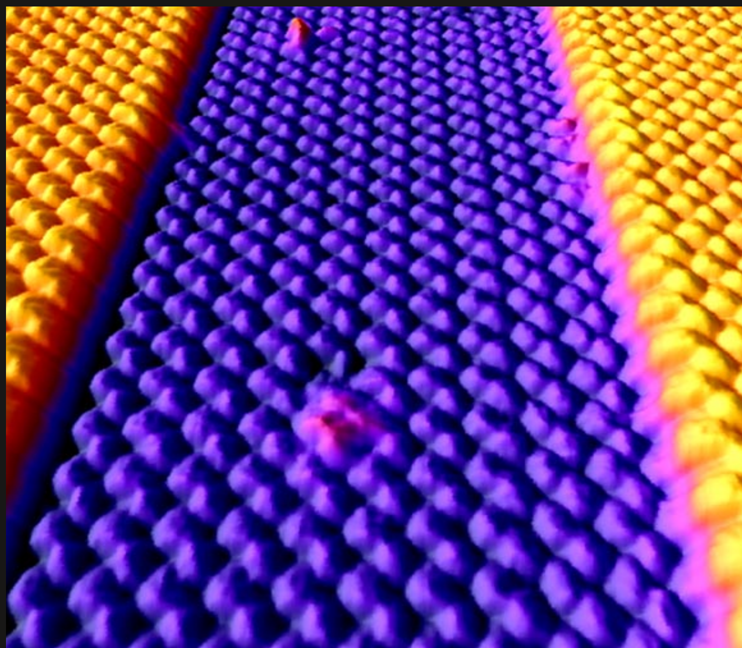
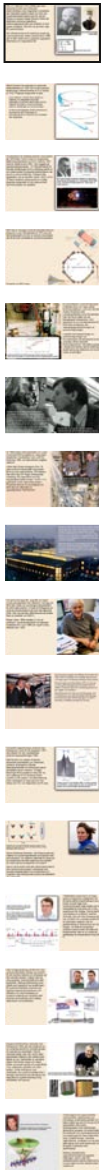
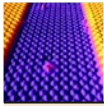


The synchrotron light from Lund

The story of how physicists in Lund learned to use synchrotron light.



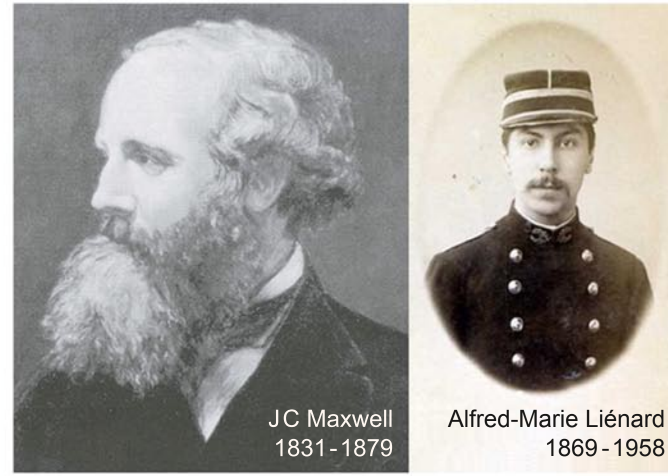


The brilliant light

The development of the famous equations linking electricity and magnetism by James Clerk Maxwell in 1873, signalled the end of the epoch of classical physics and heralded the age of quantum mechanics.

Fourteen year later, Heinrich Hertz showed that flowing electric currents caused magnetic fields that radiated with the velocity of light. This formed the basis for synchrotron radiation.

The general theory of electromagnetic radiation was found to be complicated. In 1898, one year after the discovery of the electron, Alfred Liénard wrote his treatise on *electric and magnetic fields*.



J C Maxwell
1831 - 1879

Alfred-Marie Liénard
1869 - 1958

$$\nabla\times E = -\partial B \partial t$$
$$\nabla\times H = J + \partial D \partial t$$
$$\nabla \cdot D = \rho$$
$$\nabla \cdot B = 0$$

Maxwell's equations.

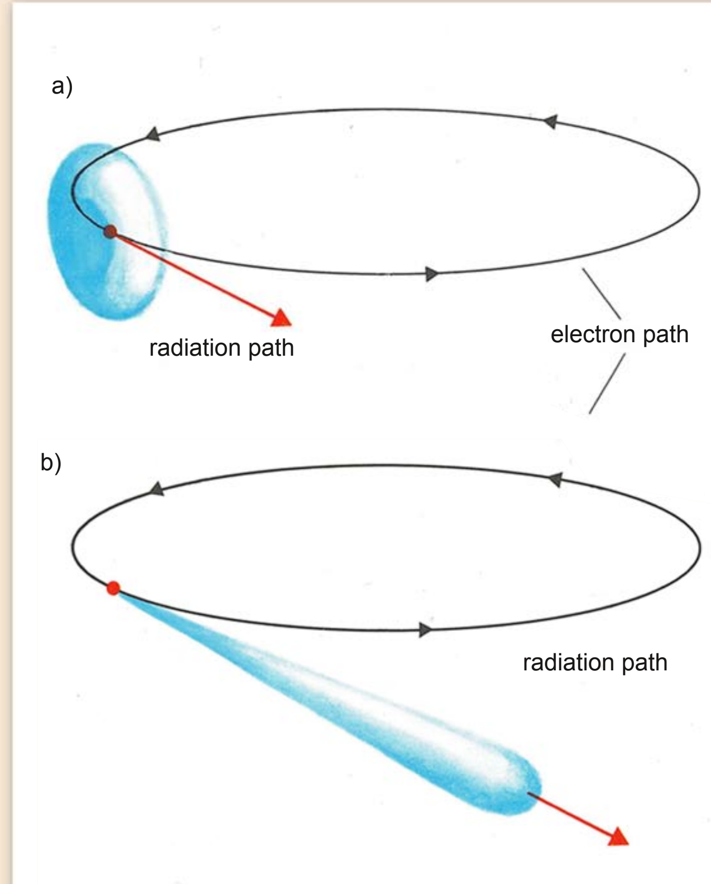
Synchrotron radiation is a relativistic effect

Albert Einstein formulated his theory of special relativity in 1905. This allowed Liénard's calculations to be further developed by G A Schott in 1912.

He arrived at the following conclusions:

a) An electron travelling in a circular path emits radiation. If the velocity of the electron is low, the radiation will be emitted isotropically (in all directions). The intensity of the radiation will be higher towards the outer edge of the path, and lower towards the centre. The radiation will be monochromatic (of a single wavelength).

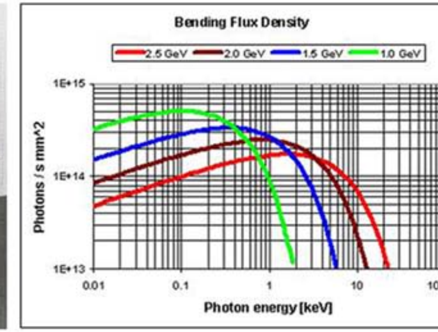
b) As the velocity of the electron approaches that of light, the radiation will become unidirectional (in one direction). It will be concentrated to a small cone, and contain all wavelengths.



The pioneers

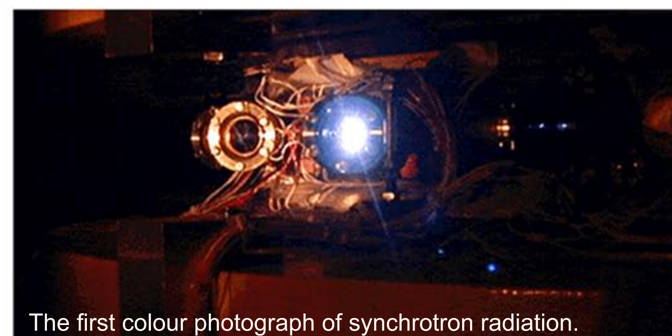
Accelerators for charged particles were developed in the 1930s. The first to produce a working electron accelerator was DW Kerst, who presented a 2 MeV betatron in 1941, based on a transformer. J P Blewett was aware of Schott's calculations on the emission of electromagnetic radiation, and observed that the circumference of the electron paths decreased as a result of this radiation.

This became clearer in spring 1947, when a technician working on a 70 MeV betatron noticed an intense beam of light leaving the beamline in a tangential direction. Synchrotron radiation had been discovered!

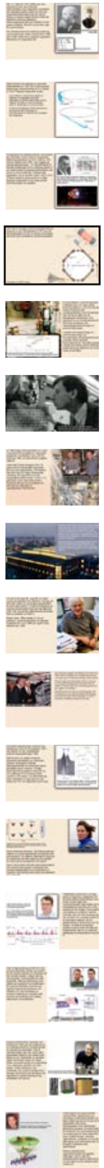


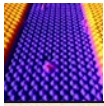
Synchrotron radiation spectra from various kinds of electron paths.

The most commonly cited theoretical work on synchrotron radiation was presented by J Schwinger (1918-1994).



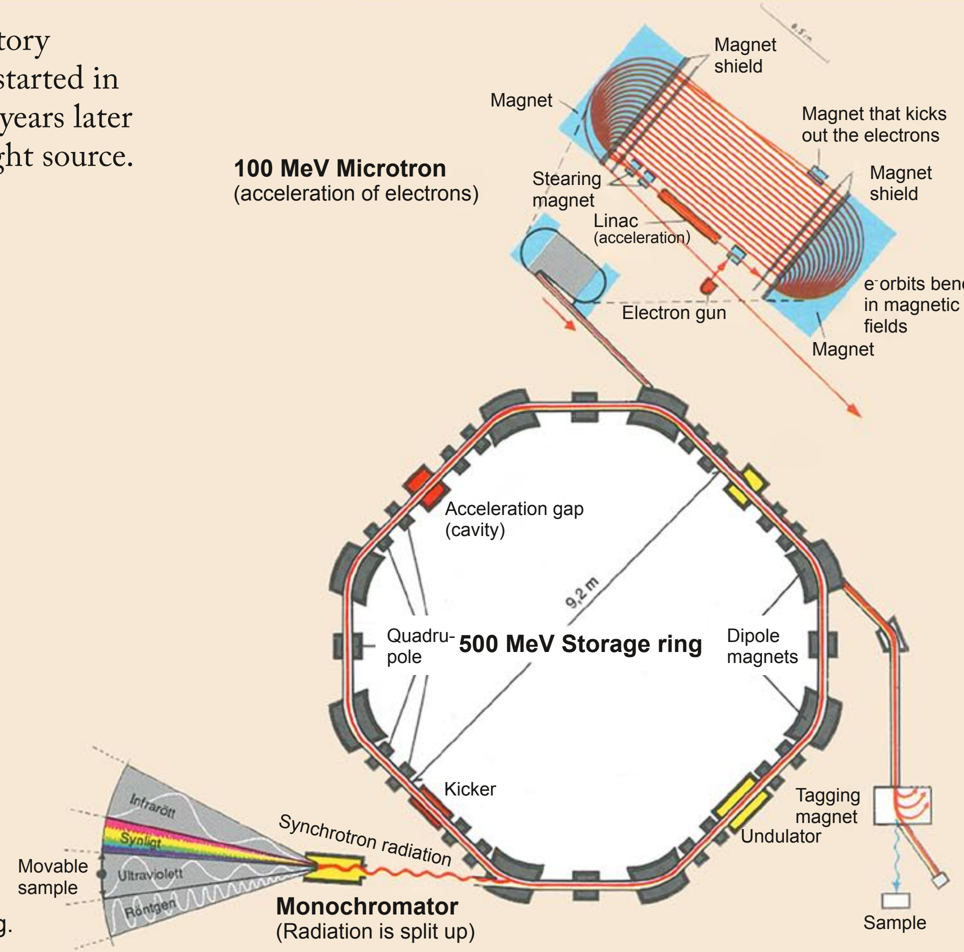
The first colour photograph of synchrotron radiation.



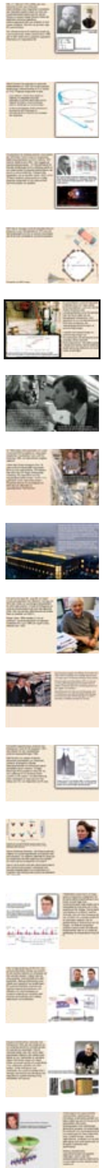


The MAX project

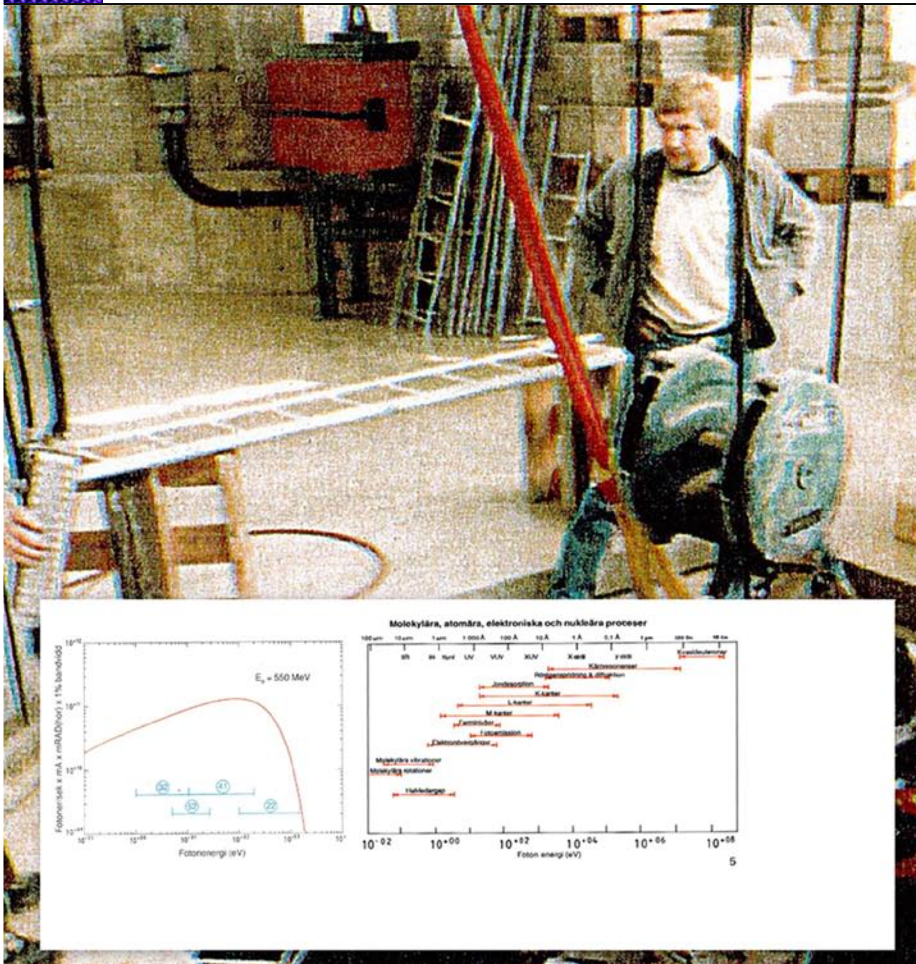
The Swedish synchrotron radiation laboratory MAX-lab is located in Lund. The project started in 1973 as a nuclear physics project, and five years later had developed to include a synchrotron light source.



Sketch of the MAX I ring.



The inception of MAX-lab



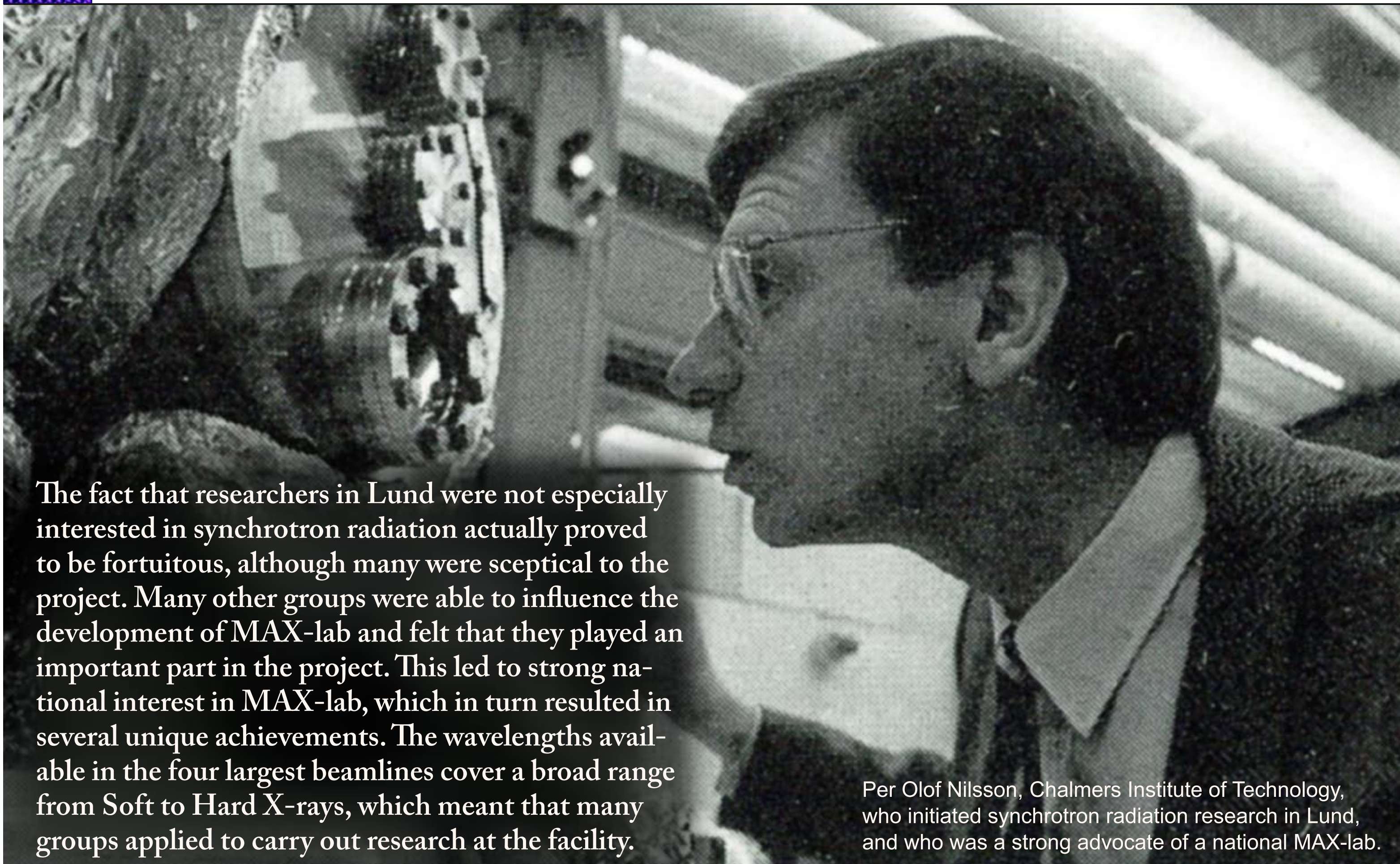
Although no research was being carried out in synchrotron radiation physics in Lund, a research position was established, and Anders Flodström from Linköping/ Stanford (USA) took up the position.

He had plenty of new ideas and was a successful entrepreneur, being one of the main applicants responsible for equipping the synchrotron with scientific equipment, with the objective of developing a national research centre.

All the Swedish research groups in this field were welcome to use the equipment.

Anders Flodström
Senior lecturer in synchrotron radiation physics from 1981 - 1985, later Professor, Faculty Dean and the Vice-Chancellor of two Swedish Universities.

A national facility



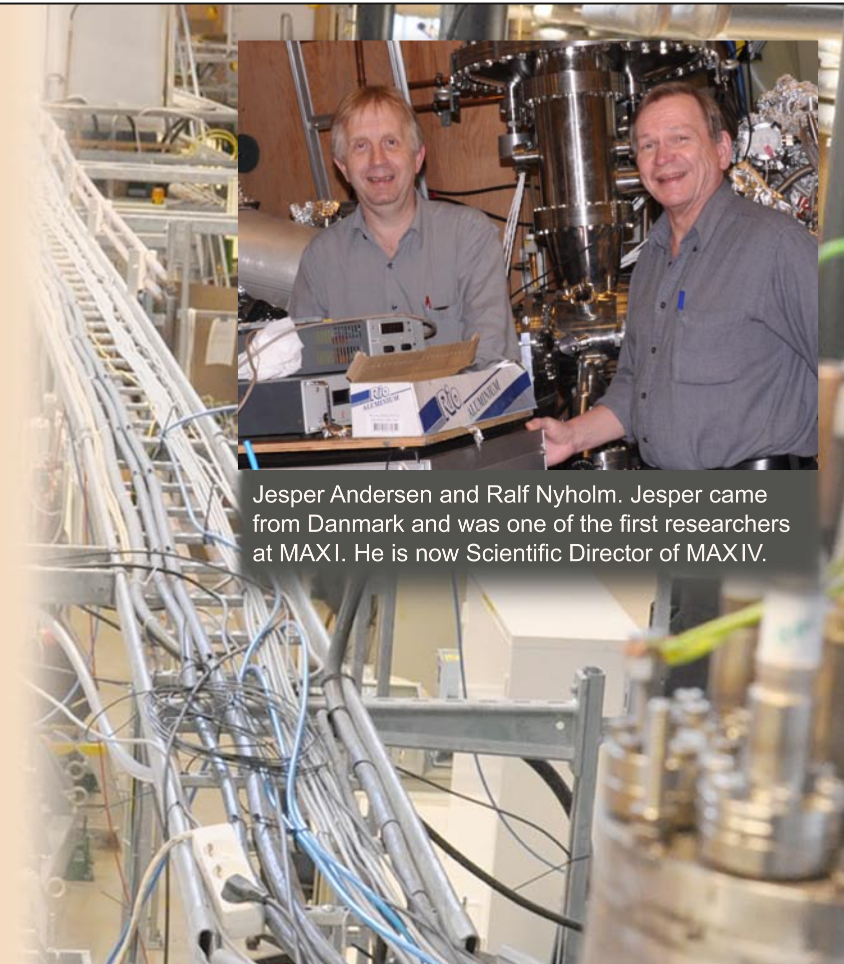
The fact that researchers in Lund were not especially interested in synchrotron radiation actually proved to be fortuitous, although many were sceptical to the project. Many other groups were able to influence the development of MAX-lab and felt that they played an important part in the project. This led to strong national interest in MAX-lab, which in turn resulted in several unique achievements. The wavelengths available in the four largest beamlines cover a broad range from Soft to Hard X-rays, which meant that many groups applied to carry out research at the facility.

Per Olof Nilsson, Chalmers Institute of Technology, who initiated synchrotron radiation research in Lund, and who was a strong advocate of a national MAX-lab.

Researchers from far and wide

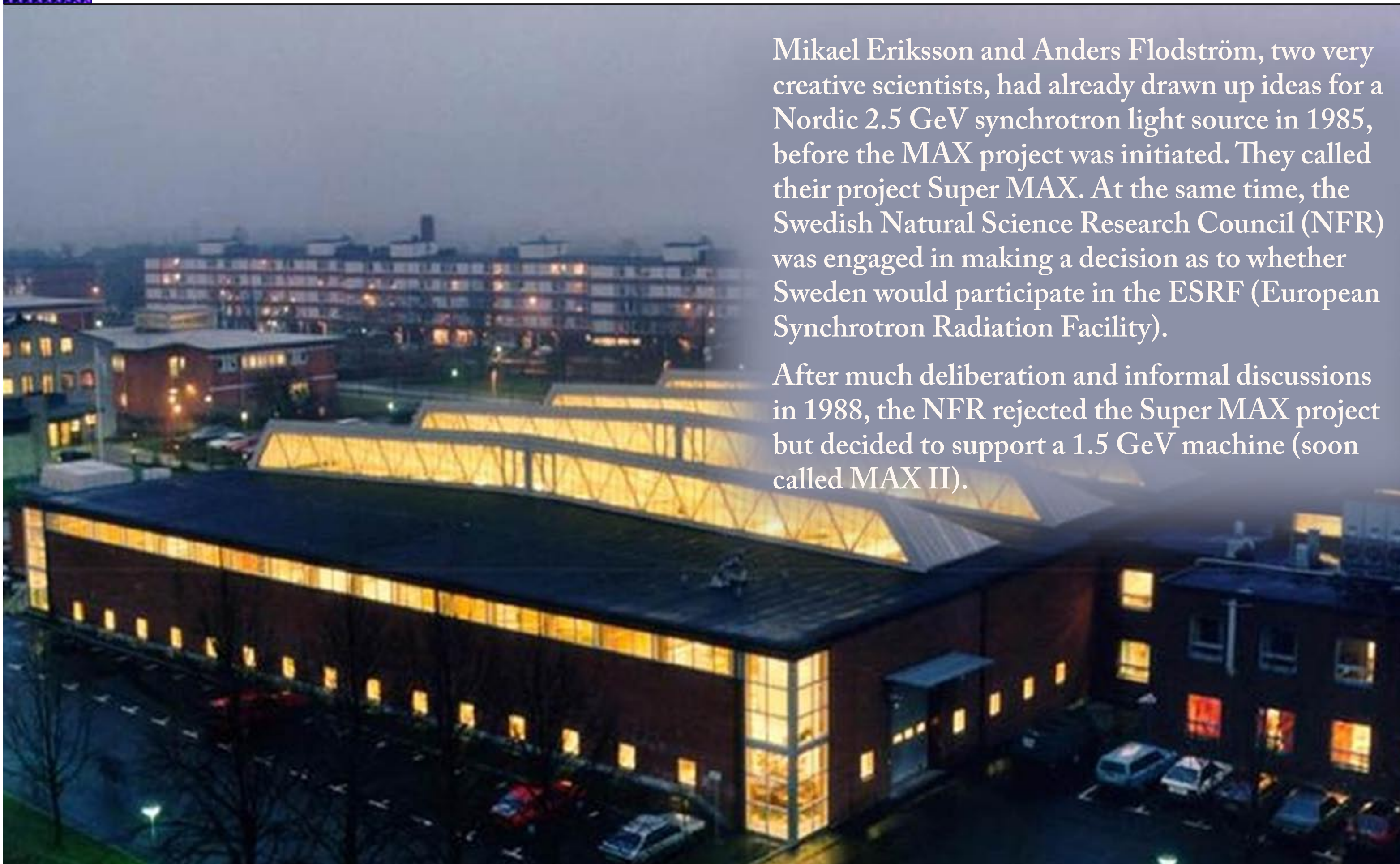
In 1980 Lund University offered well-equipped premises for the MAX project. The accelerator was commissioned in 1986, and the lab was inaugurated the following year.

Sixteen synchrotron radiation projects were described in MAX-lab's first annual report in 1987. One of these was a report by two young scientists, Ulf Karlsson from MAX-lab and Roger Uhrberg from Linköping, on highly resolved electron levels in the Au/Si (111) interface. By this time, Anders Flodström had left MAX-lab and been replaced by Ralf Nyholm from Uppsala.



Jesper Andersen and Ralf Nyholm. Jesper came from Danmark and was one of the first researchers at MAX I. He is now Scientific Director of MAX IV.

Let there be light!



Mikael Eriksson and Anders Flodström, two very creative scientists, had already drawn up ideas for a Nordic 2.5 GeV synchrotron light source in 1985, before the MAX project was initiated. They called their project Super MAX. At the same time, the Swedish Natural Science Research Council (NFR) was engaged in making a decision as to whether Sweden would participate in the ESRF (European Synchrotron Radiation Facility).

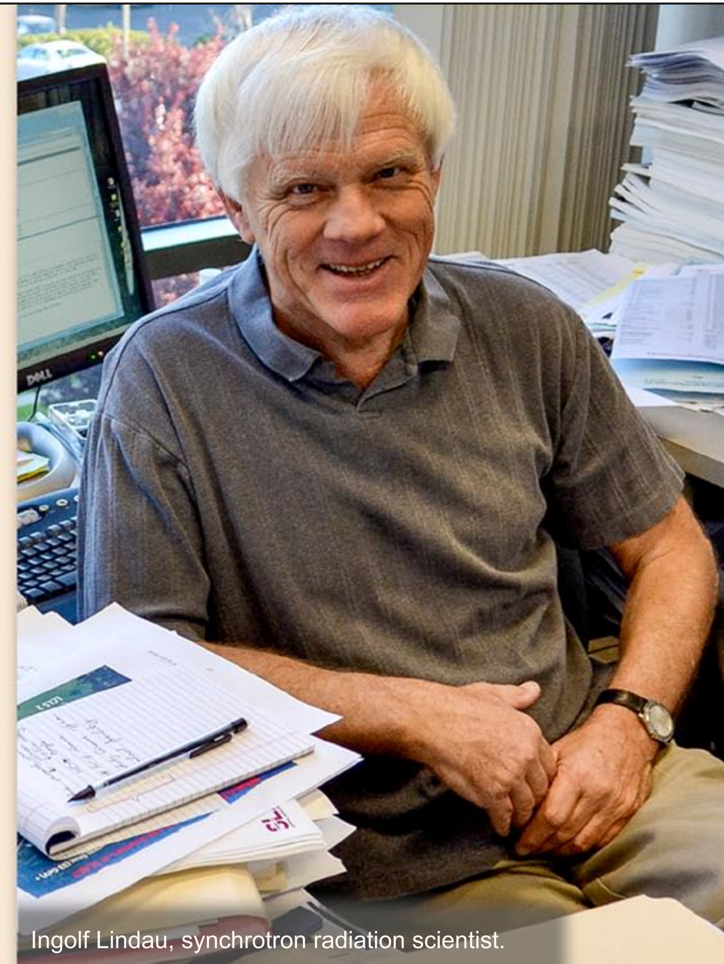
After much deliberation and informal discussions in 1988, the NFR rejected the Super MAX project but decided to support a 1.5 GeV machine (soon called MAX II).

Competence begets competence

At about this time (September 1988 - August 1989) Ingolf Lindau was on sabbatical leave from Stanford, at the MAX-lab in Sweden. This would prove to be extremely important for MAX-lab's future.

Lindau was a synchrotron radiation researcher of high international repute, and was just the person to formulate the application for MAX II.

Lund University had applied for a professorship in synchrotron radiation physics in 1986. This was approved in July 1988, and Ingolf Lindau was appointed to the position in 1990.



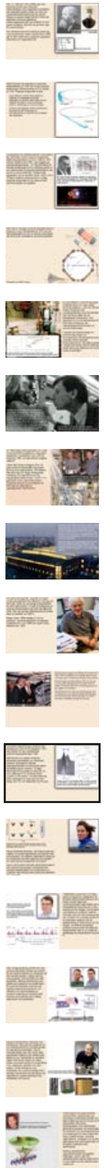
Ingolf Lindau, synchrotron radiation scientist.

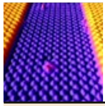
Royal splendour


Ingolf Lindau talking to the Swedish King Carl XVI Gustaf.

Ingolf Lindau's task was two-fold: To steer the MAX II project to completion and to build up a research department. He was successful in both, and by 1997, when he ceased to be director, the old and the new storage rings were equipped with 16 beamlines. He also developed and installed a number of wigglers and undulators.

Ingolf left behind him a research group consisting of 17 members, that had carried out research of the highest quality. An international assessment group had nothing but praise and admiration, and described the achievement as heroic.

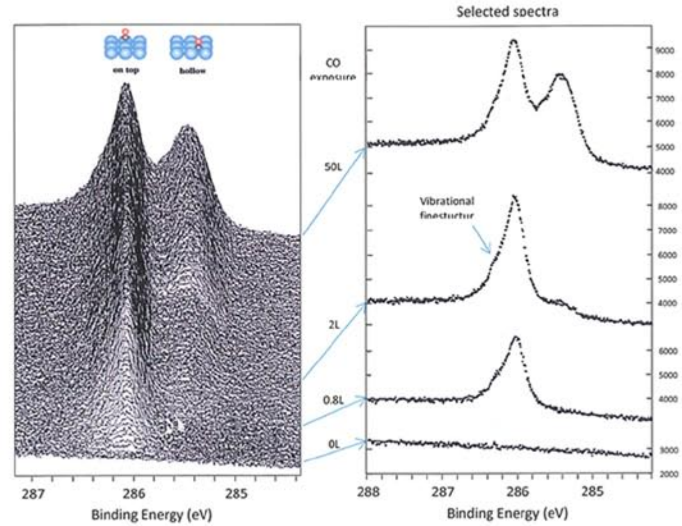




Photoelectron spectroscopy

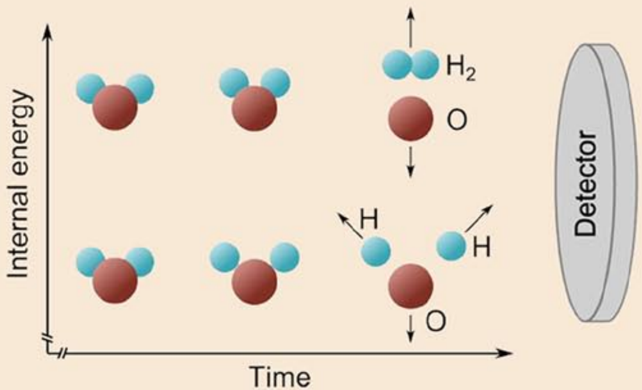
The Nobel Prize in Physics was awarded to Kai Siegbahn in 1981 for his work on photoelectron spectroscopy, and this paved the way for the new Division for Synchrotron Radiation Research in 1990.

Ralf Nyholm and Jesper Andersen were studying surface properties and surface chemistry, for example, the adsorption of carbon monoxide (CO) on a crystalline surface of rhodium (Rh). At low levels of CO they observed only one peak (the carbon 1s peak), which resulted from the binding of CO directly to a Rh atom on the surface of the crystal. However, at higher levels of CO they saw a second peak, which they interpreted as being due to binding to a vacancy in the Rh surface.



The 1s carbon peak indicates binding of CO on the surface of the material. The figure on the right shows more detailed spectra that reveal vibrational levels.

Molecular and cluster research at MAX-lab

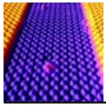


This example shows how the geometry of a water molecule is changed by electron decay which affects the molecular orbitals creates bonds between the atoms.

Stacey Ristinmaa Sörensen, head of the Division for Synchrotron Radiation Research.

Stacey Ristinmaa Sörensen was interested in the dynamics of material at very low densities when irradiated with synchrotron radiation, and was looking for answers to question such as:
How does this material react to synchrotron radiation?,
How fast are the chemical reactions that are initiated?,
and How do free nanoparticles and clusters behave?

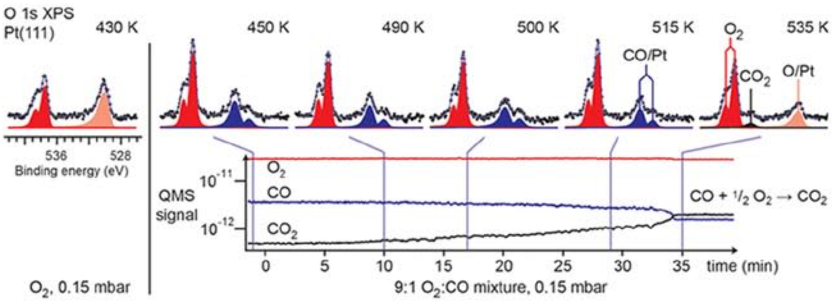
By using short-lived electronic states as a clock, her research group, collaborating with other Swedish research groups in molecular physics and quantum chemistry, was able to follow the dynamics of the molecules on timescales of 10^{-15} seconds.



Surface Catalytic Experiments

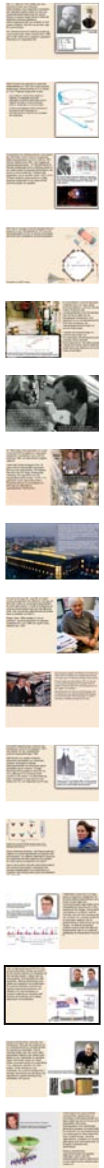
Joachim Schnadt,
Professor in synchrotron-radiation-based
in situ electron spectroscopy.

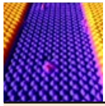
1s electron spectra from oxygen show how carbon dioxide is created by catalysis when oxygen (red peaks) and CO react strongly at the platinum surface at high temperatures. This was confirmed using mass spectrometry



The experiment reveales a new carbon dioxide gas phase peak at temperatures around 535 K.

The use of electron spectroscopy is limited in high-pressure surface catalytic experiments as the former can only be carried out at very low pressures. The high brilliance of synchrotron radiation allows this problem to be overcome and in situ experiments to be performed. The technique was developed by Joachim Schnadt. Together with his research group at MAX II, he has studied how the surface of platinum reacts with a mixture of carbon monoxide and pure oxygen. At elevated temperatures, the CO is oxidized to CO_2.

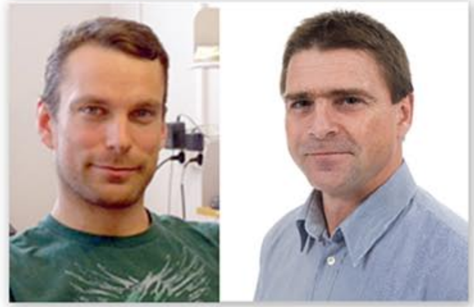




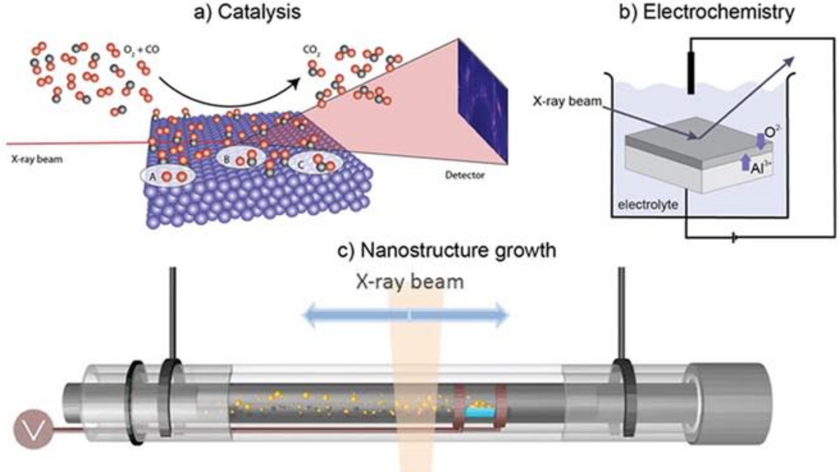
Catalysis and electrochemistry

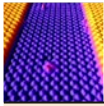
Hard X-rays (25 - 85 keV) from synchrotron radiation sources are highly suitable for studying materials and processes on the atomic scale in environments where they are used commercially.

Using the results of basic research on the surface properties of materials, the Division for Synchrotron Radiation Research has developed new methods based on interference and diffraction. These will help improve our understanding of modern materials that are already in use, or will be used in the future, in catalysis, electrochemistry and crystal growth.



Researchers in synchrotron radiation
Johan Gustafson och Edvin Lundgren





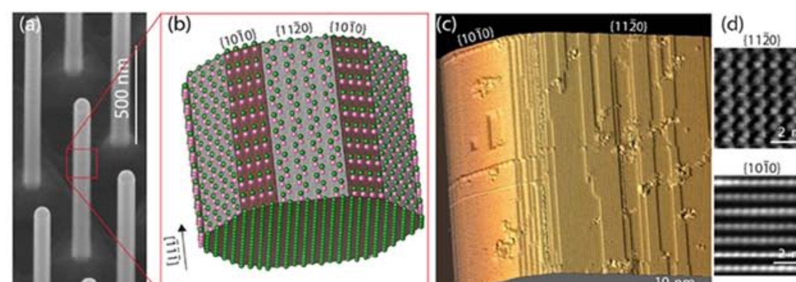
Surface structure on the atomic scale

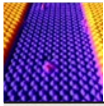
The 1986 Nobel Prize in Physics was awarded to the inventors of scanning tunnelling microscopy. With this technique it is possible to see how individual atoms are arranged on a surface, for example nanowires. The surface area of a nanowire is important for its properties as nanowires consist almost only of a surface. Nanowires are typically a few micrometres long and a few tens of nanometres thick, and are useful in electronics, solar cells and LEDs.

Researchers at Lund University under the leadership of Lars Johansson were the first in Sweden to use this kind of microscopy, and a great deal of research concerning nanowires is performed at the Department of Physics.

Anders Mikkelsen
Synchrotron radiation researcher.

From nanowires (a) to single atoms (d).

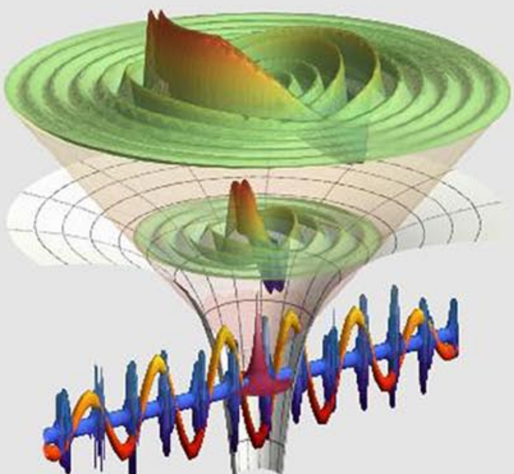




Research in Time and Space

Synchrotron radiation researcher Mathieu Gisselbrecht.

Two-electron wave function created in xenon atoms by short laser pulses i the attosecond lab.



Two of the division's experimental areas, spectroscopy and microscopy, developed in parallel, and both have proven to be a good basis for collaboration with other research groups in the department: The Attoscience Group at the Division of Atomic Physics, and the Nanometer Consortium at the Division of Solid State Physics.

Rapid events are initiated in atomic wave functions, molecules and on the surface of materials by excitation with short laser pulses, and the processes are studied using spectroscopy.

Mathieu Gisselbrecht's much-noted time-resolved measurements on xenon show that electrons are emitted at intervals of a few hundred attoseconds during double ionization.