately measuring vertical angles. This caused considerable debate among the university people in Uppsala. Celsius complained in a letter to the former university librarian that "they as usual make 100 difficulties". In the end, however, the money was granted and Celsius could order the instruments while still in Paris. In a letter from Celsius to his mother, the only preserved one from Paris, Celsius writes:

"I am happy I have been allowed to order the quadrant; it will be ready in the month of August. It was satisfying that I succeeded in that matter; I started to doubt it at the end."

Then he adds: "It is quite difficult to have to leave Paris."

Some worries concerning people close to Celsius may also be noticed in his letter. Obviously his mother had been ill, always a great difficulty at that time: "I am sad to hear that dear Mother is not quite well; there is no other remedy for it than patience, since the medics could

do very little or nothing about it." Also, of his two assistants there was apparently some problem with one of them: "Meldercreutz should by now already have talked to dear Mother in Uppsala. It is nearly two months since he left here in a great hurry." On the other hand, "Buurman is still with me and I intend to let him accompany me on my journey [to London] since it is sad to travel alone." The year in Paris had come to an end, once again it was time to leave.

#### **4.4 In London: Preparing for the north**

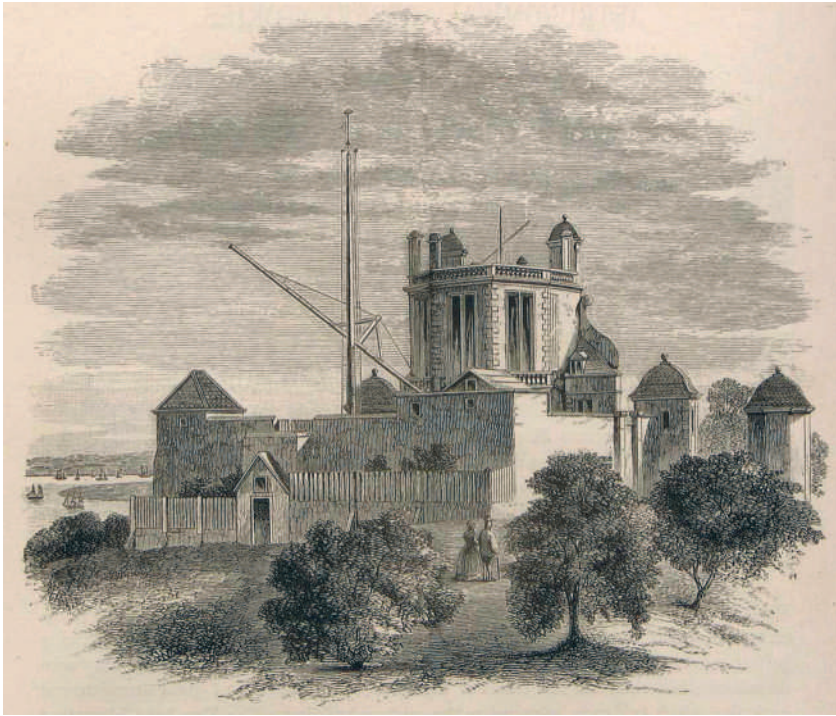
In summer 1735 Celsius left France for England. After crossing the English Channel he went straight to London.

Arriving in London Celsius went to stay with Cromwell Mortimer, a medic and secretary of the Royal Society of London, the British Academy of Sciences. Mortimer in London thus had a similar position as Celsius had in Uppsala, although the Society in London had a much larger activity. As in Paris, Celsius was invited to visit the meetings of the Society, and so he did. During the summer months, when no meetings were held, Celsius spent time learning to speak the English language.

In London Celsius did not encounter any female astronomers. But in a letter to his cousin he writes cryptically: "In a big city like London you can very well be unmarried."

On the street where Celsius lived he often visited the home of George Graham, a skilled scientific instrument maker. It was from him that Celsius now ordered the instruments for the French expedition to Sweden. Later on he also ordered instruments for his own use in Uppsala. In addition to Maupertuis in Paris, Graham in London would be one of Celsius' main scientific friends during the years to come.

Celsius of course also visited the Observatory connected to the Society, the Greenwich Observatory close to London; see Figure 4-4. Here he met Edmond Halley, the renowned Astronomer Royal, head of the Observatory. Halley was then almost 80 years old but still going strong; according to Celsius he was as cheerful as a man one generation younger. In one of his letters to the former university librarian Celsius lets us know a little about their contacts: "I have been to Dr. Halley in



*Figure 4-4.* The Greenwich Observatory during the time of Celsius.

Greenwich; he is still in full vigour, and is very easy to talk to. We meet every Thursday at a coffee house, where we then eat together.”

At the Observatory Celsius also met another important astronomer, James Bradley, later on head of the Observatory after Halley had died. But here language problems made their conversations more difficult. Apparently Celsius had not been able to learn to speak English properly enough and, according to Celsius in his letter, Bradley “can hardly speak Latin and even if he would have been able to, it is still hard to understand their pronunciation”.

In London Celsius, together with Graham, observed a few lunar eclipses. In addition Celsius made some further observations of the northern lights. Interestingly enough he suggests that not only eclipses, as already known, but also the northern lights could be used for

determining longitudes, if observed simultaneously from two different places.

Celsius' years in England and France were, from a scientific point of view, much more rewarding than his years in Italy and Germany. The fact that this was not foreseen when his study tour was planned illustrates the lack of international contacts and knowledge at the small and distant University of Uppsala before the time of Celsius. From a cultural point of view, however, especially Italy appealed to Celsius. And in all the countries Celsius made friends along his journey. But now the scene would change drastically: It was time to go to the Arctic Circle, to wilderness and cold.

#### **4.5 To the Arctic Circle: Stars and ice**

In spring 1736 Celsius crossed the English Channel arriving at Dunkerque. There he joined the French expedition heading for Sweden. There were five scientific members of the expedition. Apart from the leader Pierre Louis Moreau de Maupertuis they were Alexis Claude Clairaut, Pierre Charles Le Monnier, Charles Camus, and Anders Celsius himself. Celsius was the one with practical experience of measurements; the other ones, although mainly physicists, were more theoretically minded. In addition there was an astronomically educated priest and keeper of the journal named Reginald Outhier, an artist, a secretary, and four or five servants. They all went by a specially hired sailing ship to Sweden.

The voyage across the North Sea was rough, in rather stormy weather, and lasted for one and a half weeks. Everybody except Maupertuis got sea-sick. "Mr. de Maupertuis, however, completely kept his coolness, he inspired us with security by showing himself calm, even cheerful" according to Outhier. Approaching Sweden the ship began to heel over considerably due to the strong wind. On the coast of southern Sweden Celsius and Le Monnier left the ship; they had had enough and preferred to go by horse and carriage to Stockholm. The other ones continued with the ship.

When the ship arrived in Stockholm a salute of gunshots was fired. The members of the expedition were presented to the King and the Queen, Fredric I and Ulrica Eleonora. The plan was then to continue with the ship northwards, but this plan had to be abandoned because several members refused to go by ship due to their bad experiences. Only the instruments were sent by ship, together with some of the servants (who either were not in the position to refuse or were less sensitive). Instead the journey continued by horse and carriage; two special carriages were hired, equipped to allow sleeping.

A major stop during the journey northwards was made in Uppsala. Celsius had now been away for four years. When he left he was a young and unknown scientist, when he returned he did so together with a group of world-leading scientists from France! The members of the expedition were shown the University and the cathedral. The governor's palace was still a ruin since the great fire, but from the hill where the palace was situated they had a nice view over the whole of Uppsala. Nearly all houses were wooden houses with roofs covered by grass. According to Outhier, Uppsala as seen from above looked like a huge garden. In the evening they were invited to a dinner at the home of Celsius' mother, Gunilla Spole. This was no doubt a touching moment. Imagine Celsius' mother giving this dinner for her son whom she has not seen for four years, now returning in company with French scientists and heading for the Arctic Circle to prove or disprove Newton's theories!

When the expedition members left Uppsala they faced a two-week-journey to the north. As with Celsius' grandfather 40 years earlier the main obstacle was the passages of the large rivers. Some of them now had ferries, but even the largest river still had to be crossed in the old-fashioned way using double rowing-boats. Outhier describes this in his journal:

“There was a strong wind and the boatmen said it would be wise not to stay in the coach during the crossing. They put together two boats and tied them strongly to each other. They had the coach with its two larger wheels roll on planks into the boat farthest from land, and after that they in the same way put the two front wheels into the other boat. Then they rowed across the river, but the wind caused a lot of trouble, catching

hold of the coach. After the coach had been put ashore on the other side they returned and fetched us. The whole procedure took nearly 3 hours.”

At midsummer the expedition arrived at Torneå (Tornio), the tiny town at the northern end of the Gulf of Bothnia, close to the Arctic Circle. An unforeseen language problem immediately turned up: The population outside the town did not speak Swedish, but Finnish and Sami. Celsius did not understand these languages. Fortunately there happened to be a young educated man in the town, Anders Hellant, who knew all the relevant languages, including French. He was now included in the expedition as an interpreter. He turned out to be a most useful person; in reality he would not only act as an interpreter but also as Celsius’ assistant, taking part in the measurements.

The main task for the expedition was to find evidence for or against Newton’s theories, by finding out whether the Earth was flattened at the poles or not. To do that the expedition would perform a meridian arc measurement. This meant that they would determine the distance as well as the latitude difference between the end points of a meridian arc, and then compare the result here in the north with a corresponding result from an arc in the south, in France or at the equator. For an Earth flattened at the poles a meridian arc of a certain latitude difference, say  $1^\circ$ , will be longer, in metres, closer to the pole, because of the smaller curvature there, and shorter closer to the equator, because of the larger curvature there. For an Earth flattened at the equator the relation will be the opposite. Moreover, the expedition would perform a gravity measurement with the same purpose, but we will come back to that later.

The latitude difference of the meridian arc may be found by determining the latitudes of the end points through observations of stars. What is observed is the altitude or height angle of the star above the horizon.

The distance between the end points is too long to be measured directly; it may be found using a method known as triangulation. A comparatively short distance, a baseline, is measured with rods. Then horizontal angles are measured in a network of triangles, the sides of the triangles being sight lines between stations on hills and mountains, all



the way from the southern end point to the northern one. Included in this network are the end points of the baseline. Using (spherical) trigonometry, the distance between the southern and the northern end points of the meridian arc can be computed from the length of the baseline and the angles in the triangulation network.

Thus there were three kinds of measurements to be carried out: Length of the baseline, horizontal angles in the triangulation network, and vertical angles of stars for latitude determinations. The instruments to be used were the ones especially made for the purpose in Paris and London.

The expedition, after lengthy discussions, now chose to measure a meridian arc generally following the Torne river, running from north to south and discharging itself at Torneå at the innermost part of the Gulf of Bothnia. The southern end point would be Torneå church and the northern end point the mountain Kittisvaara, almost  $1^\circ$  or about 100 km to the north.

The star observations required dark nights. Since it was midsummer with midnight sun when the expedition arrived, the star observations had to wait until autumn. The length measurements with rods required a flat surface. The optimal solution to that was to use the ice on the Torne river; hence the length measurements had to wait until winter. Consequently one started with the horizontal angles in the triangulation network.

First of all, hills and mountain tops along the river valley were explored to select stations for the angle measurements in the triangulation. As soon as possible after that the angle measurements themselves started; there were 11 stations involved as shown in Figure 4-5. All this was complicated work. People and instruments were transported northwards from Torneå in 7 small boats on the river, in some places forming wild torrents. Then they had to walk for many hours uphill through swamps and forests, attacked by hoards of mosquitos. During two summer months of angle work the expedition members lived in tents in the wilderness. Here and there they met Sami people with their reindeers. Maupertuis writes:

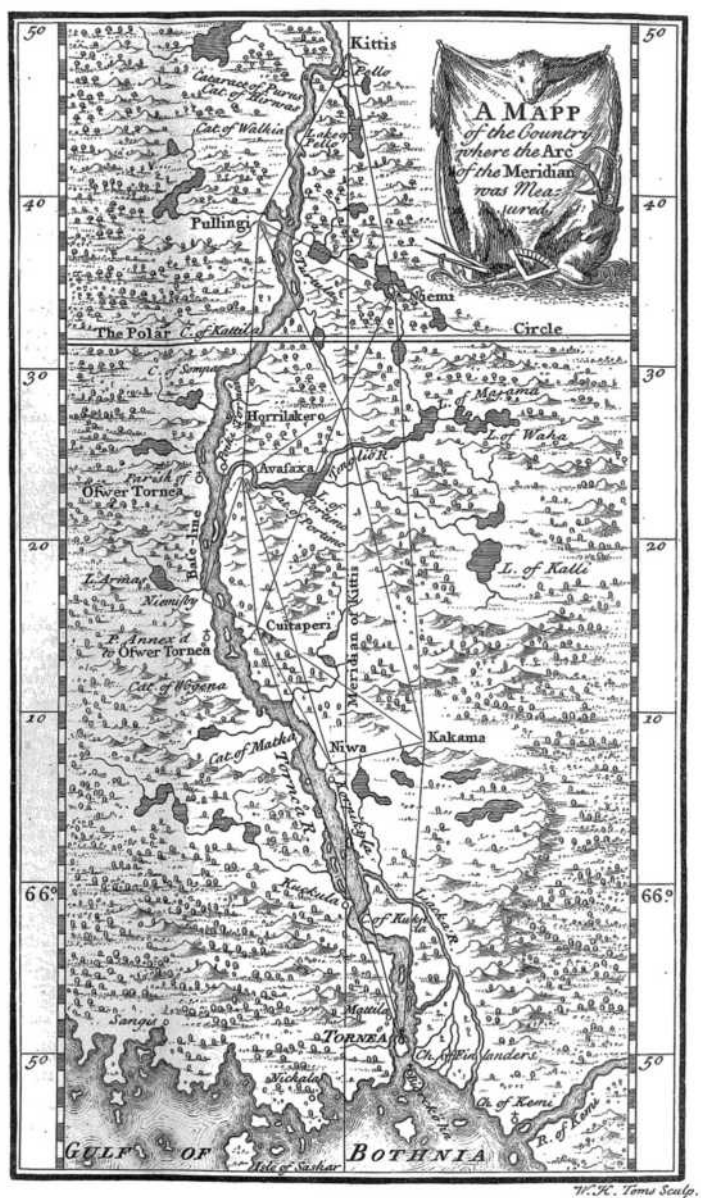


Figure 4-5. Map of the triangulation network of the arc measurement expedition to the Arctic Circle. (Due to disturbing effects of the planets the Arctic Circle has moved northwards by 2' or 4 km since then.) From Maupertuis' book 1738.

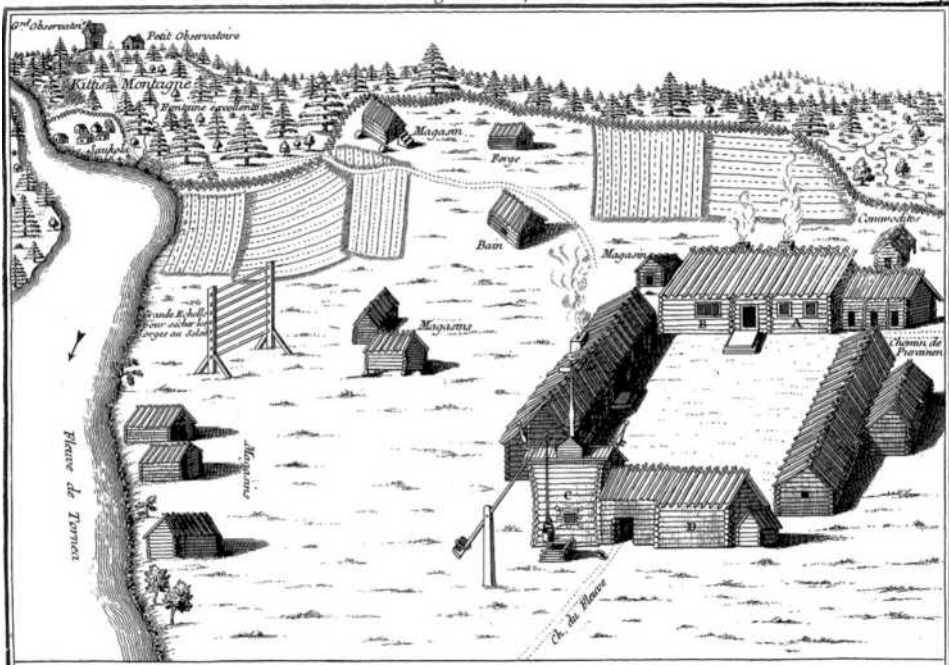


Figure 4-6. The northern end point of the arc measurement, Kittisvaara mountain with observation huts, as seen in the background from the village of Pello. In the foreground is shown the building housing the gravity station. From Outhier's journal 1744.

“For a month past we had been inhabitants of the deserts, or rather of the mountain's tops. The earth or rocks, spread with the skin of a reindeer, had been our beds, and our food chiefly fishes that the Finns brought us, or which we ourselves had caught, with some sort of berries or wild fruits that grew in the woods.”

In autumn two small observatories for star observations were built, one at Torneå church and one on Kittisvaara mountain, the two end points of the meridian arc; see Figures 4-6 and 4-7. Then the star observations commenced. Again people and instruments were transported in small boats on the river with its dangerous torrents. This time no less than 15 boats were required, with skilful boatmen who got well paid. The star observations were first performed at the northern end point. After that everybody went by the boats back to Torneå. There the

star observations were performed in the same way at the southern end point.

In winter the baseline was established on the ice of the now frozen Torne river. The length of the baseline was measured by calibrated rods or poles. In this case people and equipment were transported by horses and sledges. There was now midwinter darkness nearly all the time, but twilight in the middle of the day combined with the northern lights and white snow made it possible to carry out measurements a few hours each day. It was now very cold and especially the French found the weather conditions during these measurements hard to cope with. Maupertuis vividly describes their problems:



*Figure 4-7.* The southern end point of the arc measurement, Torneå church, its steeple forming a useful point of sight in the triangulation.

“Judge what it must be to walk in snow two foot deep, with heavy poles in our hands, which we must be continually laying upon the snow and lifting again; in a cold so extreme, that whenever we would take a little brandy, the only thing that could be kept liquid, our tongues and lips froze to the cup, and came away bloody.”

In fact, even the brandy froze a few times!

In spring the following year, 1737, the star observations were repeated. Otherwise most of the time was spent on tedious calculations of the triangulation network as well as of the star observations.

One thing remained: the gravity measurements. According to Newton gravity on the Earth’s surface would increase towards the poles due to the flattening of the Earth there. This was investigated by measuring gravity with a pendulum; its swinging time depends on the value of gravity. The result here in the north could then be compared with a corresponding one in the south, in France or at the equator. The measurements were performed in a house in the village of Pello close to the northern end point; see again Figure 4-6. The house belonged to relatives of Hellant, the interpreter and assistant. They had kindly allowed breaking up the floor in one of the rooms to have a stone pillar there as a foundation for the pendulum.

Celsius took part in all aspects of the above works, and also in some magnetic studies. Maupertuis presents him as “Mr. Celsius, the celebrated professor of astronomy at Upsal, who assisted at all our operations, and whose abilities and advice were of singular use to us.”

Of course everybody in the expedition was eager to know the result as soon as possible. Was Newton or Cassini right? Much of the theory behind the calculations was developed by Maupertuis, concerning meridian arcs, and by Clairaut, concerning gravity. A preliminary result was calculated during the winter. A final result was calculated after all the measurements had been completed, and it confirmed the preliminary one. In the words of Maupertuis:

“The degree of the meridian which cuts the Polar Circle being longer

than a degree of the meridian in France, the Earth is a spheroid flattened towards the poles.”

Cassini was wrong – Newton was right! At least the expedition members were convinced about that. But none of them was allowed to say anything before everybody had returned home and Maupertuis had had the opportunity to present their result officially before the French Academy of Sciences. So Celsius knew, but had to keep silent for some time.

The expedition members had lived in Torneå and its surroundings for nearly one year. Celsius had stayed in a house just to the south of the church where also the small observatory for latitude determination was built. During this year they had made private acquaintances with several of the families in the tiny town. Both Maupertuis and Celsius seem to have been fond of entertaining others with small personal poems; Maupertuis also was a musician and played the guitar. And Clairaut even learnt Swedish during the stay. The most interesting acquaintance was probably Carl Magnus Du Rietz, military commander in the area, and his wife Catharina Horn. Carl Magnus Du Rietz was the only person in the town apart from Hellant who could speak French. His grandfather had been a personal physician to the King of France but had then moved to a similar position to the Queen of Sweden. He himself had been a prisoner of war in Russia for more than ten years, as had also Catharina Horn. The two had met in Russia and got married there. And now they lived in Torneå close to the Arctic Circle, keeping company with a scientific expedition from France!

Celsius also had had time for other experiences. One day he went by reindeer and a Laplander’s sledge, which he tells about in a letter to Mortimer in London:

“I was obliged to pass three miles through a forest, in which there is neither road nor house, in a very troublesome and even dangerous carriage: that is in a small sledge made like a boat drawn by a reindeer. In this vehicle one must be well acquainted with the method of keeping an exact poise, otherwise one runs the risk every moment of breaking a leg, arm etc., when the reindeer runs swift among the trees.”

In Torneå also two sisters, Christina and Elisabeth Planström, daughters of a shop-keeper there, spent a lot of time with the French. Maupertuis wrote love songs to Christina. This would have unexpected consequences, as we will see below.

In summer 1737 the expedition left Torneå. Maupertuis and a few others went by ship, but most of them, including Celsius, preferred horse and carriage. However, the ship turned out to have a leak, and it had to be stranded on the Swedish coast after a few days. Thus also Maupertuis was forced to travel on land. A stop was again made in Uppsala at the house of Celsius' mother and sister. In Stockholm the expedition was once again invited to the King and the Queen. Finally the expedition left Sweden, apart from one person: Celsius, at last, returned home to Uppsala, after five years of travelling. And the King of France granted Celsius an annual pension for his works in the north.

#### 4.6 Was Newton right?

After the French had arrived in Paris, Maupertuis presented the results and experiences of the expedition to the French Academy of Sciences, in autumn 1737. Soon after that, Celsius presented the same results to the Royal Society of Sciences in Uppsala: "Prof. Celsius told that he had recently got a letter from Mr. de Maupertuis, who informs that he already has read to the Academy his observations made in Torneå, and that from these can be concluded that the figure of the Earth is according to Newton's view."

Maupertuis also presented these things in a book, in the name of all the expedition members, including Celsius. The title page of the book is shown in Figure 4-8. Maupertuis wrote not only a French version of the book but also an English one, both published in 1738. In addition Hellant translated a part of the book into Swedish the same year. In the book Maupertuis has included his speeches to the Academy. Here he concludes:

"The length of the arc of the meridian intercepted between the two parallels that pass through the observatories of Torneå and Kittis is 55 023 ½ toises [107 241 m]. The amplitude of this arc being 57'27" [after corrections 57'28.7"], the degree of the meridian at the Polar Circle is

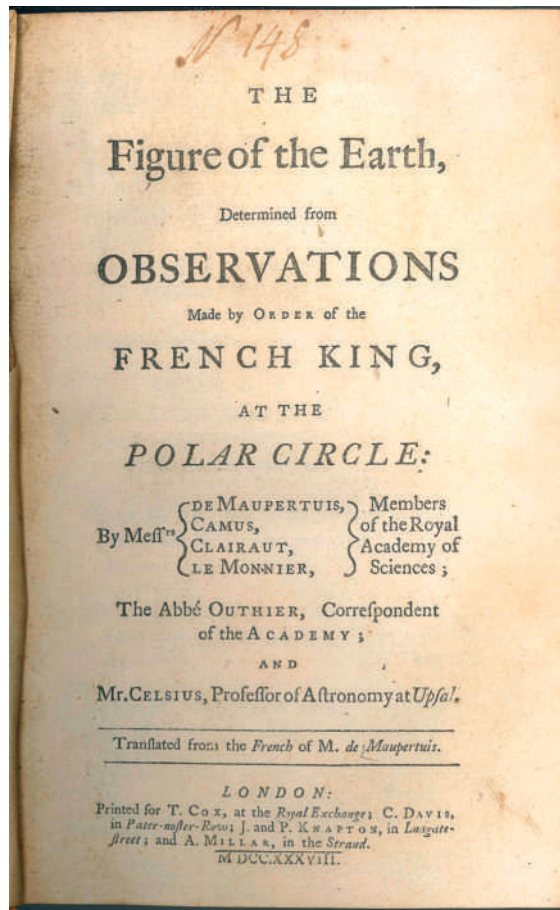


Figure 4-8. The title page of Maupertuis' book on Newton's theories and the shape of the Earth, issued in 1738. Celsius' name is given at the end of the author list.

greater by 1 000 toises [1 949 m] than it should be according to Mr. Cassini. ... Whence it is evident that the Earth is considerably flattened towards the poles."

"I shall say nothing at present of our experiments upon gravitation, a subject no less important than the other. ... Let it suffice to assure whoever has a mind to examine the Earth's figure by the weight of bodies ... that they will find all the experiments we made in the north to that purpose ... will concur in making the Earth flat towards the poles."





Figure 4-9. Maupertuis flattening the Earth at its poles. Note the reindeer at the bottom. Engraving by Jean Daullé 1741.

So, Newton was right – Cassini was wrong! Maupertuis produced a propaganda picture of himself and the flattened Earth; see Figure 4-9. The well-known French author Francois de Voltaire commented that Maupertuis had flattened both the Earth and the Cassinis.

Or maybe it was not that simple? In Paris the Cassini group claimed that some of the measurements at the Arctic Circle were not accurate enough. Others pointed out that the expedition consisted of members being convinced beforehand of getting a result in favour of Newton. And then there were the two young women from Torneå following the expedition back to Paris!

The last sentence needs a brief explanation. After the expedition had left Torneå, the two sisters mentioned earlier, Christina and Elisabeth Planström, decided to follow after the French to Paris, probably longing for both love and adventure. When they arrived in Paris, this caused embarrassment for Maupertuis and a lot of gossiping. It was suggested that the expedition had been too interested in pleasure and women in the north. Further developments, however, were tragic: Christina entered a nunnery and Elisabeth, after a marriage ending in divorce, was sent to prison.

Celsius now became involved in the conflict that had arisen between Maupertuis and Cassini on the quality of the work at the Arctic Circle. Inspired by Maupertuis, Celsius intervened, maybe somewhat too sharply, with a publication to defend their work and criticise that of Cassini in France. Cassini replied, in a more calm manner, to defend himself. In a private letter to the former university librarian in Uppsala Celsius writes: "Nature would be too bizarre if the Earth would have the figure of Cassini." But this was not an argument he used in his publication.

After several years of conflict, Cassini's son and successor as head of the Paris Observatory, César Francois Cassini, remeasured parts of his father's work in France with the new instrument that had been used at the Arctic Circle. The more accurate result thus obtained made Cassini now admit that things were in accordance with an Earth flattened at the poles. Moreover, Clairaut published a book on theory and measurements of gravity showing the same. Hence, in the middle of the 1740s doubt began to weaken: Newton was gradually more accepted.

Why was it so difficult to accept Newton's theory? His theory was an excellent example of a general theory constructed from careful observations. One hundred years earlier the Danish astronomer Tycho Brahe had made a large number of accurate observations of the apparent motions of planets as seen in the sky from his observatory. Using those data the German astronomer Johannes Kepler constructed three basic laws describing the true motions of the planets around the sun (and the moons around their planets). Using these laws Newton succeeded in deriving one fundamental law governing the motion of bodies in space, the law of gravitation. This could then explain a number of other

phenomena, too. So why was it not immediately accepted? Well, the concept of gravitation implies a force acting at a distance, without contact between the bodies involved. This seemed too abstract, in fact it seemed quite occult and mysterious! Moreover, the evidences in favour of Newton could all be questioned in various ways.

First, with his gravitation Newton could explain the way planets moved in orbits around the sun, and moons around their planets, but this could also be explained reasonably by older hypotheses. Second, Newton could explain the tides in the oceans, but this explanation to some extent did not agree with the observations. Third, Newton could explain a special characteristic in the Earth's rotation known as precession, but this was partly dependent on his explanation of the tides which seemed insufficient. Fourth, Newton could explain the Earth's flattening towards the poles, but, as we have seen, this was questioned because of measurements in France; see also below concerning the uncertain value of the flattening. So, to those who felt sceptical already because the concept of gravitation seemed strange, there was much evidence that seemed unclear.

On the other hand, it is remarkable how Newton was able to explain a variety of phenomena with one single force; in this respect his opponents had nothing to put up against him. In the end this would be of decisive importance. When it had become sufficiently clear that the Earth must be flattened at the poles, this strengthened other evidences above. With the flattening in principle accepted according to Newton, also his explanation of the precession of the Earth's rotation could be accepted, since it required a flattening of the Earth at its poles. And with the precession accepted according to Newton, also his explanation of the tides, although somewhat incomplete, could be more easily accepted, since it required a gravitational force from the moon and sun in the same way as the precession did.

Concerning the shape of the Earth there were, however, a few more things to think about. In finding the shape of the Earth from gravitation and centrifugal force Newton had assumed that the Earth behaved as a rotating fluid. This was uncertain, although we today know that it does. Newton also assumed that the Earth was homogeneous, having a constant density throughout. This could definitely be questioned, and

today we know that density increases towards the centre. A possible inhomogeneity of the Earth would influence the numerical value of the flattening.

Imagine an oval (ellipsoidal) Earth flattened at the poles, its radius of the equator being  $a$ , and its distance from the centre to the pole being  $b$ . Thus at the pole a part of the Earth corresponding to  $a - b$  is "missing", in comparison with a spherical Earth of radius  $a$ . The relation of the missing part to the whole radius is known as the flattening  $f$  of the Earth:  $f = (a - b)/a$ . Newton's main point was that the Earth was flattened at the poles, but he also gave a numerical value of the flattening based on his homogeneous Earth:  $f = 1/230$ . This was the value that the French expedition expected to find. If the Earth is denser towards its centre the flattening becomes smaller; today we know that the flattening is  $1/298$ . In the extreme case of all mass concentrated at the Earth's centre the flattening would be  $1/576$ . Thus Newton's value may be seen as a theoretical maximum, as shown by Clairaut. The value obtained by Maupertuis from the meridian arcs in Sweden and France was  $1/178$ . It was larger than Newton's. Something was not quite correct. (In fact, this would indicate an Earth denser towards its surface; in the extreme case of all mass concentrated at the Earth's surface the flattening would be  $1/115$ .)

Let us take a closer look at the results from the expedition to the Arctic Circle. The final latitude difference between the end points was  $57'28.7''$ , and the final distance between the same points 107 241 m. Modern analyses of the results show that a major part of the errors is in the latitude difference, and only a minor part in the distance. The measured latitude difference is too small by 0.25 % ( $8.8''$ ). To this is added 0.07 % ( $2.4''$ ) caused by a geophysical phenomenon unknown at the time of the expedition, namely deflections of the vertical caused by irregular mass distribution within the Earth. The distance, on the other hand, is too large by 0.06 % (65 m). These error figures are not bad but they all happen to go in the same direction; they all contribute to the flattening becoming too large, exceeding the theoretical maximum. In that situation the support of the gravity measurements made by the expedition was useful; the relative error in the gravity value obtained is one order of magnitude smaller.

On the whole, arc measurements in the middle of the 1700s tended to yield more uncertain values of the Earth's flattening than contemporary gravity measurements, although that was not realized at the time. Celsius would soon contribute further in this field by performing a gravity measurement in Uppsala.

So, what was really the outcome of the expedition: Was Newton's gravitational theory right or wrong? One might say that the expedition itself did not manage to solve the problem, but it made the balance finally tip over in favour of Newton.

## 5. At home again: Investigating the unknown Earth

### 5.1 An observatory for investigating the Earth

When Celsius returned home in summer 1737 he had been away for five years, four of them abroad. He had acquired a lot of knowledge and experience during his travels, especially during the one to the Arctic Circle. This would form the basis for many of his ideas during the years to come.

However, first of all he had to resume his ordinary duties as professor at the University of Uppsala and also as the secretary of the Royal Society of Sciences. Lectures had to be given. Publications had to be issued. There was a lot to do immediately. A portrait of him, now somewhat older than in Chapter 4, is shown in Figure 5-1.

While Celsius had been away from the Society its activity had been low. His friend and colleague Samuel Klingenstierna, the mathematics professor, should have acted as stand-in but had hardly done anything. The publication series had not been issued at all. Celsius now rapidly started reviewing and publishing papers that had not been handled during his absence, and inspired people to write new ones. In addition he wrote some papers of his own. Celsius turned out to be indispensable for the Society: When he was away it fell asleep, when he was back again it woke up.

While Celsius had been away from the University, on the other hand, things had kept going reasonably in spite of his absence. The main reason for this was a partly self-educated man named Olof Hiorter, who had acted as stand-in for Celsius. Klingenstierna had avoided to do the stand-in work himself and had suggested Hiorter instead. Hiorter, happy to do it, had given all the necessary lectures during these years. In addition, Hiorter had engaged himself as well for the Society in observations of a rare total solar eclipse over southern Sweden. When Celsius now returned he resumed his lecturing. This led to a tricky question: What to do with Hiorter?



*Figure 5-1.* Anders Celsius after his return from the Arctic Circle. Painting probably by Johan Henrik Scheffel c. 1740, contemporary with the painting of Celsius' mother in Figure 2-7. (In private possession, see Preface.)

Celsius had a lot of scientific ideas and was good at making careful observations, but he did not like tedious mathematical calculations. Hiorter was good at precisely that. As an excellent solution Celsius now turned Hiorter into an assistant of his. Hiorter himself had had a useful student, Pehr Wargentin, a statistical expert-to-be. Celsius made also Wargentin an assistant of his. Like Celsius himself in the early days, none of them, however, had any salary – there was no money for that.

When Celsius returned to Uppsala he also returned to his mother, Gunilla Spole, and his sister, Sara Märta Celsius. Since he had no place of his own to go to he started living with his mother and sister again. As mentioned in Chapter 2, the two women ran an eating-house together

at their home. Celsius as well as Hiorter from now on regularly dined there. A few years later Celsius' sister and Hiorter married.

As also mentioned in Chapter 2, Celsius' mother, being both a daughter and a wife of earlier astronomers, was well acquainted with astronomical matters. So when Celsius wanted to erect a small astronomical observatory in Uppsala as soon as possible, this could be done readily in his mother's garden! The observatory was erected during autumn 1737, at his own expense. Celsius writes in a letter to the former university librarian:

"I have now, since my return home to Upsala, had a small observatory built in my garden. Here I have put up the 3-foot-quadrant [angle instrument] bought in Paris; I also have a good clock, tubes of considerable length and a tube with a micrometer by Mr. Graham in London. With this I can perform all astronomical observations quite well, as they do in Paris. The difference is only that the Observatory in Paris is one of the most splendid palaces in Europe, and my own is just a small wooden hut."

A year later, Celsius started a campaign for having the University provide capital for a full-scale observatory that could replace his "wooden hut" and compete with the "palaces" he had seen abroad. Celsius worked along two lines.

One line was to make the people in the University Senate, of which he was himself now a member, understand the benefit for society of an observatory. Celsius clarified this in a small propaganda publication. There he pointed out four useful purposes: navigation methods, mapping of the country, calendar work, and weather studies. In Celsius' mind the Observatory should be application-oriented and Earth-centred.

The other line was to apply for money step by step, whereby the first step would later make a second step necessary and so on. In doing so, Celsius was to some extent prepared to pay himself in case the University Senate would not do it. According to the first decision of the University Senate Celsius was granted 9 000 daler in copper (a Swedish currency to be explained below) for building the Observatory. According to a second decision 8 000 daler was added to buy an already existing



house instead; the first amount of money was now to be used for rebuilding it. According to a third decision another 5 000 daler was added to pay for new instruments (in excess of the 3 000 daler already spent on the quadrant from Paris). And so on.

The instrument item is of particular interest in order to reveal Celsius' efficient but perhaps not very nice tactics. In a report of his to the University Senate he argues for the additional instrument money in the following way:

“Since at an observatory it is necessarily required to have an accurate pendulum clock, the best clock-maker in Europe, Mr. Graham in London, for use at our Observatory has constructed a clock for 30 pounds sterling [1 200 daler in copper]. ... The same Mr. Graham has taken upon himself the labour to, under his direction, have an instrument known as a sector constructed for 100 pounds [4 000 daler]. ... This instrument has also recently, together with the mentioned clock, arrived in order in Stockholm from London by sea.”

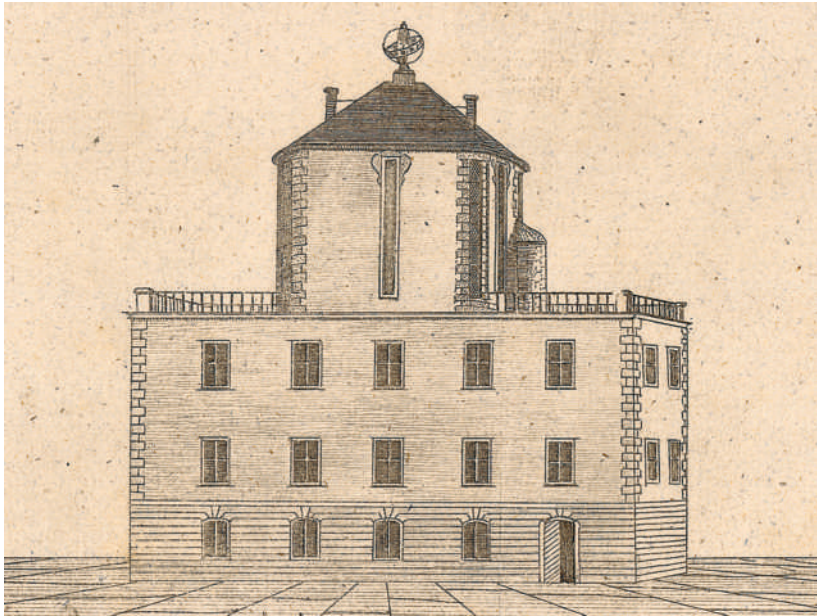
Celsius thus has personally ordered sophisticated instruments from his old friend in London, the instruments have been built, and they have even been delivered by ship to Stockholm. Actually, Celsius had sent a skilled instrument maker in Stockholm whom he supported, Daniel Ekström, as his personal representative to London for the purpose. But not until now does Celsius inform the surprised University Senate about all this! And then the obvious question: Would the Senate like to pay the instruments? In case of no success Celsius had a back-door open: He was prepared to pay himself. In the end, however, the Senate felt that they had to pay, and so they did.

The total cost for the Observatory, including instruments, was a little more than 33 000 daler in copper. Sweden at that time had two parallel currencies, one in silver coins and one in copper coins. To make this sum understandable we may compare it with the contemporary monthly salaries of a sea captain, a mate and a seaman, which was almost 150, 100 and 50 daler in copper, respectively. Thus the cost for the Observatory was equivalent to nearly 20 annual incomes for a sea captain, 30 annual incomes for a mate, or 60 annual incomes for a seaman. A more natural comparison might be with a professor at

Uppsala, but as mentioned in Chapter 2 the salaries of the professors were to some extent dependent on the grain prices. However, there was a kind of standard monthly salary of 175 daler in copper, so the Observatory would have cost the equivalent of some 15 annual incomes for a professor like Celsius.

In Celsius' view all this money was very well used. Celsius' aim with the Observatory was that it should serve the needs of society. It should focus on the Earth; in modern terminology it would become more of a geophysical observatory than an astronomical one.

The erection of the Observatory was performed according to drawings made by the well-known architect Carl Hårleman. The building works had started in summer 1739. Two years later, in summer 1741, the Observatory was completed, painted in a nice yellow colour. The instruments were moved from the small observatory to the new and large one. These instruments included angle instruments, pendulum clocks, telescopes, thermometers, barometers, magnetic compasses etc. The Observatory with its characteristic tower is shown in Figure 5-2.



*Figure 5-2.* The Uppsala Observatory during Celsius' time. Engraving by Fredrik Akrel 1769.



*Figure 5-3.* The Celsius Observatory in Uppsala today. Here Celsius and his assistants measured and studied latitude, longitude, gravity, temperature, air pressure, magnetism and the northern lights, and also worked on topics such as sea level change and land uplift.

Today the tower is unfortunately gone, but the main building is still there; see Figure 5-3.

The original drawing of the inner parts is also preserved; it is shown in Figure 5-4. The upper floor, beneath the tower, was Celsius' floor. Here he had a lecture hall, a library and a bedroom. The floor beneath that was probably used by assistants. Portraits of the former professors, Celsius' relatives shown in Chapter 2, were decorating the walls in the lecture hall.

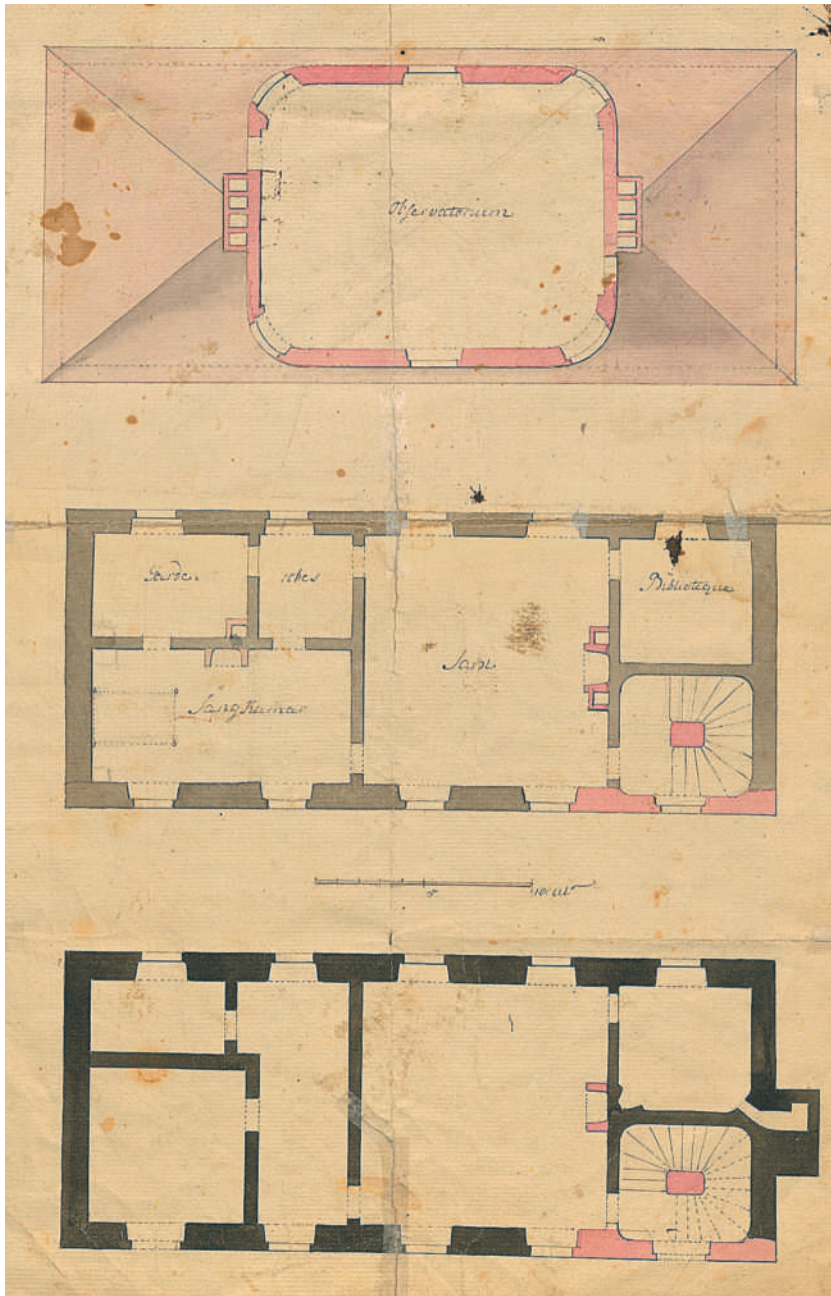


Figure 5-4. Plan of the Observatory building drawn for Celsius by Carl Hårleman in 1738. Upper floor: Lecture hall in the middle, library to the right, Celsius' bedroom and storage-rooms to the left. Lower floor: Probably rooms for assistants.

Celsius' new Observatory was located very close to the family's houses, i.e. very close to his mother and sister. This meant that their eating-house probably was within half a minute's walk from the Observatory. We can imagine that Celsius and his assistants Hiorter and Wargentin easily could go there and not only eat but also spontaneously meet other people, professors as well as students.

Walking a few minutes further north, Celsius could visit his friend and colleague Carl Linnaeus and his botanical garden. Linnaeus had, like Celsius, been abroad for several years, mainly in the Netherlands, but returned the year after Celsius. After having lived in Stockholm a few years Linnaeus moved back to Uppsala when he was appointed professor in botany; he worked in zoology as well. Linnaeus immediately started restoring the botanical garden, and soon plants from all over the world could be seen there. This was at the same time as Celsius had his Observatory completed. Linnaeus then arranged with Hårleman, the architect used by Celsius, to erect a new building also for the garden. As with Celsius' Observatory, Linnaeus' garden and its buildings are still there.

Walking instead a few minutes to the west from the Observatory, Celsius would cross the river through the centre of Uppsala. A view from there towards the Observatory is shown in Figure 5-5. Continuing on the other side of the river Celsius could reach the University building, next to the cathedral (see Figures 2-2 and 3-4 in Chapters 2 and 3). Here he might find members of the University Senate, the librarian, other professors, and students attending lectures. Not far from there, on the southern side of the cathedral, Celsius could meet his friend and colleague Samuel Klingenstierna, giving mathematical lectures in the University hospital. At the same time as Celsius had started building his Observatory, Klingenstierna had started buying instruments for a small laboratory in physics. His laboratory was located in the hospital.

Let us also look at the Observatory from the point of view of the students arriving there for a lecture. Entering the lecture hall they would find, at the other end of the room, Celsius himself at the lecturer's desk. On the walls around they would find the former professors, i.e. Celsius father's father, his mother's father, his mother's sister's husband, and his father. Meeting the main assistant, they would find his sister's husband-



*Figure 5-5.* Part of Uppsala in the late 1700s with the river and the University mill in the foreground and the tower of the Celsius Observatory seen in the background. Today the scene is not very different but the tower of the Observatory is gone. Painting by Johan Gustaf Hårstedt probably around 1790.

to-be. And going out afterwards to eat something next door, they would find his sister and his mother. The world in and around the Observatory must have appeared a complete family business!

The same year as Celsius started building his Observatory, in 1739, his interest in the usefulness of science also engaged him in the creation of a new Swedish scientific society, the Royal Academy of Sciences. Why a new one when there already existed one? The existing one, the Royal Society of Sciences, in which Celsius himself was so active, was rather theoretical in character and issued its publications in Latin. The new society, the Royal Academy of Sciences, would be more application-oriented and issue its publications in Swedish. Hence more people would be able to read them, and scientific knowledge would spread over the country. Moreover, the Academy would gather in Stockholm, not in Uppsala, and consist of a wider group of people.

The Academy was founded by a small but mixed group of people in Stockholm, among them Linnaeus (shortly before he moved back to

Uppsala). Before its constitution, Celsius in Uppsala was asked for his opinion on the matter; he gave the idea his strong support. He replied in a letter which is quite characteristic of his personality and for his views on people and institutions:

“Please be sure ... that nobody is elected a member that does not have a love for useful sciences, and also knowledge within some part of them; because some people only want to join to show their names, and others only for political intentions. Also I hope that in this academy a councillor should not consider himself too high-status to sit at table with a craftsman; the latter can often do the country much more good than the one who has been a learned person for 40 years.”

Celsius also suggested the name of the new institution, and Celsius as well as Klingenstierna were elected members of the Academy already at its first meeting.

The foundation of the Academy was facilitated by a recent change of majority in the Swedish Parliament, from a more defensive party (“caps”) to a more offensive one (“hats”). This brought about a corresponding change of the Government, a very early example of parliamentarism, favouring official support for the Academy.

Celsius who hitherto had published most of his papers in Latin in the Society’s series now started publishing his papers in Swedish in the Academy’s series, “Kongl. Svenska Wetenskaps Academiens Handlingar” (“Transactions of the Royal Swedish Academy of Sciences”). Many of Celsius’ findings at his Observatory appear in the Academy’s publication series. This was a little later translated and issued also in German to reach a wider audience; the German translation was made at the University of Greifswald in the Swedish possessions in northern Germany. Celsius, as well as Linnaeus, turned out to be one of the most productive authors in the publication series. During the first five years Celsius on an average published 4 papers per year there.

The trio Carl Linnaeus, Anders Celsius and Samuel Klingenstierna in the 1740s stood out as an internationally renowned group of scientists of a kind that suddenly made the small and distant University of Uppsala known in the world. Linnaeus was a star in life sciences, Celsius

in Earth sciences, and Klingenstierna in mathematics and its applications. Celsius was a personal friend of both Linnaeus and Klingenstierna, although they seem to have had quite different personalities. Linnaeus was sometimes rather depressed while Celsius was more cheerful, with Klingenstierna somewhere in between. They all apparently were good lecturers, with a lot of students. They also all were very productive. The outcome was, nevertheless, quite different: Linnaeus was eager to publish not only papers but also books in several editions. Celsius concentrated on publishing a lot of papers. Klingenstierna was reluctant to publish anything at all; he put most of his brilliant discoveries in his drawers.

After Celsius had returned to Uppsala from his long travels and built his small observatory in his mother's garden, he had no more than six years to live. After the erection of the full-scale Observatory there were only three years left of his life. During these years in Uppsala Celsius developed an intense activity, partly together with his assistants and disciples, in a variety of fields within what we today would call Earth science or geophysics. So, what did he actually do during these years?

## **5.2 Latitude, longitude and mapping**

### *5.2.1 Latitude*

A fundamental quantity for Celsius to determine as accurately as possible was the latitude of the Uppsala Observatory. The latitude, giving the position on the Earth in the south-north direction, was needed for calculating various other quantities; also, latitude determination was basic for constructing maps and charts. To accurately determine the latitude of a point on the Earth's surface at that time was a scientific task based on astronomical methods. Celsius for this purpose had bought a new instrument while he was in Paris, as mentioned earlier.

Up till recently latitude had usually been determined with an uncertainty of several minutes, corresponding to many kilometres on the ground, often by observing the sun. By instead observing stars, using a telescope, the uncertainty could be considerably decreased. Celsius,



based on his experience from the Arctic Circle, now devoted himself to this. But this meant that the observations had to be made when the sky was not only clear but also dark enough. This occurred predominantly during cold winter nights. Working with scientific accuracy outdoors during cold and dark nights was not easy; moreover, it could be tiring. Celsius once commented on this in connection with another kind of night observations. In a letter to the Royal Academy of Sciences he describes the effect of night observations of a comet:

“The comet restrains me so much during the nights that I walk around completely sleepy during the days, and can do very little.”

When determining the latitude of a point one observed the altitude of a star, i.e. the height angle of a star above the horizon. For a specified star this angle is directly dependent on the latitude of the observation point. There were two main error sources connected to this. The first error source was the refraction of the star light in the atmosphere, which could not be sufficiently corrected for. In one of his letters to the former university librarian Celsius writes:

“I am at present accurately determining the latitude, and in autumn, God permitting, I will set about the refractions; without knowing them well I cannot conclude anything.”

The second error source was the so-called declination of the star, i.e. its “latitude” on the celestial sphere (the sky), which was not sufficiently well known. Now, there was a method of avoiding the refraction, by observing a star close to zenith, but then one needed to know the declination. On the other hand, there was also a method of avoiding the declination, by observing a star twice in certain positions, but then one needed to know the refraction. Celsius now invented a new method for determining latitude, combining the two standard methods in an optimal way. This required observing two stars, one of them twice, in a certain combination of positions. By doing so Celsius was able to eliminate the refraction at the same time as the effect of the uncertainty in the declination was reduced to one third. He published this idea in 1739. Le Monnier, one of the participants at the Arctic Circle, in a letter to Celsius characterized his method as “very ingenious”.

Celsius applied his method to the determination of the latitude of the Observatory, starting his observations the same year as he had his method published and continuing now and then the following years. Thereby he most probably used the quadrant he had purchased in Paris. Strangely enough he never published any result (except for a rounded value in a nautical almanac of his). This may be because he had in mind making more observations before fixing the final value of the latitude, at the same time as he had too many other things going on. In any case his life came to an end before he managed to put his observations and calculations together into a final result. However, among his papers left at his death there are a number of latitude calculations according to his own method, based on his observations at the Observatory; see Figure 5-6. Recent investigations of these data, together with the method itself, reveal that Celsius obtained latitudes of the Observatory with an average of  $59^{\circ}51'39''$  and an approximate standard error as small as  $2 - 3''$ , corresponding to less than 100 m on the ground. The same investigations further reveal that the absolute error in Celsius' average latitude is only  $3''$ , close to 100 m, the correct value being  $59^{\circ}51'36''$ . This was a considerable improvement.

At the Copenhagen Observatory in Denmark the astronomy professor Peder Horrebow had recently invented and applied a later wide-spread method to eliminate refraction, but without reducing the declination problem. As shown in the above investigation, the error in Horrebow's latitude is  $6''$ , twice that of Celsius. (Horrebow's standard error is unknown.) Thus Celsius' interesting method used for the latitude determination of the Uppsala Observatory must be considered very successful. In the long run, however, the declinations would become sufficiently known, making Celsius' method obsolete.

It should be mentioned, as at the end of Chapter 4, that there is a special geophysical phenomenon affecting all astronomical latitude (and longitude) determinations, namely deflections of the vertical. This phenomenon was unknown at the time of Celsius; it is caused by the irregular mass distribution within the Earth. The effect can amount to several seconds of arc, corresponding to some hundred meters on the ground. In this case the effect happens to be quite small, and we do not enter deeper into that problem here.

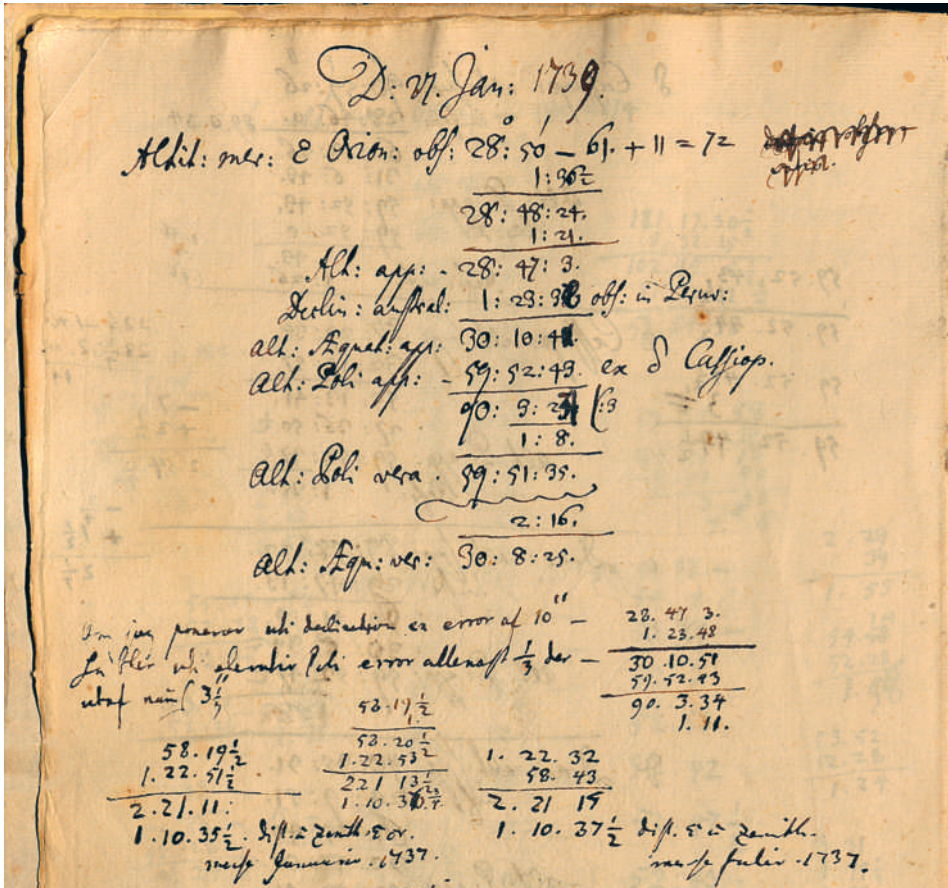


Figure 5-6. Example of Celsius' calculations of the latitude of his Observatory according to his new method, based on observations during a winter night in 1739. The upper part shows Hiorter's calculations according to Celsius' instructions, the lower part shows Celsius' comments on the results.

Once Celsius had started his latitude observations the Royal Survey Office became interested, for mapping purposes. There was a map of the whole country, in fact of the whole Nordic area, but that was quite old, and there were no useful maps at all of the Swedish provinces. The Survey Office agreed with Celsius that the Observatory of Uppsala should measure the latitudes of a number of places in the provinces around Stockholm and Uppsala as a basis for such maps. This was made by Celsius' assistant at the Observatory, Olof Hiorter, who travelled

around and carefully determined the latitudes of 20 places for the Survey Office. This was in line with Celsius' idea of science useful for society.

### 5.2.2 *Longitude*

At the same time as working with the latitude, Celsius started working with the other coordinate on the Earth, the longitude, giving the position on the Earth in the west-east direction. The situation here was different: While latitude for a long time had been possible to determine, although not with the accuracy of Celsius, longitude had until recently not been possible to determine at all, except by indirect estimates. Such estimates could be in error by more than one degree, corresponding to more than 100 km on the ground. Thus there was a great need for longitude determination for constructing maps and charts. To try to reliably determine the longitude of a point on the Earth's surface at that time was a scientific task based on astronomical methods, but of a quite different character than that for the latitude.

Celsius, in his first paper on longitudes in 1741, states:

“During the work with my astronomical observations I have especially paid attention to such phenomena, whereby the positions of places here in Sweden as well as abroad, with respect to their longitude east or west of the Uppsala meridian, may be more accurately marked on the maps than hitherto.”

This reveals not only Celsius' interest in science useful for society, but also his ambition to make the Uppsala Observatory a zero meridian for longitudes; this would place Uppsala so to speak in the centre of the Nordic area.

Determining the longitude of a point was principally the same thing as determining the difference in local time between the point and a zero meridian observatory. Local time could be determined by setting a pendulum clock through observing the sun, both at the point and the observatory. The time difference, however, was tricky to find out in those days. How to do that for two widely separated places on the Earth? This was solved as follows. At the point in question, one observed an event in the sky that simultaneously could be observed at the observatory.

Such an event was usually the eclipse of one of the moons of Jupiter, more rarely a lunar or solar eclipse. From the point you then had to send a letter to the observatory asking if somebody there had observed the same eclipse. Sometimes you might receive an answer that the sky had been cloudy, or maybe that the observer had been away or fallen asleep. But sometimes you could get a positive answer, whereby you could compare the two local times for the observed eclipse and thus obtain the time difference, giving the longitude. A problem, however, was to know beforehand when an eclipse of a Jupiter moon could be expected to occur.

Celsius now started determining longitudes relative to the Observatory of Uppsala, applying the method above. In doing so he established the Uppsala Observatory as a Nordic zero meridian, as illustrated in Figure 5-7. First he determined the longitude of the Observatory of Copenhagen in Denmark, in 1741. He obtained  $4^{\circ}58'$  west of Uppsala. Then he determined the longitude of Torneå in today's Finland, two years later. His assistant at the expedition to the Arctic Circle, Anders Hellant, had remained there, establishing a small branch observatory for him at Torneå. He obtained  $6^{\circ}34'$  east of Uppsala. These were the first reliable longitude determinations in the Nordic countries.

The errors in Celsius' values are  $6'$  and  $3'$ , respectively, the correct values being  $5^{\circ}04'$  and  $6^{\circ}31'$ . Celsius also determined the longitude difference between Paris and Uppsala, obtaining  $15^{\circ}22'$ , which is  $4'$  too large, but never found time to publish the details. These errors are small, although they are nearly two orders of magnitude larger than those in latitude. The errors in longitude are of the order of minutes, corresponding to several kilometres, while those in latitude are of the

Stockholm	$0. 1\frac{1}{2} \text{ Ö.}$	0	22	59	20
Ön Teneriffa	$2.10 \text{ W}$	32	31	27	50
Venedig -	$0.20\frac{1}{2} \text{ W}$	5	7	45	33
Uppfala - -	$0. 0$	0	0	59	$51\frac{2}{3}$
Uraniburg -	$0.19 \text{ W}$	4	45	55	54

Figure 5-7. Uppsala as the zero meridian in a list of latitudes and longitudes of important harbours and observatories in a nautical almanac by Celsius 1743.

order of seconds, or a hundred metres. This reflects the difficulty in measuring times, used for longitudes, compared to measuring angles, used for latitudes. The comparatively large errors in longitude nevertheless correspond to errors in time of only some 15 seconds.

The obtained longitudes were included as an important part of the basis for a new map of Sweden, Finland and the Baltic Sea, including neighbouring parts of Denmark and Norway. This was the first Nordic map based also on longitude determinations, Uppsala being the zero meridian. The map was constructed in 1747 by Celsius' assistant Georg Biurman, who had accompanied him on his international study tour. Biurman had become a map engraver at the Royal Survey Office. However, the Survey Office did not have money for issuing the map, so Biurman issued it himself at his own expense. Although very few, Celsius' measured longitudes were essential for the mapping. Because of their geographical distribution, widely separated in the direction southwest-northeast, they contributed considerably to correcting and controlling the map. A few years later, Hellant extended this further northeast to Vadsø on the Arctic coast of Norway.

The longitude work at Uppsala also turned out to be useful in a global context. In the Indian Ocean, east of Madagaskar, there is an island called Réunion, earlier known as Île Bourbon. This was at Celsius' time an important base during voyages to the East Indies. Le Monnier at the Paris Observatory informed Celsius of an observation of an eclipse of one of Jupiter's moons that had been made at the island harbour, stating that at the same instant the sky had been cloudy in Paris. What about at Uppsala? In Uppsala, fortunately, the sky had been clear and the same eclipse observed. Celsius therefore was able to determine the longitude of this important island in the Indian Ocean relative to Uppsala. Having earlier determined the longitude difference between Uppsala and Paris, he could also calculate the longitude of the island relative to Paris, for the benefit of international marine charts and global navigation.

As stated above, the moons of Jupiter played a fundamental role in longitude determination. Jupiter has four large moons. They move in orbits around Jupiter, the innermost moon (Io) having the shortest period, only 42 hours. This means that an eclipse occurs every second

day, thus providing frequent and well-defined events useful for longitude determination in those (unfortunately limited) cases the planet can be clearly observed. However, each moon, in addition to being governed by the gravitation of Jupiter, is perturbed by the gravitations of the other moons. Hence the orbital motions of the moons become irregular, their periods not being constant. This makes it difficult to predict when the eclipses will occur, something that was essential for the determination of longitudes. Celsius now made his assistant Pehr Wargentin at the Observatory interested in this matter, leading to a series of remarkable events.

To start with, Celsius and Wargentin used a set of tables for the moons of Jupiter and their eclipses produced at the leading observatories of Paris and Greenwich. It turned out that their predicted times often failed by as much as one hour. In his memoirs Wargentin describes the problems encountered by Celsius and himself in Uppsala because of that:

“Sometimes, although we were prepared to observe well before the calculated time, we were still too late, the eclipse having already occurred; sometimes we had to stand in cold and snow under the open sky (since the Observatory was not yet completed) and fatigue the eyes one whole hour.”

Celsius had sent for improved tables recently calculated in Paris but they had for some reason been delayed. Wargentin then started to systematically study the irregularities in the motions of Jupiter’s moons himself. He turned out to have natural gifts for analysing large amounts of numerical data. Using an intuitive statistical method, he spent two years in computing a set of tables for the Jupiter moons, allowing predicting the times of their future eclipses. To Celsius’ surprise it turned out that the tables produced in 1741 by Wargentin at Uppsala were superior in accuracy not only to the old ones of both Paris and Greenwich, but even to the new ones recently obtained from Paris! While their tables failed by up to one hour, Wargentin’s tables kept correct to within one minute for the innermost moon and a few minutes for the outer ones; see Figure 5-8.

Soon after Wargentin had had his tables completed, but before they were printed, a dreadful thing happened. Wargentin was travelling by

**Observationes Eclipsium Primi Circum-Jovialium.**

An.	Menf.	D. h. ' "	Error calculi	Ph.	Locus	An.	Menf.	D. h. ' "	Error calculi	Ph.	Locus
1736	Oct.	17 6 57 16	0 42	+	E. Berol.	1739	Sept.	12 10 16 25	0 14	+	J. Petr.
	Nov.	2 5 16 0	1 44	+	E. Berol.		Sept.	19 12 11 27	1 38	+	J. Petr.
1737	Jun.	9 13 21 0	0 47	+	J. Petr.	Oct.	19 11 21 53	0 42	+	J. Petr.	
	Jul.	11 11 39 48	0 37	—	J. Petr.	Oct.	3 16 3 54	0 41	+	J. Petr.	
	Aug.	27 9 56 44	0 45	—	J. Petr.	Oct.	5 10 33 17	0 15	+	J. Petr.	
	Aug.	17 15 43 26	0 33	—	J. Petr.	Oct.	12 12 28 47	0 12	+	J. Petr.	
	Sept.	19 10 12 38	0 27	—	J. Petr.	Oct.	12 11 37 12	0 53	+	J. Petr.	
	Sept.	19 9 5 7	0 26	—	J. Petr.	Nov.	21 8 50 28	1 13	+	J. Petr.	
	Sept.	18 14 42 41	0 29	—	J. Petr.	Nov.	20 13 0 12	0 27	—	J. Petr.	
	Sept.	27 11 8 7	0 18	+	J. Petr.	Dec.	22 7 28 2	0 15	—	J. Petr.	
	Oct.	27 9 52 7	0 18	+	J. Petr.	Dec.	6 11 10 13	0 31	+	J. Petr.	
	Oct.	6 7 34 0	0 16	+	J. Petr.	Dec.	8 5 38 27	0 2	+	J. Petr.	
	Nov.	29 7 50 21	0 42	—	J. Petr.	Dec.	20 14 2 41	0 27	+	J. Petr.	
	Nov.	29 5 58 47	0 34	—	J. Petr.	Jan.	23 5 51 47	1 40	—	J. Petr.	
	Nov.	5 9 44 20	0 11	+	J. Petr.	Jan.	30 6 49 54	0 10	—	J. Petr.	
	Nov.	5 8 36 57	0 4	+	J. Petr.	Feb.	22 8 2 20	0 26	+	J. Petr.	
	Nov.	12 10 31 40	1 1	—	J. Petr.	Feb.	22 6 10 45	0 1	+	J. Petr.	
	Nov.	12 9 6 50	0 28	—	J. Petr.	Feb.	22 7 13 25	1 9	—	J. Petr.	

Figure 5-8. Times of eclipses of the innermost Jupiter moon predicted by Wargentin in 1742, based on the tables of the motions of the Jupiter moons provided by him for international longitude determination. Included are the prediction errors in minutes and seconds found by comparison with observations.

horse and carriage from Uppsala to Stockholm to spend Christmas there when he was attacked and his suitcase on the back of the carriage was stolen. He lost almost everything he owned – including his manuscript containing the tables of the Jupiter moons! All his work was gone. There was nothing else to do but to start from the beginning again. And so Wargentin patiently spent another two years with Celsius in Uppsala recomputing all his tables. When finally they were published, Wargentin's tables rapidly spread among longitude people and soon became a sort of international standard. Repeatedly improved versions by Wargentin himself were later included in the astronomical tables of Paris, Greenwich and Berlin for several decades.

Wargentin spent nearly his whole life observing Jupiter's moons and improving his tables. When Jupiter's moons had been observed for longitude purposes at one station in Europe, the largest probability of finding corresponding observations at another station was at the



Observatory of Uppsala, or later Stockholm when Wargentin moved there (see Chapter 6). Because of this, Uppsala, and later Stockholm, became an international key observatory for longitude determinations in their early days.

### *5.2.3 Positioning and mapping*

A special measurement Celsius had in mind to perform was carefully determining the longitude difference across the Åland Sea, the part of the Baltic Sea between the Swedish coast east of Uppsala and the Åland Islands midway to Finland. The Åland Islands include an extensive archipelago comprising thousands of islands, islets and rocky reefs. Between Sweden and Finland (then the eastern half of the Swedish realm), across the Åland Islands, ran the important “Post route”, used for transporting not only mail and goods but also diplomats and other people travelling between the western and eastern parts of northern Europe. This area certainly was in need of a more reliable mapping. Celsius was an expert not only in astronomical positioning for finding latitudes and longitudes; he also had experience of positioning through triangulation from his work at the Arctic Circle. Moreover, he had in his possession one of the two angle instruments used by the expedition there.

One of Celsius’ students, Jacob Gadolin, made use of all this, in 1748 – 1752, a few years after Celsius had died. Gadolin performed a triangulation across the Baltic Sea between Sweden and Finland, via the Åland Islands, in the manner of Celsius, even using his angle instrument from the Arctic Circle. Included in the triangulation was an astronomical positioning; for all triangulation stations latitudes and longitudes could then be determined. The project was a kind of cooperation between the Royal Survey Office, the University of Åbo (Turku) in Finland, to where Gadolin had moved, and the University of Uppsala. This was the first triangulation for official mapping in the Nordic area. It also led to a continuation: The whole coast of the Baltic was later triangulated under the leadership of another student of Celsius, Mårten Strömer, together with Wargentin. The triangulation across the Åland Islands seems to have been the first triangulation in the world for marine purposes, resulting in nautical charts as well as a land map; see Figure 5-9.



Figure 5-9. Accurate nautical chart of the Åland Sea and its surroundings based on triangulation campaigns initiated by the early works of Celsius and Gadolin.

A recent investigation of this pioneering triangulation shows that the resulting latitudes and longitudes of the triangulation stations have an uncertainty of only about 100 m relative to each other, valid across the whole width of the Baltic Sea. The triangulation of the Åland Islands appears to have been of the same quality as the one at the Arctic Circle, and considerably better than later ones in the 1700s along the Baltic coasts. So high was the quality of this work that when the Russian navy 100 years later managed to borrow the documents with the coordinates, they did not want to return them. In the end they returned a copy instead. Fortunately, the original documents had been made in duplicate.

Finally, a highly original positioning idea that never went into practice must be briefly considered. It was put forward in 1741 by Celsius' assistant Jonas Meldercreutz, who had accompanied him on his international study tour. Meldercreutz had become a mathematician at the Fortification Office in Stockholm. He had married a girl from the Finnish side of the Baltic which made him travel several times between Sweden and Finland across the Åland Islands, probably along the postal route mentioned above; this was before the triangulation. Here he must have had unlimited possibilities to experience the lack of knowledge of the positions of islands and coasts; there was no reasonably accurate map or chart available. Meldercreutz now suggested that points along coasts and in the archipelago could be positioned by measuring distances to a few sailing war-ships with known positions. The distances were to be determined from travelling times of sound waves emitted from firing cannons aboard the ships. In practise, however, times in those days could not be measured with sufficient accuracy for the purpose. But the interesting thing here is the basic principle: Remarkably enough it is the same as for modern positioning with satellites. Only the technology is older. Exchange sailing war-ships for satellites and sound waves for radio waves – and you get modern satellite positioning.

Looking back we note that Celsius and his loose group of assistants were eagerly active concerning new or improved methods for positioning on the Earth. Celsius invented and applied a new method for determining latitude, minimizing major error sources. Furthermore, he made the first reliable longitude determinations in the Nordic countries, leading also to a new map. Wargentín, inspired by Celsius, constructed world-leading tables of the Jupiter moons for longitude

determination. Gadolin, using Celsius' experience as well as instrument, made the first marine triangulation in the world for producing maps and charts. And Meldercreutz came up with a kind of fore-runner to satellite positioning, although it never went into practice.

Celsius' ambition to undertake science serving the needs of society is reflected in a scientific almanac of his, issued in addition to all his ordinary almanacs. It was a small nautical almanac containing data for latitude and longitude determination at sea, for the purpose of navigation. It contained necessary data for the sun and a number of stars as well as for two of Jupiter's moons, including data on refraction and other effects. Moreover, it contained instructive examples on how to determine latitude as well as longitude at sea and in harbours on the coast. This was the first nautical almanac designed for use in the Nordic area.

In connection with his almanac works, Celsius came across the special problem of how to calculate Easter day; this is dependent on the vernal equinox and the full moon. Celsius constructed an astronomically more accurate method for this, adopted by the King instead of the approximate one agreed upon already at the Council of Nicaea in 325 A.D. This led to strange consequences. Some years, seemingly at random, Sweden alone had Easter day one week different from all the other relevant countries. It took one hundred years before Sweden returned to calculating Easter day in the traditional way used by the others.

### **5.3 Gravity and the Earth's shape**

The French expedition to the Arctic Circle, in which Celsius took part, arrived at the conclusion that the Earth was flattened at the poles. To begin with, as described in Chapter 4, this conclusion was questioned. The arc measurements at the Arctic Circle and in France yielded a flattening larger than allowed. Fortunately there was also a gravity measurement made at the Arctic Circle, which could be compared with gravity measurements made in London and Paris and even one as far south as Jamaica made during a British voyage there. If the Earth were flattened towards its poles, gravity on the Earth's surface would increase from the equator to the poles according to a certain law involving the flattening. Celsius, inspired by the gravity work he had taken part in at

the Arctic Circle, decided to determine the value of gravity also at Uppsala.

Gravity at that time was determined by using a pendulum. The swinging time (period) of a pendulum depends on the length of the pendulum as well as on the value of gravity at the point on the Earth where the pendulum is suspended. Thus if the period of a pendulum of known length is measured accurately, the value of gravity can be determined.

We noted in Section 5.1 that Celsius was eager in ordering a high quality pendulum clock from Graham in London, so eager that he sent the instrument maker Daniel Ekström there to buy it and bring it home before the University Senate knew anything about it. The main reason for this was probably Celsius' wish to find the value of gravity at Uppsala, for further verification of Newton's theories. The pendulum clock was installed in the Observatory. Celsius writes in his published paper:

"For making this experiment I could never get a better opportunity than in 1741, when Mr. Graham for the Observatory in Uppsala had constructed an accurate astronomical clock. ... Now when the clock through Mr. Ekström arrived undamaged by sea from London to Uppsala ... I soon started, at the end of July 1741, to compare the swinging of the pendulum with the daily revolution of the stars."

Celsius used the pendulum clock for his gravity measurements on occasions during two years, from 1741 to 1743. This pendulum clock is preserved and still functioning; see Figure 5-10.

In order to keep the length of the pendulum constant it was important to keep the temperature reasonably constant. To check this, Celsius measured the temperature in the room when making observations with the pendulum clock. On Christmas Day 1741 he made a notable change regarding the thermometer used: He introduced his own newly invented thermometer scale for the first time (see further Section 5.6).

Celsius published the result in 1744. His result as well as other contemporary gravity measurements for studying the flattening of the



*Figure 5-10.* The pendulum clock of Celsius, constructed for him by Graham in London in 1741 and used by Celsius for determining the value of gravity at the latitude of Uppsala.

Earth has been investigated in a modern analysis. This reveals that the gravity value obtained by Celsius in Uppsala was, in modern units,  $9.8154 \text{ m/s}^2$ , the error of which is only  $0.0036 \text{ m/s}^2$  (0.04 %), the correct value being  $9.8190 \text{ m/s}^2$ . Half of this error might be due to the pendulum not swinging in vacuum. The rest of the error would represent the uncertainty in the observations; it is comparable to the errors at the other four gravity stations in the world at that time. On the whole, Celsius' gravity value at Uppsala fitted with the other four gravity values at different latitudes on the Earth, thereby further supporting the theories of Newton.

Then there was the additional problem of whether the Earth was homogeneous or not. Clairaut, one of the expedition members at the Arctic Circle, published a book on gravity in 1743. In that he noted that the gravity data he had at hand indicated a flattening smaller than the  $1/230$  prescribed by the homogeneous Earth used by Newton. As showed by Clairaut this indicated that the Earth might be denser towards its centre. Celsius does not comment on this, probably because he had not yet seen the book when he wrote the report on his own gravity determination.

By the 1750s the arc measurements in the world yielded quite disparate values of the Earth's flattening, with some sort of average around the  $1/230$  required for a homogeneous Earth. The gravity measurements, on the other hand, at the same time yielded a flattening about  $1/330$ , with a much smaller uncertainty, clearly indicating an inhomogeneous Earth denser towards its centre. This also reflected the greater difficulties in performing the arc measurements. Celsius had been active in both methods.

Typical for Celsius he also stressed, in another paper, the practical use of the flattening of the Earth: Knowledge of the flattening was useful for society when constructing accurate maps and charts. The length in miles or fathoms of one degree of latitude or longitude would be a function of latitude because of the flattening of the Earth. Celsius, with mathematical support from Klingenstierna, had Hiorter calculating a pioneering table of this, explaining why such a table was important for charts to be used for careful navigation. Celsius made a point in convincing the reader that his expensive scientific work was "not a trifling one" but a "necessary and useful science".

#### **5.4 Land uplift/ water decrease and history**

A strange phenomenon that people living along the coasts of the Baltic Sea had noted was what seemed to be a gradual lowering of the sea level. In some coastal areas where earlier generations were used to go by boat there was no longer any water, or too little water. Knowledge about the phenomenon was, however, very vague; although there were several indications of something going on, there was no proof of it in a

more scientific sense, and even less was there any measure of its rate of change.

Celsius had become interested in the phenomenon and had started working on it already before his international travels. To prove that a gradual change of the vertical relation between land and sea was going on in the Baltic Sea area, and to find its rate, Celsius needed some kind of determination of mean sea level at some specific time long ago, allowing it to be compared with a recent determination. He invented an original and useful method to deal with this problem.

Celsius had travelled along the coast of the Gulf of Bothnia a couple of times, the last time when going with the French expedition to the north. He was, therefore, aware of the existence of so-called seal rocks along the coast. These are rocks in the sea water used by seals to rest on. Celsius realized two interesting things about the seal rocks. First, to make it possible for the seals to get up on the rock, its top has to be close to mean sea level. Second, since a seal rock might be economically important as a place for shooting seals, there are in some cases written documents on the ownership of such a rock.

Celsius now managed to find four seal rocks useful for his purposes. They were situated in widely different places along the coast of the Gulf of Bothnia, two of them on the Swedish coast and two on the Finnish coast. These seal rocks were explicitly mentioned and valued in old inheritance documents and bills of sale. However, in later taxation certificates they were declared unusable because they were too high above the water or standing on dry land. Celsius' conclusion was that mean sea level must be falling. People had, unwittingly, recorded this phenomenon in legal documents!

Now, one abandoned seal rock was especially rewarding because it could be identified in nature and measured. This seal rock was situated in the south-western part of the Gulf of Bothnia, at the island of Iggön, some 100 km north of Uppsala. Celsius here engaged a local mathematics teacher, Johan Rudman, who made a first visit to the rock and then sent Celsius a sketch map of the island with the rock especially marked. This rock Celsius used for determining the vertical rate of change. Celsius



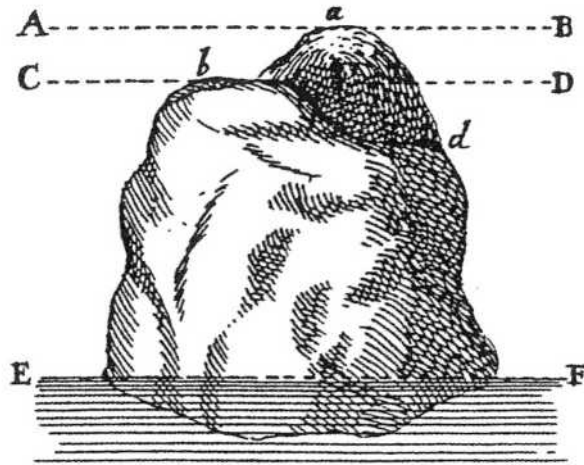


Figure 5-11. Celsius' sketch of the seal rock at the island of Iggön on the coast of the Gulf of Bothnia, used by him for finding the rate of the water level decrease (postglacial land uplift) in 1743. The rate obtained led him to claim a considerable change in the distribution between land and sea area through history as well as in the future.

writes, in his paper on the subject in 1743, illustrated by a sketch of the rock as shown in Figure 5-11:

“Formerly there lived a peasant here called Rik-Nils [Rich Nils] because of plentiful fishing. He caught seals on the top *a* of this rock, where in the beginning the seals could get up when the sea was still, in calm weather, and was equal to AB. But later, when the water in his time decreased and fell to CD, the seals used to lie on *b*. And since the top *a* then prevented Rik-Nils from shooting the harpoon at the seals when coming from the island, he burnt out of the rock [using an old mining method] the whole piece down to *d*, in winter when the water generally is at its lowest. There can still be seen clear traces of this and it is also confirmed by all Rik-Nils' descendents. The sons of Rik-Nils then purchased this island from the Crown and they have received a taxation certificate of this by King Jan [Johan] III, dated 1583, March 24th. ... The rock was burnt by the father about 20 years before his sons purchased the island, i.e. in 1563. But in 1731, in summer when the water was approximately

at its mean level, the horizontal line EF of the sea was found to be 8 [Swedish] feet below CD. This is thus the amount the water has fallen in 168 years.”

With this original method Celsius succeeded in making the very first determination of the rate of what is now known as the postglacial land uplift or postglacial rebound of the Nordic area, although Celsius looked upon it as a water decrease. In more well-known units his rate becomes 1.4 cm/year. From modern methods, and taking into account not only the land uplift but also climatological changes of sea level, we have 0.8 cm/yr. Thus Celsius’ value is of the right order of magnitude.

Nevertheless, Celsius’ value of the vertical rate of change was too large by a factor of nearly two. Why? According to a recent investigation it could be due to two different circumstances, or a combination of both. First, the seals might have used the rock during long wind-induced high water periods of half a metre occurring sometimes in the Baltic Sea. Second, the seals might easily have been able to get up on a top of a rock like this one half of a metre above sea level. Ignoring these circumstances led Celsius to assume that the top of the rock coincided with mean sea level when it actually must have been three quarters of a metre above. Today the rock is difficult to identify as it is on dry land in a forest; see Figure 5-12. In fact, no one knew where the rock was until recently, when it was identified through the above investigation.

Celsius did not confine himself to determining the rate of change of the land uplift / water decrease. He went one step further. He widened the perspective by asking himself what this vertical rate of change would mean when looking back in time as well as forward, what it would mean for history and future. He presented a table showing the total change in sea level for up to 10 000 years, provided the rate had kept, or would keep, constant. Let us listen to Celsius again, first looking back and then into the future:

“If we knew here in Sweden the height above sea level of the most important places, which easily could be done if our land surveyors were equipped with a levelling instrument, one would be able to state, according to the above calculation, which places in earlier times had been under water and what our geography was like, say, two thousand years



*Figure 5-12.* The seal rock at Iggön today, now in a forest due to the continued land uplift.

ago, when the water was 45 ells [90 feet, 28 m] higher. ... One would find that a long time ago ... not only had Scandinavia been an island, but also that its southern part had consisted of small islands."

"On the other hand, imagining what effect this lowering of sea level might have in the future, then the boundaries of Sweden would continuously expand. ... Our archipelagos would become gradually more filled with islands and rocks, so that pilots should measure the depth of the sailing routes at least every 20th year, not trusting what their ancestors have made. In the long run, finally, the whole Baltic Sea would disappear."

Celsius' results caused a considerable scientific interest. Support came first from Linnaeus. On the island of Gotland in the Baltic Sea Linnaeus had come across a sequence of ridges, all parallel to the coast, which he interpreted as old shore-lines having successively lost contact with the sea because of the water decrease. Further north Nils Gissler, a

former student of Celsius, studied similar sequences of shore-lines, realizing that they might be formed by severe storms occurring with intervals of several decades. This would reasonably agree with Celsius' value of the rate of the water decrease.

But even more important was the interest in Celsius' results from quite a different side. Soon after Celsius' paper had been published, Olof Dalin, an author and historian, happened to be asked by the Parliament to write a history of Sweden. Dalin, a free-thinking person like Celsius, included recent scientific findings in his history and directly adopted Celsius' wide perspective on the water decrease. The very first sentence in Dalin's history reads:

"The Nordic countries were still mainly under water, and were like an archipelago divided into a large number of small islands, when their highest areas were populated by the people, the history of which I am now going to write."

This gave Celsius' results a more rapid break-through than anything else – but also opposition. Even in the Parliament there were members discussing the matter. Could it really be accepted that a central part of Sweden had not existed a few thousand years ago? The bishop and scientist Johan Browallius tried to explain Celsius' observations as what we today would call systematic and random errors, thereby also defending the biblical view of the Earth. But by then Celsius was no longer alive.

In the paper published by Celsius he further informs us that he has had a special mean sea level mark cut into another seal rock, at the island of Lövgrund not far away. Celsius' mean sea level mark consists of a horizontal line and above that the year "1731"; see Figure 5-13. It is still there, only it is now nearly 2 m above mean sea level; see Figure 5-14. The mark was cut according to Celsius' instructions by Rudman, the same person who Celsius had involved earlier. Celsius states that he had the mark made "in order to make future generations able to determine this rate of change more accurately". We here recognize Celsius' scientific philosophy of leaving "true observations to later generations", revealed in connection with his early observations of the northern lights (Section

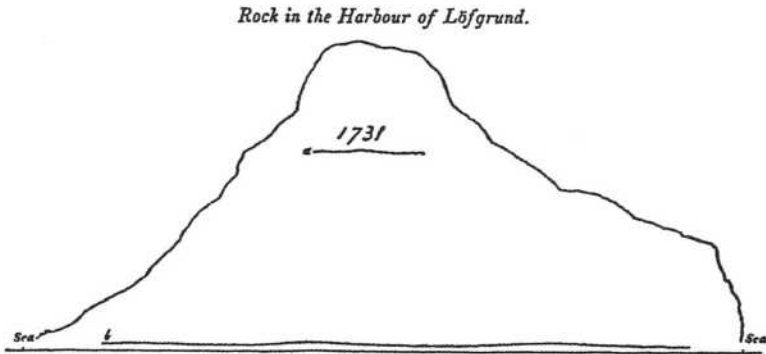


Figure 5-13. Celsius' mean sea level mark of 1731 on the seal rock at the island of Löfgrund off the coast of the Gulf of Bothnia, according to a drawing by Lyell from England in 1835. Celsius made this mark for the benefit of future generations.

4.2); we will encounter it again in connection with his temperature measurements. Today the mark can be shown to have been placed a little more than 10 cm too high, but this is within the uncertainty of estimating mean sea level without having a long series of sea level measurements.

Celsius' expectation that future generations would benefit from his mark would come true one century later. Then the world-leading geologist Charles Lyell, coming all the way from the British Isles to study what was going on in the Baltic Sea, used Celsius' mark to find a reliable value of the annual rate of change. Together with some data from other parts of the Baltic Sea he found that the rate was very different in different parts of the Baltic, leading him to the conclusion that the phenomenon must be a land uplift. In this way Celsius' foreseeing mark contributed to inverting the view of the phenomenon, from that of a water decrease to that of a land uplift.

Today there are (approximate) mean sea level lines on the rock not only from 1731 but also from 1831 and 1931. In 2031 there will be a possibility to make a fourth line, but that will be the last one. Soon after that the rock will inevitably be on dry land.



*Figure 5-14.* The seal rock at Lövgrund today. Celsius' mean sea level mark of 1731 at the top, later marks for each centenary below, illustrating the gradual land uplift. There will be room for a last mark in 2031.

## 5.5 Sea level and the atmosphere

When dealing with the water decrease / land uplift, Celsius noted that sea level of course could be sometimes higher and sometimes lower than normal, but that during summer it usually had its "ordinary and average height". This is a quite correct observation concerning the Baltic Sea, indicating larger deviations in sea level during the other seasons.

Celsius' interest in and paper on the change of the vertical relation between land and sea caused a former student of Celsius, Nils Gissler,



*Figure 5-15.* “Our archipelagos would become gradually more filled with islands and rocks” as Celsius said in his paper on the lowering of the Baltic Sea level; this encouraged Gissler to start studying variations in sea level caused by the atmosphere.

briefly mentioned above, to investigate possible relations between instant sea level and the atmosphere; see Figure 5-15. Gissler, who had also been a student of Linnaeus, had become a medical officer at Härnösand on the coast far north of Uppsala. Living at the sea, inspired by Celsius’ paper involving mean sea level problems, and knowing Celsius’ series of air pressure and temperature observations at Uppsala since his own time there, Gissler decided to combine sea level observations with air pressure and temperature observations.

Gissler set up a sea level scale, one of the first in the Baltic Sea, at his coast. There he observed sea level frequently throughout the year 1746, at the same time as he measured the air pressure with a barometer and the temperature with a thermometer. He did not know what he would find, but his own experience at the coast told him that instant sea level could deviate quite a lot from mean sea level, for unknown reasons. After

some time a pattern emerged; Gissler writes in his paper published the year after:

“Since I often checked the changing water level on this scale I noticed that the rising and falling of the barometer reasonably agreed with that of the water. ... From the above observations I have found that, for the most part, whenever the barometer rises the sea level falls, and whenever it falls the sea level rises.”

In this way Gissler discovered what is now known as the inverted barometer effect in the sea level. It is a global effect, but it took one century after its discovery in the Baltic before it was studied elsewhere, on the northwest coast of Europe, in the Mediterranean Sea and the Arctic Ocean.

On some occasions the inverted barometer effect seemed to fail. Gissler noted that this might be due to strong winds. However, although winds play a major role for the sea level in the Baltic, their effects are complicated; they turned out to be much more difficult to investigate.

## 5.6 Temperature, air pressure and climate change

As we have seen in Chapter 3, Celsius was involved in systematic temperature and air pressure measurements right from their beginning in 1722. This was a pioneering work in the Nordic countries, and it contained comparative studies of different instruments and scales. In particular, there were several different temperature scales and thermometer constructions, none of which seemed accurate and reliable enough to Celsius.

To create a useful temperature scale it is necessary to define two fixed temperatures in some way as accurately as possible; then the space between the fixed points can be arbitrarily divided. In Uppsala in the early years, temperature scales according to Hawksbee in England, Fahrenheit in Holland and Réaumur in France were used. They all (approximately) had the freezing point of water as one fixed point on the scale, although also alternative points were used. The other fixed point was different in all three cases. Hawksbee’s other fixed point was the maximum heat in London. Fahrenheit’s other fixed point, originally





Figure 5-16. Celsius' experimental thermometer sent to him from Delisle in St. Petersburg. Delisle's temperature scale to the left with Celsius' new temperature scale, completed in 1741, added to the right.

stemming from Rømer in Denmark, was the heat in the human body. Réaumur did not actually have another fixed point but combined his only one with a measure of the volume expansion of the liquid in the thermometer.

During his international study tour Celsius came into contact with the Delisle family. Joseph Nicolas Delisle had been an astronomer at the Paris Observatory, but had moved to St. Petersburg after an invitation by the Russian emperor. When Celsius arrived in Paris he stayed with Delisle's astronomically interested mother and sister and became close friends with them, as described in Section 4.3. Now, Delisle was also a constructor of a thermometer. His scale had the boiling point of water as one fixed point, whereas the other fixed point was the heat (or rather coolness) in the basement of the Paris Observatory. After he had moved to St. Petersburg, where there was no suitable basement available, the other fixed point was changed to be the freezing point of water. In 1737, soon after Celsius' return to Uppsala from the Arctic Circle, Delisle in St. Petersburg sent Celsius two of his thermometers, asking him in a letter to make comparisons between them and the other ones in Uppsala. One of them was damaged in the transport, but the other one was used by Celsius as one of his experimental thermometers; it is still preserved, see Figure 5-16.

After Celsius had found all temperature scales too inaccurate and unreliable he started developing a temperature scale of his own, based on the freezing and boiling points of water. In the papers he left after his death, as well as in his published paper on how to define these two points on a thermometer, we can see how he worked and what kind of experiments he performed to solve the problem. There were several things he wanted to test, the most important one being the possible dependence on the air pressure.

Concerning the freezing point of water Celsius tested various ways of melting snow:

"I have put the thermometer in the melting snow ... not only when there has been a thaw. Also, when there has been strong winter I have taken the cold snow and put it in my room at the fire, making it melting. I have also made fire in a tiled stove and put ... a kettle with melting snow

together with the thermometer inside the stove. However, I have always found the mercury showing the same point, as long as the snow was tight around the thermometer ball."

Celsius also tested the freezing point in various kinds of weather, especially during differing air pressures:

"This experiment I have now repeated over two years, several times, during all winter months, in all sorts of weather, and at several changes of the barometer. And I have always found precisely the same point on the thermometer."

Earlier Celsius had even tested whether the freezing point could be dependent on the latitude, by checking it both at Paris in the south, at Torneå in the north, and at Uppsala. He found it was not.

Concerning the boiling point of water Celsius tested various kinds of water: river water, snow water, and well water. The last category he divided more closely into three different qualities: "a well in the city that does not have good water, not useful for making tea", "a well with reasonably good water", and "a well with good water, normally used for making tea". Using these kinds of water Celsius now tested, in the Observatory, the boiling point at different air pressures. This yielded an accurate table showing a linear decrease of the boiling temperature with increasing air pressure. The linear relationship found by Celsius agrees well with modern knowledge. Celsius writes:

"From the experiments can be clearly seen that the height of the thermometer in boiling water is always proportional to the height of the barometer. ... Consequently, if now the point defined by boiling water should be fixed, it is necessary to determine a certain height of the barometer to which it will always correspond. And since according to all meteorological observations, here in Sweden as well as in other places in Europe, the mean height of the barometer is close to 25 [Swedish decimal] inches and 3 lines [751 mm, corresponding to 1001 hPa], it is best to choose that point as fixed which the thermometer shows in boiling water when the barometer is at the mentioned height."

Celsius thus defined the two fixed points on his thermometer by melting snow and boiling water at the air pressure of 1001 hPa. He also

gave a rule for correcting the points in case of deviating air pressure. The interval in between he divided into 100 degrees. In this way Celsius had succeeded in constructing a sufficiently accurately defined temperature scale, and thereby temperature unit, useful universally. Celsius concludes:

“When one thus is certain about these two fixed degrees ... then you can be sure that several such thermometers, put in the same air, will always show the same degree, and that e.g. a thermometer made in Paris will, at the same heat, show the same height as a thermometer made in Uppsala.”

As stated in Section 5.3, the very first time Celsius used his own thermometer scale was on Christmas Day 1741, in combination with his indoor gravity measurements. This thermometer is possibly the one still preserved; see Figure 5-16. Outdoors, for the official weather observations, Celsius' temperature scale was introduced on 2 June 1743. A note in the meteorological diary by Hiorter states that this day was introduced “the experimental thermometer, hereafter called the Celsius one”; see Figure 5-17.

Between these two events, in winter 1742, Celsius in a letter to the Royal Academy of Sciences on some meteorological matters informs: “I have also worked on some *Remarks on how to achieve two fixed degrees on the thermometer*, which I soon will have the honour to submit to the Royal Academy.” He did so, and his paper, from which is cited above, was published later the same year; see Figure 5-18. In the end, as we know, Celsius' way of constructing a temperature scale spread over the world, now being an international standard.

Celsius' division of the scale into 100 degrees is not surprising bearing in mind that the decimal system had been introduced into the Swedish length units in 1739, at the same time as he worked on the unit for temperature. (The decimal system for lengths was used parallel to the duodecimal.) The same year the decimal system was also partly introduced in the monetary system. Celsius used the new decimal system for lengths himself in his temperature paper, giving the height of the barometer in decimal inches and lines according to 1 Swedish foot = 10 inches = 100 lines.

31. 1. 5 $\frac{1}{2}$ a.	91.	40,3.	130,0.	39,8.	SO.	1.	-	Nubes sparsae.
10. a.	92.	32,2.	123,7.	27,8.	S.	1 $\frac{1}{2}$	-	Nubes sparsae.
5 $\frac{1}{2}$ p.	91+	18,7.	116,4.	12,8.	S.	1 $\frac{1}{2}$	-	Sol inter nubes spissiores.
10 $\frac{1}{4}$ p.	92.	27,9.	121,0.	23,4.	SSW.	1.	-	Nubes sparsae.
Jun: 1. h. 5. a.	90+	37,6.	128,8.	37,2.	SW.	1 $\frac{1}{2}$	-	item.
10 $\frac{1}{4}$ a.	89.	31,1.	123,9.	27,6.	SW.	1 $\frac{1}{2}$	-	nubecula tenues.
3 $\frac{1}{2}$ p.	87.	24,4.	117,5.	16,5.	WSW.	2.	-	- sparsae.
10. p.	87.	31,8.	126,1.	31,2.	W.	2.	-	Serenum.
2. 6. a.	82.	40,7.	129,2.	37,8.	W.	2 $\frac{1}{2}$	-	Sol inter nubes.

Denna dagen blefwo Thermometerne omväxlande, liä at i fallet för den li kallade Norum eller Hankbyanum minus, kom Prinjianum majus & minus, tillika med Experiment-thermometern, som hädan-efter här kallas Celsiusium.

1743. Jun.	Baro- metr.	Thermometra				Cels:	Ventus:		Plu- brom.	Caeli facies!
		Hankb. de Cij.	Prinjian. majus.	Prinjian. minus.	Cels:		plu: & gr:	brom.		
2. 3 $\frac{1}{4}$ p.	29.81.	29,8.	122,6.	68,5.	68,5.	80,7.	WSW.	3.	-	Sol inter nubes.
10. p.	81.	32,1.	123,5.	68,4.	68,2.	83,4.	SW.	1 $\frac{1}{2}$	-	Serenum fore.
3. 5 $\frac{1}{4}$ a.	82 $\frac{1}{2}$	40,0.	129,2.	66,3.	66,5.	85,0.	SW.	1.	-	item.
10. a.	87 $\frac{1}{2}$	36,5.	126,6.	64,0.	64,0.	83,4.	WSW.	2.	-	Sol inter nubes.
3 $\frac{1}{2}$ p.	90.	28,9.	124,5.	70,0.	70,0.	79,8.	W.	2.	-	item.
10 $\frac{1}{4}$ p.	75-	28,3.	123,2.	68,0.	68,0.	81,6.	W.	1 $\frac{1}{2}$	-	Serenum.
4. 5. a.	78.	40,1.	129,2.	68 $\frac{1}{4}$ .	68 $\frac{1}{4}$ .	85,2.	W.	0 $\frac{1}{2}$	-	item.
3 $\frac{1}{2}$ p.	30.02.	20,0.	116,0.	76 $\frac{1}{2}$ .	76 $\frac{1}{2}$ .	76,0.	N.	1 $\frac{1}{2}$ fl. SO.	-	Nubes sparsae.
10 $\frac{1}{4}$ p.	07.	25,6.	124,6.	70+	70 $\frac{1}{4}$ .	80,8.	-	0.	-	Serenum.
5. 4 $\frac{1}{4}$ a.	09-	39,0.	129,7.	68 $\frac{1}{2}$ .	68 $\frac{1}{2}$ .	86,0.	-	0.	-	item.
10. a.	09.	27,8.	124,8.	70 $\frac{1}{4}$ .	70 $\frac{1}{4}$ .	77,8.	S.	1.	-	it.
4 $\frac{1}{4}$ p.	03.	15,0.	113,5.	80.	79.	74,5.	SSW.	1 $\frac{1}{2}$	-	item.
10 $\frac{1}{4}$ p.	29.97.	24,5.	131,2.	70 $\frac{1}{2}$ .	70 $\frac{1}{2}$ .	80,5.	SW.	1 $\frac{1}{2}$	-	item.

Figure 5-17. Part of the weather journal of the Uppsala Observatory with a note, inserted into the chronological table, introducing Celsius' thermometer in 1743. The readings according to Celsius' scale (the inverted version) are given in the column "Cels" added after the note. Celsius' careful temperature data later led Wargentin to discover a climate change.

Celsius put 0 degrees at the boiling point and 100 degrees at the freezing point; the scale was so to speak upside down. This was not unusual at that time, thereby avoiding negative numbers for normal temperatures. However, only a few years later the scale was turned the way we are used to, with 0 degrees at the freezing point and 100 degrees at the boiling point. As far as can be judged this was probably done by the instrument maker often used by Celsius, Daniel Ekström. This was only a minor modification; the fundamental property of the Celsius

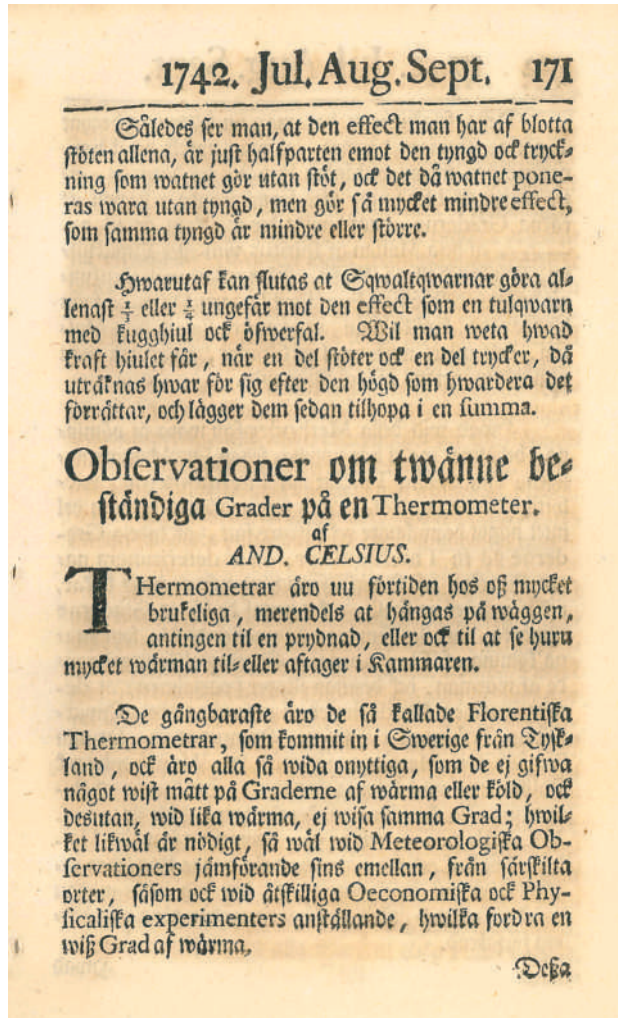


Figure 5-18. The title page of Celsius' paper announcing his well-defined temperature scale in 1742.

temperature scale is its accurate physical definition of the two fixed points.

As pointed out earlier, in connection with the northern lights as well as land uplift, Celsius had a long-time perspective on the collection of scientific data. This appears also from his letter to the Academy concerning temperature measurements where he says:

“One has reasons to believe that here at the Observatory a meteorological journal will be kept ever after.”

Celsius' belief has become true. Since 1722 there have been temperature, air pressure and other meteorological data recorded at Uppsala, the longest reliable series in the Nordic countries and one of the longest in the world. Modern investigations have confirmed that the thermometer measurements and thermometer scales used in the early years, before Celsius invented his own, are capable, through Celsius' overlapping measurements, of being transformed into the Celsius scale.

The temperature measurements at Uppsala during Celsius' time were made at least twice a day. This was at sun rise and after noon, when the temperature could be expected to have its minimum and maximum, respectively. This meant that the observer, first Celsius and then Hiorter, had to get up extremely early in the morning day after day during the summer. Wargentin, their colleague, later paid his tributes to them:

“The effort of every day getting up with the sun, especially in summers when it by us rises so early, shows the endurance of our observers, something which few foreign observers in the long run have endured.”

Wargentin knew what he talked about; he had to do the same thing himself in Stockholm where he had moved from Uppsala when he wrote this.

The systematic temperature series resulting from the work of Celsius and his followers was a data set that caught the interest of the statistically minded Wargentin. Instead of concentrating on extreme values, as had been done hitherto, he concentrated on mean values. He calculated mean values for 10-day-periods, months, and years, showing among other things numerical values of the seasonal variation. Doing the same also for the temperature at the Paris Observatory, he was able, for the first time, to compare the temperature climate at different latitudes. He found that an average winter in Paris was one month shorter and 6 - 8 degrees Celsius warmer than in Uppsala, and that an average summer in Paris was two months longer and 2 - 3 degrees warmer than in Uppsala. He also noted the difficulty in finding

systematic temperature data from other places; not even Paris could produce useful data for more than a few years.

After a long series of years had passed, Wargentin, based on the temperature records at Uppsala by Celsius and his followers, was able to make a remarkable discovery. The winters had become systematically colder and longer! This must be the first discovery in the world of a climate change. It was made possible through Celsius' early and systematic temperature measurements. Wargentin comments:

“We hope that the winter and spring cold will not continue to increase in the future, but that the seasons will return to their normal state.”

The cold did not continue to increase, but neither did the seasons return to what Wargentin thought was their normal state. Today we can confirm that winters at Uppsala during Celsius' time were very mild for three decades, 2°C warmer than afterwards. That is comparable only to the mild winters during the recent few decades.

## **5.7 Magnetism and magnetic changes**

The magnetism of the Earth had been studied since the early 1600s. The horizontal direction of the magnetic field could in principle be investigated by a compass. The compass needle shows the direction approximately towards the magnetic pole, which differs somewhat from the direction towards the rotational pole. This deviation of the magnetic field, also known as its declination, was both practically important for navigation and interesting from a scientific point of view. It could be determined by comparing the direction of the compass needle with the direction towards north, the latter being found astronomically through observing the culmination (extreme altitude) of the sun or a star.

In London, Graham had constructed a sort of large compass, with a needle one foot long, for more accurate studies of the magnetic declination. Celsius had ordered such a one when he was there and now used it in Uppsala. When observing the needle he was careful not to carry anything containing iron, like keys or shoe-buckles.



Celsius made a careful determination of the magnetic declination in Uppsala in 1740. In order to avoid disturbing magnetic material he used his large compass outdoors in his mother's garden. He read the direction of the needle several times, after having in between disturbed it in two different ways: sometimes by putting his keys close to it, sometimes by moving the compass to another place. He obtained an average declination of  $8^{\circ}49'$  to the west, with an uncertainty of only some  $3'$ . Four years earlier, during the expedition to the Arctic Circle, he had found the magnetic declination at Torneå to be  $5^{\circ}05'$  to the west. It should be mentioned here that Hellant, Celsius' assistant continuing to operate the small branch observatory at Torneå, performed further studies of the magnetic declination there.

The magnetic field also has a vertical direction, known as the inclination. This is close to zero at the equator and close to  $90^{\circ}$  at the magnetic poles. Celsius bought a special instrument from London for determining also the magnetic inclination in Uppsala. From a large number of observations he found an average inclination of  $74^{\circ}58'$ , however with a much larger uncertainty than for the declination. Four years earlier, during the expedition to the Arctic Circle, he had found the magnetic inclination at Torneå to be  $78^{\circ}05'$ .

The magnetic declination in particular had been measured at several places on the Earth. Apparently the Earth as a whole functioned as an enormous magnet. Today one can trace its origin to currents in the fluid core of the Earth. It was also known that the magnetic declination was not constant; it changed gradually with time. Celsius, in one of his papers, gives an increase of the declination of the order of  $10'$  per year, as found in London and Paris, but does not seem to have shown any particular interest in the phenomenon, in spite of its importance for navigation.

What made Celsius interested, however, was Graham's recent finding in London that there was a daily variation in the magnetic declination. Celsius decided to investigate that more closely. Observing carefully the direction of his long magnetic needle about once every hour Celsius could establish that there was such a daily variation also in Uppsala. As usual Celsius was careful about investigating perturbing effects:

“When I observed, I had no key or iron with me. All iron that might be here and there in my room, as in the window and the door, was always kept at the same distance from the needle, to permanently affect it in the same way. I have also, especially when the first changes appeared, pulled the needle by a key from its position and kept it at its position by the former observation, but when the key was taken away I have always found the needle returning accurately to the same point.”

While Celsius’ original long compass is no longer preserved, a contemporary copy of it made by Ekström is; see Figure 5-19.

Celsius found an amplitude in the diurnal variation of the magnetic needle of some 10'. He checked whether this magnetic variation could be in some way correlated with meteorological parameters but did not find anything of the kind: “I have still not noticed that cold, heat, differing air pressure, wind etc. have anything to do with this change.” The periodic variation in the direction of the magnetic needle seemed to depend only on the time of the day. This would indicate some kind of dependence on the sun.

After some time, Celsius left Hiorter to care for the magnetic measurements “for further investigating the changes of the magnet”. The magnetic needle was moved from Celsius’ room to Hiorter’s, where it



*Figure 5-19.* The contemporary copy of the long magnetic needle (compass) ordered by Celsius from Graham in London in 1736 and used for studying changes in the magnetic field.

would not be disturbed by visitors. Perhaps Celsius also would like his sleep not to be disturbed. From now on, Hiorter observed the magnetic needle almost every hour for nearly one year, except for a short sleep during night. He writes:

“Within one year or during 46 weeks I had 6638 mostly difficult observations performed (with a very convex glass, by candlelight, in a cold room during winter) of the magnetic needle.”

Later on, after moving to the large Observatory, Celsius again, for some time, continued the observations. Hiorter, using his own as well as Celsius’ observations, now found that the diurnal variation was not the same all through the year. The diurnal variation of the magnetic needle to some extent depended on the season of the year. This, again, indicated some kind of dependence on the sun.

In addition to the above more or less systematic and periodic changes there sometimes appeared something else: Seemingly spontaneous changes of the direction of the magnetic needle. They could be both large and rapid: The direction of the needle could change by the order of  $1^\circ$  within less than one hour. In spring 1741 Celsius wrote a letter to Graham in London asking him to check his magnetic needle for such unpredictable changes. The purpose of this was to find out whether these magnetic changes occurred at the same time in London and Uppsala and, hence, had some global origin and not a local one. Probably sooner than expected Celsius obtained a reply:

“I began to observe the needle upon April 3, 1741, but did not write down the observations till Sunday the 5th and did not observe the needle till after 12 o’clock at noon that day. The alterations that day were greater than I had ever met with before, though no alteration of any thing in the room could occasion it. It was a fine day. I was alone all the time, and observed the needle with all the care possible.”

At the same time Hiorter had observed the same alterations of the magnetic needle in Uppsala! The conclusion was clear: The considerable spontaneous magnetic changes could not be a local effect – they had to be a global phenomenon. But what caused them was a mystery.



*Figure 5-20.* Strong northern lights over Uppsala of the kind often observed by Celsius.

## 5.8 Northern lights and a big surprise

Northern lights (aurora borealis) had been rarely seen during the 1600s but were now, during the first half of the 1700s, much more frequent. We have seen in Chapter 4 that Celsius during his international tour collected observations of the northern lights to try to find out where in relation to the Earth they occurred. If possible to simultaneously observe from widely separated places on the Earth, the northern lights had to occur sufficiently high up in the atmosphere; see Figure 5-20. He even suggested that simultaneous observations of the northern lights, like those of Jupiter's moons, might be used for longitude determination in northerly countries.

In the preceding section we noted that when Celsius started his magnetic observations in Uppsala he checked whether there could be any correlation between magnetic changes and meteorological ones. The meteorological observations included the northern lights. Nothing

particular of this kind was observed until suddenly one day in winter 1741, after Hiorter had taken over the magnetic observations. Then there were magnificent northern lights over more than half of the sky, also in the south:

“The first time I noticed northern lights in the south and also a large change of the magnetic needle was on March 1, 1741, in the evening. ... A few times thereafter the needle was again disturbed, but in cloudy weather. Then on March 26, after 12 o'clock in the night, a large change of the magnetic needle occurred and strong northern lights covering the whole sky could be seen, also in the south. Through this the professor [i.e. Celsius] together with me began to be more convinced about this matter. Such combination was, from now on, observed more than 40 times, especially on April 5.”

At the first event the magnetic needle changed its direction by 24', at the second event by 52', and at the third event by as much as 1°40'. It was between the first and second events that Celsius sent his letter to Graham in London, asking him to observe the magnetic needle there, and so Graham fortunately observed the third event, on April 5, simultaneously as Hiorter did so in Uppsala, as explained in the preceding section.

Hiorter and Celsius had discovered something most unexpected: There was a connection between northern lights and magnetism! And it seemed to be a global phenomenon. When strong northern lights occurred, covering more than half of the sky, the direction of the magnetic field underwent rapid changes. And the changes could be considerable, up to 4°; see Figure 5-21.

In common with his determinations of latitude, Celsius never published anything on this topic of the northern lights before he died a few years later. It was Hiorter who published the discovery in 1747. In his paper he claims that the discovery was made first by Celsius and then by himself independently of each other. He may, however, have had special reasons for giving Celsius the credit. The fact that it was Hiorter who made the magnetic observations at the time of the discovery speaks in favour of Hiorter actually having made the discovery. On the other hand, it seems that Celsius already had practised the idea of comparing observations of the magnetic field and those of phenomena in the

Year	Month	Day	Disturbance
1741	Mart.	1	-- 0, 24
	Mart.	26	-- 0, 52 $\frac{1}{2}$
	Apr.	5	-- 1, 40
	Jul.	12	-- 0, 15
	Jul.	29	-- 0, 10
	Jul.	30	-- 1, 12
	Aug.	2	-- 0, 7 $\frac{1}{2}$
	Aug.	9	-- 0, 34
	Sept.	21	-- 1, 33
	Sept.	27	-- 0, 22
	Sept.	28	-- 3, 40
	Sept.	29	-- 0, 32
	Oct.	4	-- 0, 18
	Oct.	8	-- 0, 40 $\frac{1}{2}$
	Oct.	24	-- 0, 38
	Oct.	31	-- 0, 23
	Nov.	1	-- 0, 26
	Nov.	20	-- 0, 48
	Dec.	10	-- 0, 40

Figure 5-21. List by Hiorter and Celsius of large magnetic disturbances observed by them in connection with strong northern lights in 1741. This was the basis of their discovery of the connection between the magnetic field and the northern lights, presented by Hiorter 1747.

atmosphere, and it was Celsius' idea to establish magnetic comparisons with Graham in London. Without knowing the details it seems fair to give Hiorter the main credit for the discovery, with Celsius as an important contributor.

Celsius' two main assistants in Uppsala, in their comments on the discovery, both reveal what a surprise this was. Hiorter himself when publishing the discovery writes:

"But who could have imagined that the northern lights have something in common with and are connected to the magnet?"

And Wargentin a few years later says:

“One of the most remarkable discoveries in nature having been made during these last years is the connection between the magnetic needle and the northern lights.”

### 5.9 Science, family and friendship – and love?

In the life of Celsius science, family and friendship seem to have been closely connected. We have earlier noted that a long row of his relatives were involved in various ways in astronomy and Earth science, holding prominent positions at the University or the Academy: His father’s father (Magnus Celsius), his mother’s father (Anders Spole), his mother’s sister’s husband (Pehr Elvius), his father (Nils Celsius), his sister’s husband (Olof Hiorter), his cousin (Pehr Elvius the younger), his cousin’s fiancée (Daniel Ekström), and his cousin’s husband (Mårten Strömer). There were also some relatives holding prominent positions in law, languages and history, respectively: His father’s elder brother (Johan Celsius), his father’s younger brother (Olof Celsius) and his cousin (Olof Celsius the younger). And his mother (Gunilla Spole) and his sister (Sara Märta Celsius), as we know, managed a university eating-house.

We have also noted that Celsius had several friends with scientific connections. At the University both Carl Linnaeus and Samuel Klingenskierna were his friends, as were also his co-workers Olof Hiorter and Pehr Wargentin. And during his scientific travels abroad he easily made friends with the people he met there, also with the female scientists.

But what about love? Celsius never married and raised a family of his own. Nor did he have any other known relationship of such a kind. There is no sign of love, at least not of a permanent character. Bearing in mind his many contacts and his easiness to make friends everywhere, even with female scientists, this is rather surprising.

Did he miss not having a wife and a family? There is no sign of that either. He seems to have been a person quite content with his life. To his cousin Beronius he once wrote, during his time at the Arctic Circle, in

his easy-going way: "I, who neither have wife nor children, as far as I know, do not worry about tomorrow."



## 6. After Celsius: An unusual heritage

### 6.1 The sudden end of life

In 1743 Celsius was chosen to be the rector of the University for a period, something he was not happy about. He would not allow this to prevent his scientific work: "Rather they may complain that I am a neglectful rector" he remarked to the former university librarian, by now the archbishop of Sweden. Not much later an astronomical surprise occurred.

Towards the end of 1743 Hiorter one evening discovered an object in the sky that had not been there before. It turned out to be a comet. Next evening also Celsius observed it. From now on they observed the comet every clear night. On Christmas Day the comet had developed a small tail, as it does when approaching the sun. One month later the comet was brighter than every star in the sky, and its tail extended for nearly 18 degrees. At this stage, on 29 January 1744, Celsius arranged a visit of the Crown Prince, Adolf Fredric, to the Observatory in Uppsala. In the dark evening the Observatory was beautifully illuminated in his honour, and after having arrived he studied the comet through various telescopes. The event was a propaganda show by Celsius.

The following month the comet gradually faded. On February 24 Celsius as usual made annotations in the observation journals. After that day there is nothing more written by his hand. Celsius had suddenly become ill, seriously ill. He was affected by a lung disease, probably tuberculosis. His condition rapidly deteriorated.

Two months later Celsius was on his death-bed. His uncle sent him a clergyman to prepare him for his death. When the clergyman talked to Celsius about the immortality of the spirit and a life after death Celsius responded, in his usual free-spoken way: "Is that what you think, Sir? Well, quite soon I will be in the state where I will see whether that is true or not."

Anders Celsius died on April 25, 1744. He was only 42 years old. One week later he was buried in the Celsius family grave in the ancient



*Figure 6-1.* Epitaph over Celsius in the church of Gamla Uppsala. The text reads: “Clear sense, honest will, careful work and useful learning. As a memorial this monument was put up to the professor of astronomy Mr Anders Celsius, born 27 November 1701, dead 25 April 1744, resting below in the grave of his ancestors. May his bones rest in peace as safely as his reputation will never rest.”

church of Gamla Uppsala, a few kilometres north of Uppsala; see Figure 6-1.

After the funeral Celsius’ mother, Gunilla Spole, made an inventory of all his private belongings and submitted it to the University Senate. The list gives an interesting insight into Celsius’ private world at home. His clothes were old and well used. For daily use he had two gowns, one brown and one black, turned inside out because of wear and tear. For more special events he had two old coats, both of them red. Furthermore there were eight shirts, three pairs of stockings, three pairs of shoes and

one pair of boots. He also had a few silver things and some simple wooden furniture. In addition he owned a closed carriage, a gift from Maupertuis. On the whole, Celsius' personal belongings appear to have been remarkably few and simple. One might say that he lived in rather meagre circumstances. The exception from this was his library: It contained nearly 1500 books. They were donated by his mother and sister via Hiorter to the Observatory.

Celsius had died unexpectedly right in the middle of his active scientific life. A group of students expressed this both poetically and astronomically in the introductory rows of a long poem in memory of Celsius:

“What’s this? Is evening now arriving,  
When sun from highest still is shining?”

Gunilla Spole had lost her son, Sara Märta Celsius had lost her brother, Olof Hiorter and Pehr Wargentin had lost the one who inspired them, Carl Linnaeus and Samuel Klingenstierna had lost their friend, the Observatory had lost its founder, the University had lost a star.

## 6.2 The decline of the observatory

Only one week after Celsius' funeral the university chancellor started discussions with the University Senate on how to secure the immediate continuation of the observation series commenced by Celsius. The Senate decided that Hiorter should be responsible for continuing the observations; when needed, he should be assisted by Klingenstierna.

A related matter to be solved, although not quite as urgent, was to appoint a successor to Celsius as professor at the Observatory. This turned out to be a tricky question. There were two obvious persons who might apply for the professorship after Celsius: his two main assistants Hiorter and Wargentin. However, there were problems with both of them: Hiorter wanted the position, but was not qualified from the formal point of view; Wargentin was qualified from the formal point of view, but did not want the position.

Hiorter had served as stand-in for Celsius during his years abroad and had successfully worked together with Celsius during all the years after his return to Uppsala. However, Hiorter had only partially studied at the university level and was mostly self-educated. This was a clear draw-back when applying for the professorship after Celsius. This delicate situation was solved by making Hiorter an assistant professor at the Observatory, with the title Astronomer Royal, a new position especially created for the purpose. Wargentin, on the other hand, had a complete education and had already become known as a qualified scientist. He, however, felt too shy and humble to apply for the professorship after Celsius. He simply refrained from applying for it in spite of people supporting him.

What to do in this situation? Well, Klingenstierna seemed prepared to exchange his professorship in mathematics for Celsius' professorship in astronomy. Before Klingenstierna was appointed, however, one of Celsius' former students announced his interest. That was Mårten Strömer, now at the Lund University in southern Sweden. Klingenstierna immediately informed the University that he wished to withdraw his application provided Strömer was appointed instead. So finally Strömer became professor in astronomy at Uppsala, with Hiorter as assistant professor and Astronomer Royal. In reality Hiorter would do most of the work at the Observatory.

For nearly 100 years astronomy at Uppsala had been in the hands of the Celsius family. Now Strömer arrived from the outside, with no connections to the family. In the end, however, this could be dealt with. As mentioned earlier, Ekström, the instrument maker, was engaged to be married to a cousin of Celsius, Anna Maria Elvius. It so happened that Ekström died. Hence Celsius' cousin became free to marry someone else. And Strömer took the opportunity: They married. In this way also Celsius' successor became related to the Celsius family.

Within some years after Celsius' death, both Hiorter and Strömer started complaining about the location of the Observatory. Hiorter complained in a letter to Wargentin that the Observatory was situated at a low level in the city with smoke and fog, and that the towers of the cathedral prevented free line of sight to a part of the sky. Strömer pointed out the same things in a memorandum to the University Senate, and

added that carriages moving on the street caused vibrations in the Observatory building. In summary: Polluted air, high buildings and heavy traffic. This sounds like the problems of today! Strömer even proposed building a new observatory at a better location.

One might understand that the University Senate was taken by complete surprise by this. Only a decade ago had the Senate, persuaded by Celsius and his smart methods, contributed a lot of money to create the Observatory. And now Celsius' successors more or less condemned the same Observatory and wanted a new one! What should the University Senate believe?

It cannot be denied that much of the criticism against Celsius' location of the Observatory building was justified. Then why had Celsius chosen such a strange location for his Observatory? A more adequate location would have been on the hill on the outskirts of the city. There might have been several concurrent reasons for Celsius' choice. First, an opportunity emerged of buying an already existing house, and he was eager to get started as soon as possible. Second, the house was almost a neighbour to his mother's houses, where he himself lived and met people at her eating-house. Third, as more of a geophysical observatory than an astronomical one, its location might have appeared quite acceptable to him.

Six years after the death of Celsius, Hiorter also died. He was by then 54 years old. This was a further blow to the activities at the Observatory. Hiorter was succeeded as assistant professor by a student of Klingenstierna and Strömer, Bengt Ferner. It turned out that Ferner, among other things a great lover of the theatre, was not quite as ambitious as Hiorter.

With both Celsius and Hiorter dead, and with an unfavourable location for the Observatory, the activities at the Observatory started to decline. Celsius' Observatory, flowering for a decade, started fading. But everything was not going down. Temperature and air pressure continued to be measured with great patience. Moreover, work in the spirit of Celsius continued elsewhere; Wargentin was highly active in a new place.

### 6.3 A new observatory in Stockholm

In 1739, as stated in Section 5.1, the Royal Swedish Academy of Sciences had been founded in Stockholm, with the strong support of Celsius. Five years later, the same year as Celsius died, a cousin of Celsius, Pehr Elvius (the younger), was appointed secretary of the Academy. This was the same kind of position that Celsius had held in the Royal Society of Sciences in Uppsala. Elvius brought about something in Stockholm that Celsius had not managed to do in Uppsala: a privilege to issue almanacs. The Academy of Sciences was granted an exclusive royal privilege to issue astronomically-founded almanacs. This provided the Academy with a permanent and considerable annual income. Due to efforts of the Church, practically all the people in Sweden at this time were already able to read, and the annual almanacs by the Academy were published and sold in large numbers. With the Academy's finances thus secured, a further step could be taken: An observatory, erected for the Academy on a hill on the outskirts of Stockholm.

The Observatory of the Royal Academy of Sciences in Stockholm was founded in 1748. At the beginning of its erection Elvius unexpectedly died. A new secretary for the Academy was needed, and also an astronomer for its coming Observatory. Within a week after Elvius' death the Academy had, without hesitation, appointed a person for the combined position as secretary and astronomer. This person was Celsius' former assistant in Uppsala, Wargentin; a portrait of him is shown in Figure 6-2. This time Wargentin could not escape. There was no application procedure to consider; he was simply asked by an unanimous Academy to accept the position. He humbly and gratefully did so. Wargentin could now in Stockholm further develop several of the works that Celsius had started upon in Uppsala.

The Stockholm Observatory was inaugurated five years later, in 1753. It was designed by the same architect that Celsius had used for the Uppsala Observatory, Carl Hårleman. The result this time was an observatory building both somewhat larger and more beautiful; see Figures 6-3 and 6-4. In particular, it had a splendid location on top of a nice hill. Its yellow colour was the same as in Uppsala. When the building was completed Wargentin moved in, to work on his science as well as to live with his family. The Stockholm Observatory is still there



*Figure 6-2.* Pehr Wargentin, Celsius' assistant who moved to Stockholm.  
Painting by Carl Fredrich Brander 1774.

to be seen on its hill. It is one of the oldest observatories in the world kept in its original state, and without considerable later expansion.

Wargentin kept in close contact with his friend and colleague in Uppsala, Hiorter. A week after his appointment in Stockholm he wrote to Hiorter to thank him for "every happy moment we have had together in Uppsala". He also sent his greetings to "the wives", i.e. Celsius' mother and sister, the latter being married to Hiorter.

Wargentin's activities at the Stockholm Observatory were very much inspired by those of the Celsius group at Uppsala. He concentrated on the novelty so eagerly promoted by Celsius, long consistent data series and their analysis. He observed the motions of Jupiter's moons for longitude determination, measured temperature and air pressure for climate studies and followed the changes of the magnetic field.



*Figure 6-3.* The Stockholm Observatory during Wargentin's time. Engraving in the Transactions of the Royal Swedish Academy of Sciences 1761.



*Figure 6-4.* The Stockholm Observatory today.



The Jupiter moons, which had made Wargentin internationally known already in Uppsala, became the passion of his life in Stockholm. He took almost every opportunity to observe the eclipses of the four moons, trying to figure out patterns in their irregular motions. When sometimes prevented by some other duty, he loyally undertook it but was not happy about it. In a letter to Hiorter in Uppsala he once writes:

“May God give a clear sky tomorrow evening. I was prevented from observing the eclipse last Saturday, because Meldercreutz was quarrelling such a long time in the Academy meeting.”

From his steadily increasing data set of observed times for eclipses of the Jupiter moons he was able to produce steadily improved tables of predicted times for future eclipses. Wargentin had a remarkable ability to detect statistical patterns in large amounts of data; he used this ability to construct his tables. As explained in Section 5.2, Wargentin’s tables became world-leading and were used internationally for determination of longitudes.

Wargentin’s observations themselves also became used internationally. When Jupiter’s moons had been observed for longitude purposes at one station in Europe, the largest probability of finding corresponding observations at another station was by Wargentin at the Stockholm Observatory. This made Wargentin a key person and Stockholm a key observatory for longitude determination in their early days.

After 12 years at the Stockholm Observatory Wargentin had collected a large number of observations of the Jupiter moons. From the Observatory in Paris he received their Jupiter observations during the same period. Wargentin in a longitude paper of his writes:

“I have, during the last 12 years, had the opportunity to make a number of reliable observations at the Observatory in Stockholm, with the purpose of finding out its geographical longitude. ... Since the observations of the first or innermost moon of Jupiter give the most reliable values of the longitude, without troublesome calculations, I will keep to them in order to obtain the difference between the meridians of Paris and Stockholm.”

Wargentin's result for the longitude of Stockholm relative to Paris was  $15^{\circ}42.5'$ . The error in this result amounts to  $0.8'$ , the correct value being  $15^{\circ}43.3'$ . This error is nearly one order of magnitude smaller than that of Celsius for Uppsala, but it required a tremendously larger amount of observations.

After another 12 years Wargentin had improved the longitude difference between Paris and Stockholm, using the Jupiter moons, to  $15^{\circ}43.2'$ . This yields an error as small as  $0.1'$ , corresponding to less than 1 s in time and 200 m on the ground. This was probably the best longitude determination in the world at that time.

Wargentin then turned his interest towards Greenwich in London. Using 10 years of observations of Jupiter's moons from the observatories of Stockholm and Greenwich he found a longitude difference between them of  $18^{\circ}05.2'$ . This yields an error of  $1.7'$ , the correct value being  $18^{\circ}03.5'$ . This is clearly less accurate than the difference between Stockholm and Paris. Hence the error here must primarily have depended on the observations at Greenwich.

Actually, the head of the Greenwich Observatory, the Astronomer Royal, Nevil Maskelyne, had asked Wargentin to calculate for him the longitude difference between Greenwich and Paris. Maskelyne in his paper on this characterizes Wargentin as "the learned secretary of the Royal Academy of Sciences at Stockholm, and author of the improved tables for computing the eclipses of Jupiter's satellites, who collected observations of them from the principal observatories of Europe". It is quite remarkable that one of the official values at this time of the longitude difference between the fundamental observatories of Greenwich and Paris was determined in Stockholm, through Wargentin's observations of his beloved Jupiter moons there.

Of course, Wargentin also made an accurate determination of the latitude of the Stockholm Observatory. He obtained  $59^{\circ}20'31.3''$ , where the standard error seems to be as small as  $1 - 2''$ . His absolute error turns out to be only  $1.7''$ , corresponding to 50 m on the ground, the correct value being  $59^{\circ}20'33.0''$ . As mentioned earlier deflections of the vertical caused by irregular mass distribution within the Earth will also influence the result, but we leave that aside here.

The accurate values of the coordinates of the Stockholm Observatory proved useful in a very special international context. In the early 1750s French scientists wanted to determine accurately the distance to the sun and the planets, then only poorly known. This could be accomplished by making simultaneous observations of the planet Mars from an extremely southern station, decided to be Cape Town in South Africa, and an extremely northern station on (almost) the same longitude. Such a project had already been planned by Celsius ten years earlier but never materialized. The optimum northern station now turned out to be Stockholm, thus becoming part of an early scientific cooperation across the whole Earth. The results, first published by Wargentin, soon proved less accurate than expected, but renewed attempts with better methods some years later using Venus were quite successful.

Moreover, Wargentin together with Strömer, Celsius' successor, through several decades led a large positioning project of great practical importance, decided by the Swedish Parliament. This was a triangulation along almost the whole coast around the Baltic Sea, combined with astronomical positioning, with the purpose of producing nautical charts. This was extended from the pioneering triangulation across the Åland Islands treated in Section 5.2. In this way the Baltic Sea very early obtained greatly improved charts based on the new method of triangulation, introduced here by Celsius' participation in the French arc measurement at the Arctic Circle.

Wargentin, as Celsius in Uppsala, also started meteorological observations in Stockholm, performed in a systematic way since 1756. The combination of the Uppsala and Stockholm series of temperature and air pressure is valuable; it allows checking of a number of error sources that are important when using the series for studying climate changes.

However, a most interesting novelty created by Wargentin was something completely different and yet closely related to his ordinary works at the Uppsala and Stockholm Observatories: population statistics and insurance mathematics. Through the Church of Sweden, data about the Swedish population, like births, marriages and deaths, had been collected for many years. Wargentin, with his statistical ability to handle large amounts of data of Jupiter's moons for longitude determination,

or long series of temperature data, realized that he could use this ability of his also for population data. This resulted in Sweden starting the first systematic collections and analyses of population statistics in the world. As with the Jupiter moons, Wargentin spread his ideas and results internationally via renowned authors in other countries; in particular his methods and tables were included in the first British books on population statistics and insurance mathematics. Thus, even Sweden's uniquely long population statistics goes back to the fact that Celsius' Observatory in Uppsala was one of the first institutions in the world to systematically collect and handle large amounts of numerical data.

#### **6.4 The unknown man with the well-known name: Looking back**

The title of this book indicates that the person behind "degrees Celsius" was a not only a temperature man but more generally a pioneer in investigating the Earth and its changes, a kind of pioneer in geophysics in a wide sense. And in the Introduction it says that he did not work alone, but created a loose group of assistants around him whom he inspired and who worked in his spirit. So what were the pioneering works of Celsius and his assistants? Collecting what has been treated in the chapters of this book we might list them briefly as follows:

- First arc measurements in the world for determining the shape of the Earth and testing the theories of Newton (Celsius & French scientists 1736/1738)
- New method of latitude determination by means of stars (Celsius 1739)
- First longitude determinations and first zero meridian in the Nordic countries (Celsius 1741)
- World-leading tables of Jupiter moons for longitude determination (Wargentin 1741)
- New idea of coastal positioning for mapping, basic principle similar to satellite positioning (Meldercreutz 1741)
- First triangulation in the world for marine charting (Gadolin 1748)
- First gravity measurements in the world for determining the flattening of the Earth and testing the theories of Newton (Celsius & French scientists 1736/1741)
- First determination of a continued vertical motion of the Earth's surface in the world, sea lowering / land uplift (Celsius 1731/1743)

- First air pressure measurements in the Nordic countries (Celsius 1722)
- Discovery of relation between air pressure and sea level (Gissler 1747)
- First temperature measurements in the Nordic countries (Celsius 1722)
- World-leading temperature scale and international temperature unit (Celsius 1742)
- First climate statistics and first study of climate change in the world (Wargentin 1757/1778)
- First measurements of magnetic changes in the Nordic countries (Celsius 1740)
- Discovery of relation between the northern lights and the magnetic field (Hiorter & Celsius 1747)

Taken together the above items no doubt form a pioneering work in the scientific study of the Earth and its changes, performed through systematically collecting and handling numerical data. This was deliberately made for the benefit of future generations, too.

We have also learnt to know Celsius as a friendly and free-thinking person, interested in spreading useful knowledge to others in society. This is summarized in the obituary after his death: "A special gift for making his views understandable also to the general public made his name known with credit among them as well as among learned people. In personal relations he showed both kindness and brilliance, making a relation with him nice as well as desired."

As all of us, Celsius also had his weaknesses. They have shown up in his way of buying instruments before he was allowed to, and in his erecting of the Observatory in a location less suited for its purpose. And, as for all of us, Celsius also had his somewhat mysterious side, easily finding friends but never finding someone to live with. His mother and sister, however, running their eating-house for students and teachers, were always close to him.

Today, as said, Celsius is the unknown man with the well-known name. Hopefully, this book has given you some impression of Celsius and his novel contributions, made at a small northern university three centuries ago, to understanding the planet we live on.

## Appendix: A dramatic love story

As said in Chapter 4 (Section 4.2), Celsius during his international study tour, while being in Bologna in Italy in 1733, became fascinated by a mysterious text on an old Roman tombstone, commemorating two persons known as Laelia and Agatho. The text is enigmatic, like a riddle. Inspired by this unusual tombstone Celsius wrote a short and tragic love story as a possible solution to the riddle. This love story is still preserved among Celsius' papers left at his death (now in the University Library). Celsius' story is here translated and published, together with the riddle on the tombstone. The translation of Celsius' story from Swedish is due to the author, the translation of the riddle from Latin is a combination from several sources.

### *An unsolved riddle on a Roman tombstone*

Aelia Laelia Crispis  
 Not man, nor woman, nor androgyne  
 Not girl, nor youth, nor old  
 Not chaste, nor unchaste, nor modest  
 But all  
 Carried off  
 Not by hunger, nor by sword, nor by poison  
 But by all  
 Lies  
 Not in air, nor in earth, nor in water  
 But everywhere

Lucius Agatho Priscus  
 Not her husband, nor her lover, nor her friend  
 Not mourning, nor rejoicing, nor weeping  
 But all  
 Erecting this  
 Not mound, nor pyramid, nor tomb  
 But all  
 Knows and knows not  
 To whom he erects it

*A solution to the riddle: A love story by Anders Celsius*

Laelia was in love with Agatho, but they could not have each other. Laelia's parents wanted her to marry another man, one she did not want. Now since Agatho was a soldier he persuaded her to run away without permission from her parents and follow him. He was going to war. Laelia therefore dressed in men's wear and went together with Agatho in the field. She became a soldier like him. During this time Laelia and Agatho were always comrades. Otherwise they lived together like man and wife, but apart from that Laelia was chaste and shy and loved nobody else than her lover Agatho.

Once when they, after some days of marching, had got nothing to eat, and in the evening arrived at a lodging, they were very hungry. Especially Laelia, who did not have power to fast as much as Agatho, was very hungry, so she unwittingly and in haste came across bread that was poisoned and ate it up. When the people there told her that she had eaten poisoned food, she made the decision that she would kill herself. In that way she would spare herself from being tormented for a long time, since the poison was of the kind that you do not rapidly die of. Because of this she made her dear Agatho, through a will, her heir, as her parents were quite rich.

Since neither Agatho nor she herself wanted the other soldiers to know that she was a female, which easily could have happened if she had died by the poison in their presence and then, because of that, would have been buried, she soon went with Agatho to the sea shore. There they took a boat and went out to a small island that was mostly covered by water but now could be seen just above the water. There Laelia said farewell to her faithful Agatho, and then stabbed herself with the sword.

After that Agatho went away, leaving his dear Laelia with much mourning and weeping, but also happy to some extent because he had inherited so much. When the war came to an end Agatho went home. Since Laelia's parents then were dead and she was their only heir, a nice property came into his hands. Since he was an educated man he also wanted to make Laelia the last token of honour that could serve as a memorial for the future of her spiritual fate. He thus erected a pyramid on his land that he now had inherited, and put on it their enigmatic

inscription. [An additional sentence by Celsius' hand is no longer possible to fully read.]



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## Illustrations

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4-2 Author

4-3 Public

4-4 Public

4-5 Maupertuis (1738)

4-6 Outhier (1744)

4-7 Author

4-8 Maupertuis (1738)

4-9 Author

5-1 Author, painting in private possession, see Preface (photo by Yehia Eweis)

5-2 Busser (1769)

5-3 Author

5-4 Uppsala University Library

5-5 Uppsala University Library



- 5-6 Uppsala University Library
- 5-7 Celsius (1743c)
- 5-8 Wargentin (1742)
- 5-9 Author
- 5-10 Author (object in possession of Uppsala University)
- 5-11 Celsius (1743a)
- 5-12 Author
- 5-13 Lyell (1835)
- 5-14 Author
- 5-15 Author
- 5-16 Uppsala University, Museum Gustavianum
- 5-17 Uppsala University Library
- 5-18 Celsius (1742a)
- 5-19 Author (object in possession of Royal Swedish Academy of Sciences)
- 5-20 Walter Puccio, Swedish Institute of Space Physics
- 5-21 Hiorter (1747)
  
- 6-1 Author (photo by Mikael Wallerstedt)
- 6-2 Royal Swedish Academy of Sciences, Center for History of Science (photo by Staffan Waerndt)
- 6-3 Wargentin (1761)
- 6-4 Author

## Index

### A

- Åbo (Turku) 88  
 Adolf Fredric (Crown Prince of Sweden) 120  
 Agatho (Lucius Agatho Priscus) 133-134  
 Akrel, Fredrik 14, 73  
 Åland Islands 88, 90, 130  
 Åland Sea 88-89  
 Algarotti, Francesco 47  
 Amsterdam 21  
 Antibes 47  
 Arctic Circle 11, 15-16, 24, 50, 53-55, 57, 61, 64-65, 67, 69-70, 80, 84, 88, 90-92, 94, 105, 112, 118, 130  
 Arenius, Olof 41

### B

- Barbara ("Signora Barbara") 46  
 Benzelius, Eric (former university librarian) 16, 25, 36, 43-44, 50-51, 65, 71, 80, 120  
 Berlin 16, 43-44, 47, 87  
 Beronius, Magnus 46, 118  
 Bilberg, Johan 15, 24  
 Biurman, Georg 43, 47, 51, 85  
 Blaeu, Joan 21  
 Bologna 21, 45, 133  
 Boyle, Robert 21  
 Bradley, James 52  
 Brahe, Tycho 22, 65  
 Brander, Carl Fredrich 126  
 Browallius, Johan 99  
 Burghard, Georg 20  
 Burman, Eric 33-36, 38-39

## C

- Camus, Charles 53  
 Cape Town 130  
 Carl XI (King of Sweden) 15, 19  
 Cassini, César Francois (de Thury) 48, 65  
 Cassini, Jacques 48, 60-61, 63-65  
 Cassini, Jean Dominique 48  
 Celsius, Anders 10 onwards  
 Celsius, Johan 28, 118  
 Celsius, Magnus (grandfather) 17-19, 23, 25-26, 29, 31, 76, 118  
 Celsius, Nils (father) 11, 14, 16, 19, 23, 25-29, 31-33, 76, 118  
 Celsius, Olof, the elder 29, 40, 118  
 Celsius, Olof, the younger 118  
 Celsius, Sara Märta (sister) 29-30, 62, 70-71, 76-77, 118, 122, 126, 132  
 Christina (Queen of Sweden) 14, 21  
 Clemens XII (Pope) 46  
 Clairaut, Alexis Claude 53, 60-61, 65, 67, 94  
 Constantinople 21  
 Copenhagen (København) 12, 22, 81, 84

## D

- Dalin, Olof 99  
 Daullé, Jean 64  
 Da Via, Giannantonio 46  
 Delisle, Joseph Nicolas 37, 47-48, 104-105  
 Delisle, mother of Joseph Nicolas 47, 105  
 Delisle, sister of Joseph Nicolas 47-48, 105  
 Duhre, Anders Gabriel 32, 36, 39  
 Dunkerque 53  
 Du Rietz, Carl Magnus 61

## E

- Ekström, Daniel 72, 92, 108, 113, 118, 123  
 Elvius, Anna Maria 123  
 Elvius, Pehr, the elder 28-29, 31, 33, 76, 118

Elvius, Pehr, the younger 118, 125  
Etna 21

## F

Fahrenheit, Daniel Gabriel 37, 103  
Falun 37  
Ferner, Bengt 48, 124  
Figrelius, Edmund 19  
Figrelius, Sara 19  
Fredric I (King of Sweden) 54, 62

## G

Gadolin, Jacob 88-89, 91, 131  
Gamla Uppsala 19, 121  
Genova 47  
Gissler, Nils 98, 101-103, 132  
Gotland 98  
Graham, George 51-52, 71-72, 92-93, 111-114, 116-117  
Greenwich 51-52, 86-87, 129  
Greifswald 20, 43, 78  
Gripenhielm, Edmund 19  
Gulf of Bothnia 24, 50, 55-56, 95-96, 100  
Gustaf II Adolf (King of Sweden) 13-14  
Gustavus Adolphus (King of Sweden) 13-14

## H

Hawksbee, Francis 37, 103  
Halley, Edmund 51-52  
Hårleman, Carl 73, 75-76, 125  
Härnösand 102  
Härstedt, Johan Gustaf 33, 77  
Hedraeus, Bengt 18  
Hellant, Anders 55, 60-62, 84-85, 112  
Hiorter, Olof 69-71, 76, 82, 94, 107, 110, 113-114, 116-118, 120, 122-124,  
126, 128, 132  
Högen 17

Hooke, Robert 21  
 Horn, Catharina 61  
 Horrebow, Peder 81  
 Huygens, Christiaan 21  
 Hven 22

## I

Iggön 95-96, 98  
 Île Bourbon 85

## J

Jamaica 91  
 Johan III (King of Sweden) 96

## K

Kepler, Johannes 65  
 Kirch, Christfried 43-44, 47  
 Kirch, Christine 44  
 Kirch, Gottfried 44  
 Kirch, Margaretha 44  
 Kittisvaara 56, 58, 62  
 Klingensstierna, Samuel 32, 35-36, 39-40, 43, 69, 76, 78-79, 94, 118, 122-124  
 Klopper, Jan 27

## L

Laelia (Aelia Laelia Crispis) 133-134  
 Lapland 43  
 Leiden 21  
 Leipzig 44  
 Le Monnier, Pierre Charles 53, 80, 85  
 Lindelius, Marta 25  
 Linnaeus, Carl 40, 43, 76-79, 98, 102, 118, 122  
 Lövggrund 99-101  
 London 16, 21, 50-52, 56, 61, 71-72, 91-93, 103, 111-114, 116-117, 129

Louis XIV (King of France) 21  
 Louis XV (King of France) 49-50, 62  
 Lund 22-23, 29, 123  
 Lyell, Charles 100

## M

Manfredi, Eustachio 45  
 Manfredi, Maddalena 45  
 Manfredi, Teresa 45  
 Maskelyne, Nevil 129  
 Maupertuis, Pierre Louis Moreau (de) 49-51, 53, 56-57, 59-65, 67, 122  
 Meldercreutz, Jonas 43, 47, 51, 90-91, 128, 131  
 Mortimer, Cromwell 51, 61

## N

Newton, Isaac 11, 24, 48-49, 54-55, 60-62, 63-68, 92-94, 131  
 Nicaea 91  
 Nürnberg 44

## O

Outhier, Reginald 53-54, 58  
 Oxenstierna, Axel 13  
 Oxford 21

## P

Paris 16, 21-22, 47-51, 56, 62, 64-65, 71-72, 79, 81, 84-87, 91, 105-107, 110-112, 128-129  
 Pello 58, 60  
 Picard Jean 22  
 Planström, Christina 62, 65  
 Planström, Elisabeth 62, 65

## R

Réaumur, René Antoine Ferchault (de) 37, 103, 105  
 Réunion 85

Rik-Nils [Rich Nils] 96  
 Rome 12, 21, 46-47  
 Rømer, Ole 22, 105  
 Rudbeck, Olof, the elder 13-14, 16-17, 19, 28  
 Rudbeck, Olof, the younger 16  
 Rudman, Johan 95, 99

## S

Sala 37  
 Scheffel, Johan Henrik 30, 70  
 Sicily 21  
 Skytte, Johan 13  
 Spole, Anders (grandfather) 15-16, 19-29, 31-32, 39, 49, 54, 76, 118  
 Spole, Andreas 29  
 Spole, Anna 29  
 Spole Gunilla (mother) 11, 25, 28-31, 45, 50-51, 54, 62, 70-71, 76-77, 79,  
 112, 118, 121-122, 124, 126, 132  
 Stockholm 10, 20, 32, 43, 53-54, 62, 72, 76-77, 82, 87-88, 90, 110, 125-130  
 St. Petersburg 47, 104-105  
 Strömer, Mårten 88, 118, 123-124, 130

## T

Torneå (Tornio) 24, 55-56, 58-59, 61-62, 64-65, 84, 106, 112  
 Torne river 56, 59

## U

Ulfsson, Jacob 12  
 Ulrica Eleonora (Queen of Sweden) 54, 62  
 Uranienborg 22  
 Uppsala 10 onwards

## V

Vadsø 85  
 Ven 22

Venezia 45

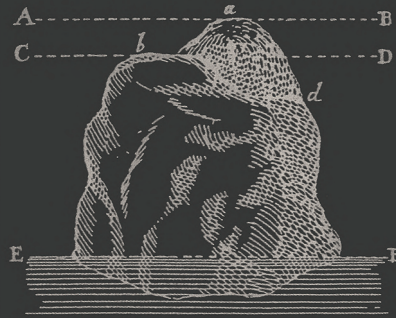
Voltaire, Francois (de) 64

W

Wargentín, Pehr 70, 76, 86-88, 90, 108, 110-111, 118, 122-132

Winkelmann, Maria 44





This is a book about an unknown person with a well-known name, Anders Celsius, a book about his life and works. It is, thereby, also a book about the beginning of systematically investigating the Earth and its changes.

Celsius may be characterized as a pioneer in investigating the Earth by means of systematic observations and by collecting long series of numerical data. In the early 1700s he and his assistants measured and studied latitude, longitude, gravity, magnetism, sea level change, land uplift, air pressure, temperature and northern lights. Much of Celsius' inspiration for his works came from his participation in an international expedition to the Arctic Circle, the purpose of which was nothing less than trying to confirm the theories of Newton. In many respects Celsius concentrated on utilizing Sweden's northerly position on the Earth, promoting such investigations that could not easily be made in more southerly countries.

This book is the story of the life and works of a man who started from meagre circumstances in an isolated northern university but developed into a pioneering Earth scientist with international contacts. It is also the story of a scientist who was engaged in creating an observatory and supporting an academy for the benefit of society but who died in the middle of his activities. And it is also the story of a person who made friends easily everywhere but never found someone with whom to share a common life.

In short: This is a book about science, about history, about people and about a life. I hope you will find it interesting.



*Martin Emaas*