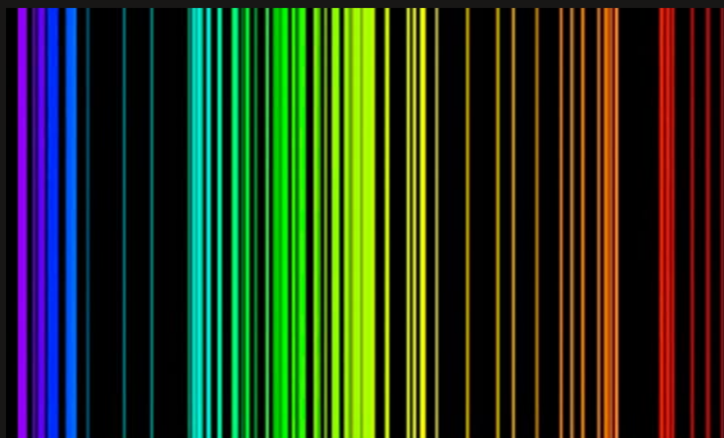


Fast atoms and shining stars

How spectral lines tell us the lifetimes of excited atoms and the chemical composition of stars.

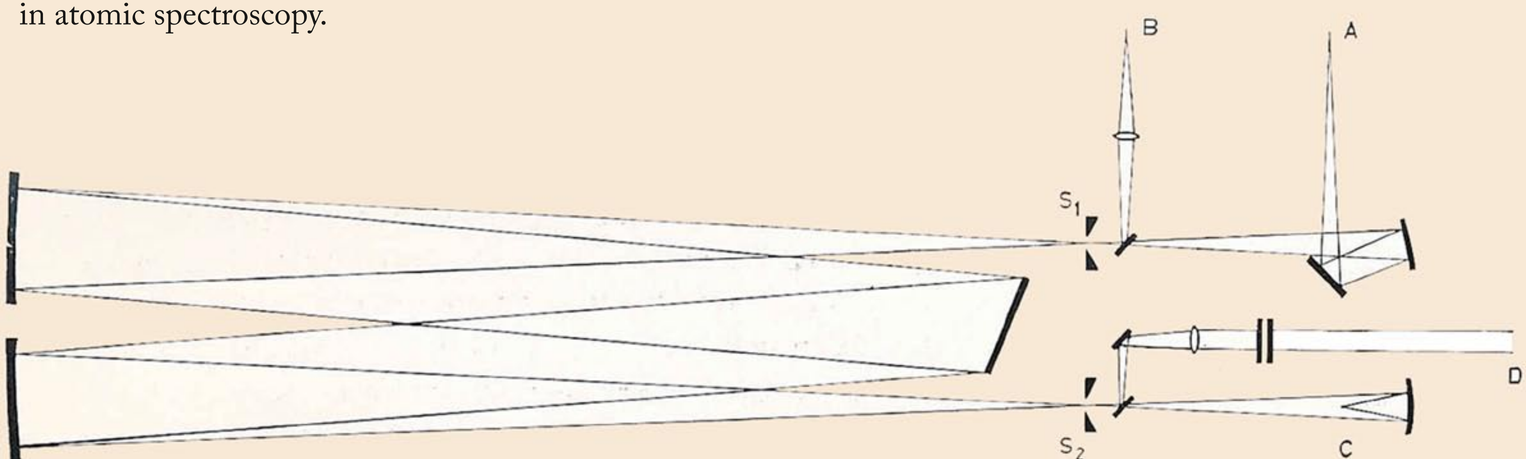
Atomic spectroscopy – a tradition in Lund

The Department of Physics in Lund has a long tradition of the investigation of atomic spectra. The work performed by Rydberg and Siegbahn laid the foundation for our knowledge on the structure of atoms.

Siegbahn's successor, Koch, studied the effects of electric fields on atomic spectra, and Edlén's analysis of spectra from complex atoms and highly charged ions provided new knowledge on atomic structure.

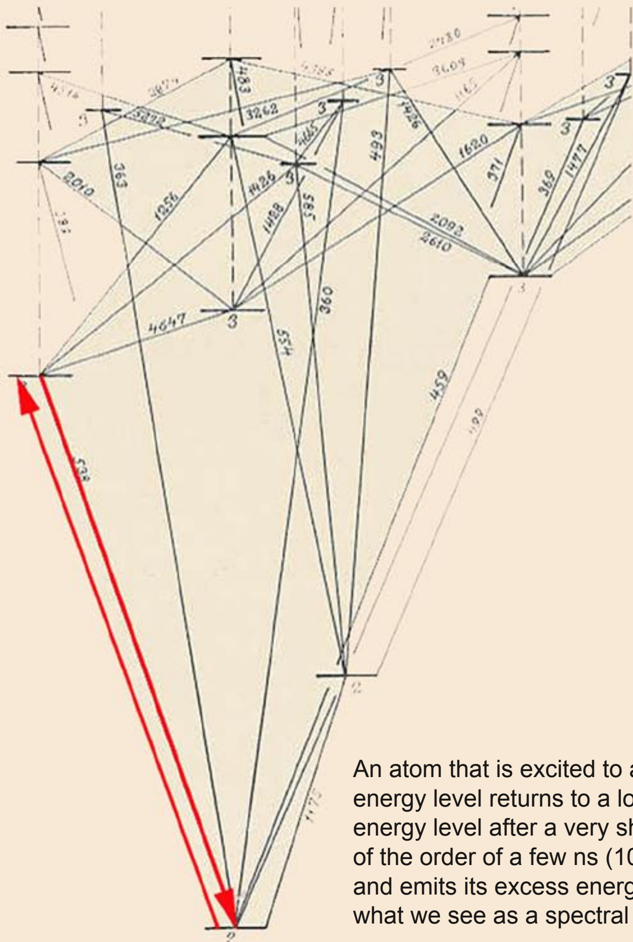
When the Institute of Technology was founded in Lund, Minnhagen established a research division in atomic spectroscopy.

An X-ray spectrum on a photographic plate, recorded by Siegbahn.



A spectrometer for infrared radiation, constructed in Lund in 1969.

Atomic lifetimes



An atom that is excited to a higher energy level returns to a lower energy level after a very short time, of the order of a few ns (10^{-9} s), and emits its excess energy. This is what we see as a spectral line.

Indrek Martinson 1937 - 2009

Indrek Martinson took over from Bengt Edlén in 1975. He expanded the field of spectroscopy by introducing measurements of atomic lifetimes. Martinson had obtained his PhD in nuclear physics in Stockholm, under the supervision of Manne Siegbahn. During a period as a post doc in Tucson, Arizona he had learnt a new experimental method called beam-foil spectroscopy.

Beam-foil spectroscopy

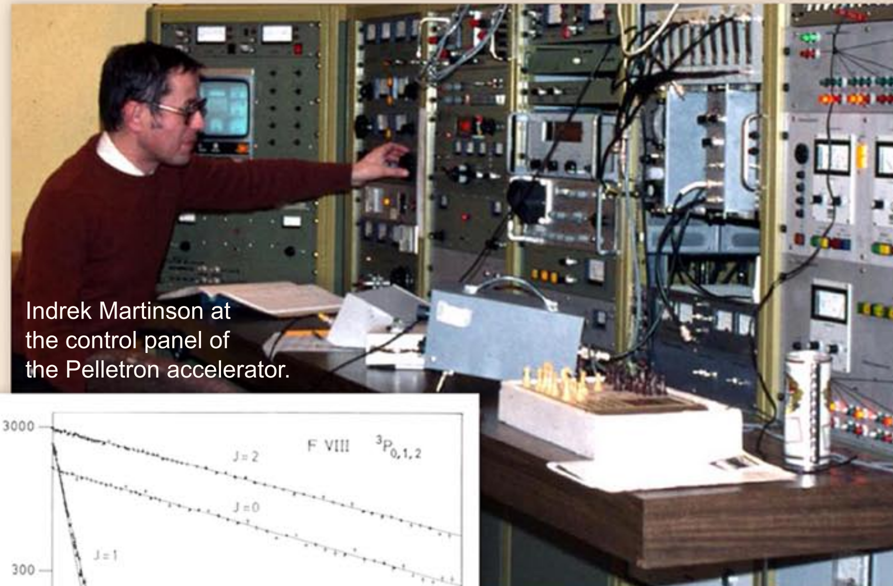
In the beam-foil method, ions are excited by passing them through a thin carbon foil. The intensity of the emitted spectral lines decreases along the path of the travelling ions. If the velocity of the ions is known, the lifetime of the excited state can be determined. Instead of measuring a very short time, this method involves the much simpler measurement of a distance of a few cm.

The experimental equipment for beam-foil spectroscopy was set up at the Physics Department´s Pelletron accelerator, where ions could be accelerated to velocities of 10,000 km/s.

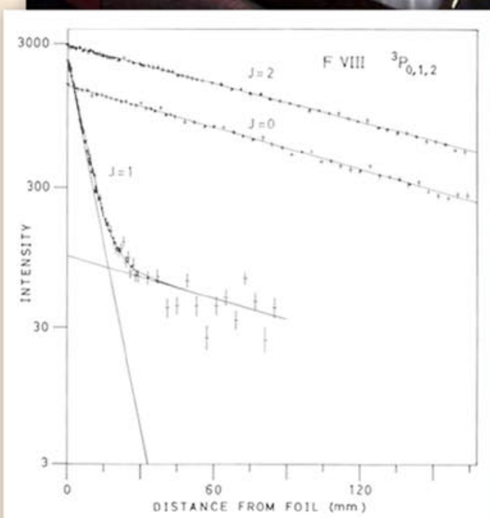
A beam of lithium ions passes through a thin carbon foil, allowing two atomic decays to be observed, one which is short-lived (5 ns), and can be seen as the blue light, and a longer-lived one (46 ns), seen as the longer-wavelength green light.

Lifetime measurements

Measurements of atomic lifetimes at the Pelletron accelerator were combined with theoretical studies. The accurate lifetime measurements allowed various theoretical and mathematical models to be tested.



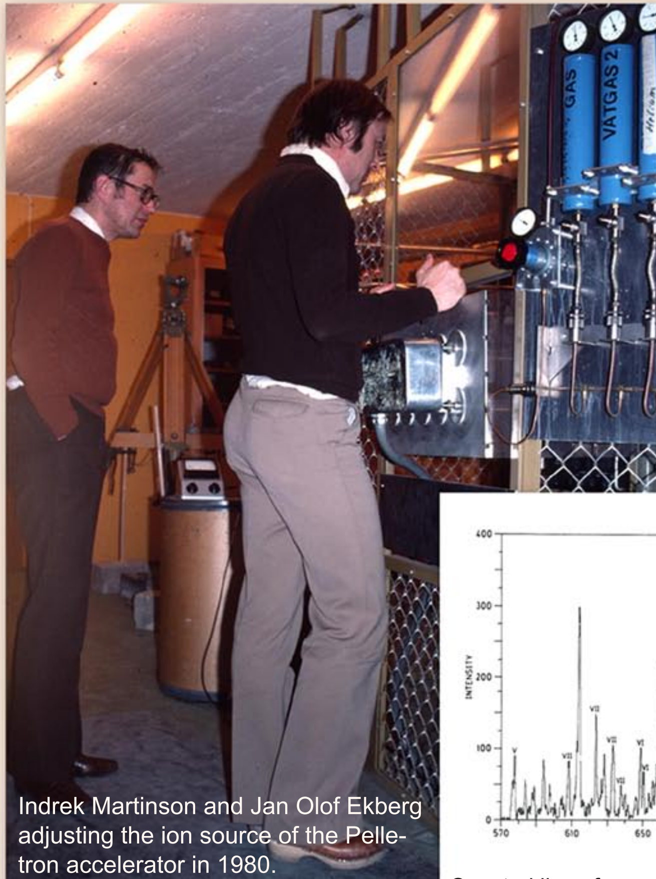
Indrek Martinson at the control panel of the Pelletron accelerator.



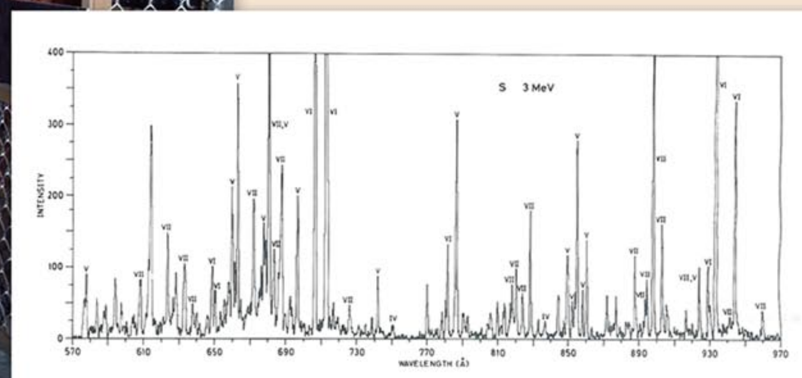
This figure shows the measurement of three states in a positively charged fluorine ion, F^{+7}. According to elementary theory, they should have the same lifetime, however, the experiment showed that one of the states (J = 1) had a much shorter lifetime than the other two, which also differed a little. Extensive theoretical calculations showed that the difference in lifetimes was due to the spin of the electrons and the nucleus.

Highly charged ions

When positive ions pass through the carbon foil, one or more electrons are stripped off, increasing the positive charge on the ion. The beam-foil method can, therefore, also be used to analyse the structure of highly charged ions of, for example, fluorine and sulphur.



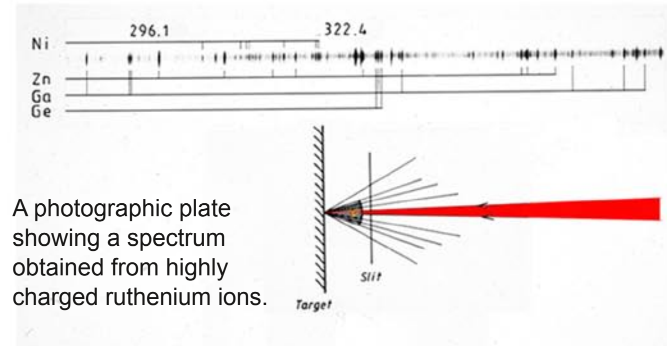
Indrek Martinson and Jan Olof Ekberg adjusting the ion source of the Pelletron accelerator in 1980.



Spectral lines from a beam of positively charged sulphur ions: S^{3+}, S^{4+}, S^{5+}, S^{6+}.

Laser-generated plasma

The energy structure of highly charged ions can also be studied with high-energy lasers with pulse energies of 1 GW. The laser beam is focused onto the material to be studied using a lens. The energy of the pulse was so high that a plasma was formed at a temperature of a million degrees. The ions in the plasma lost up to 20 electrons.



A photographic plate showing a spectrum obtained from highly charged ruthenium ions.

Ulf Litzén, one of Lund's atomic spectroscopists, beside the high-energy laser in 1985.

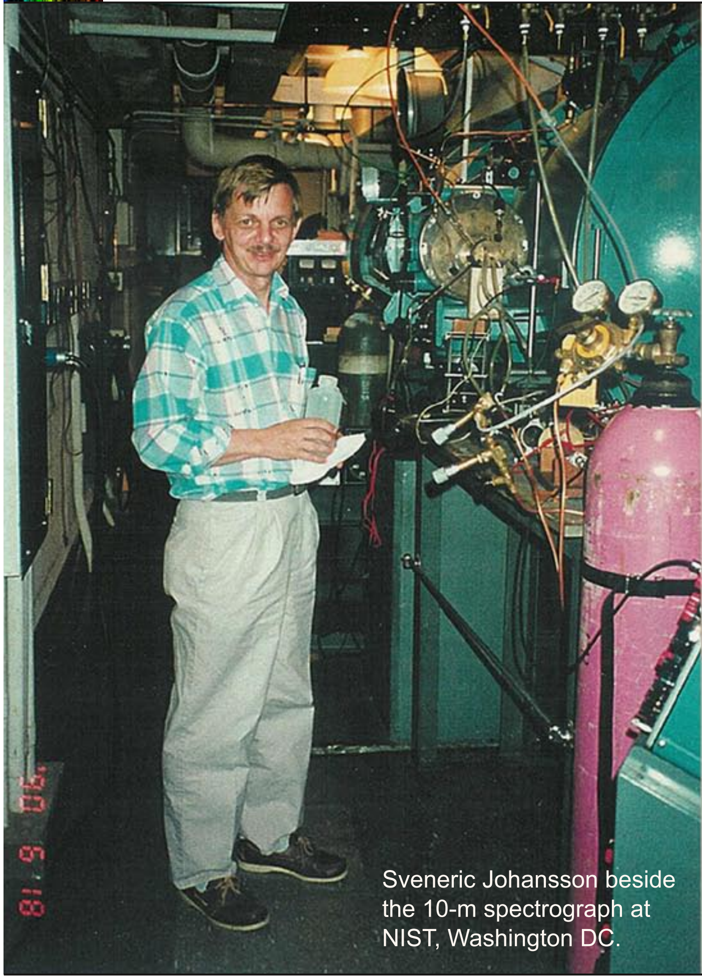
Plasma diagnostics

PhD students and postgraduates from the Division of Atomic Spectroscopy took part in international collaboration at laboratories in the UK (JET), and Princeton, USA. These experiments were aimed at producing energy by fusion resulting from the collision of deuterium and tritium atoms at temperatures of tens of millions of degrees.

The spectroscopists from Lund measured levels of contaminants by analysing spectra from the superheated plasma. These measurements are important, as even extremely small levels of heavier atoms reduce the temperature, preventing fusion from taking place.

Joint European Torus, JET.

Astrophysics in the lab



Sveneric Johansson beside the 10-m spectrograph at NIST, Washington DC.

In 1970, Sveneric Johansson started his PhD studies under the supervision of Bengt Edlén. His research was on the structure of ionized iron, Fe^{+}.

The spectra from several kinds of stars contain many spectral lines arising from iron. Sveneric's new measurements showed that there were many more lines from iron than previously thought.

After obtaining his PhD, Sveneric formed a research group to study astrophysics in the laboratory, and they investigated atoms of special interest in astronomy.

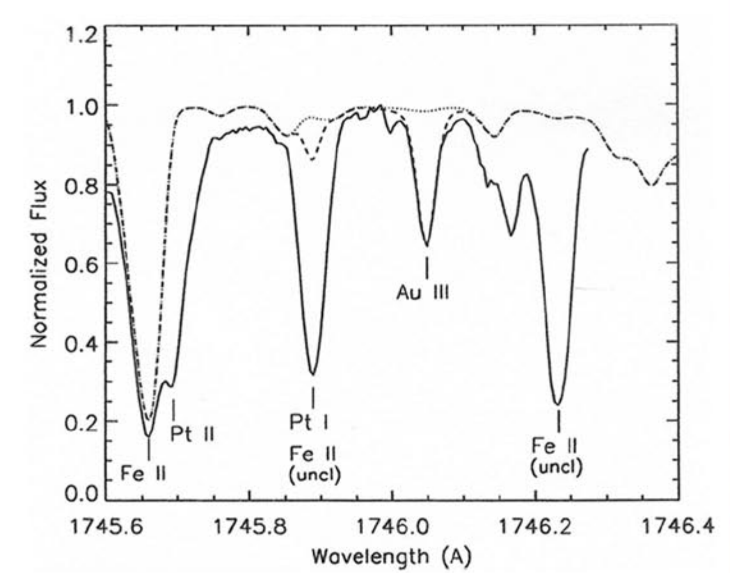
The Hubble Space Telescope

Sveneric Johansson spent a year as a visiting scientist and expert in atomic spectroscopy at the NASA Space Flight Center. When the Hubble Space Telescope was launched in 1990, the research group from Lund were given plenty of observation time.

As the telescope was in space, above the Earth's atmosphere, it was possible to see detailed spectra of stars in the ultraviolet wavelength region for the first time. The group in Lund was no longer only analysing spectra in the lab, but also stellar spectra from space.

The spectrum of a star provides information on the elements present. If sufficient knowledge is obtained from laboratory experiments, it is possible to determine the amounts of elements, and other characteristics of stars.

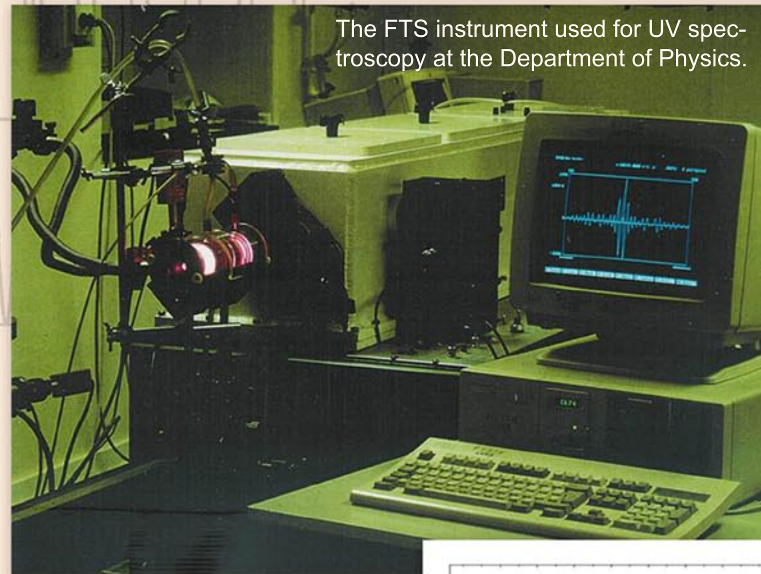
Atomic astrophysics



Details in the UV spectrum from Chi Lupi showing spectra lines from Au, Pt, and Fe.

Analysis was carried out in Lund of, among other things, stars with very high amounts of heavy elements such as gold and platinum. It was found, for example, that the amount of gold and platinum in the star Chi Lupi was 30,000 times higher than in our planetary system. This unusual composition was thought to be due to processes leading to the enrichment of heavy elements in the outer layers of stars. The Lund group was also the first to find thallium in a star.

Fourier transform spectroscopy

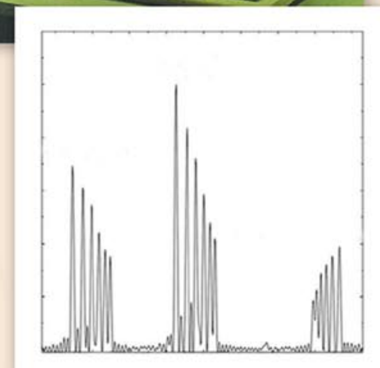


The FTS instrument used for UV spectroscopy at the Department of Physics.

Accurate laboratory measurements of wavelength are required to identify spectral lines in a stellar spectrum containing many lines from different elements. It is also necessary to measure the intensity of lines in the laboratory in order to determine the amount of each element.

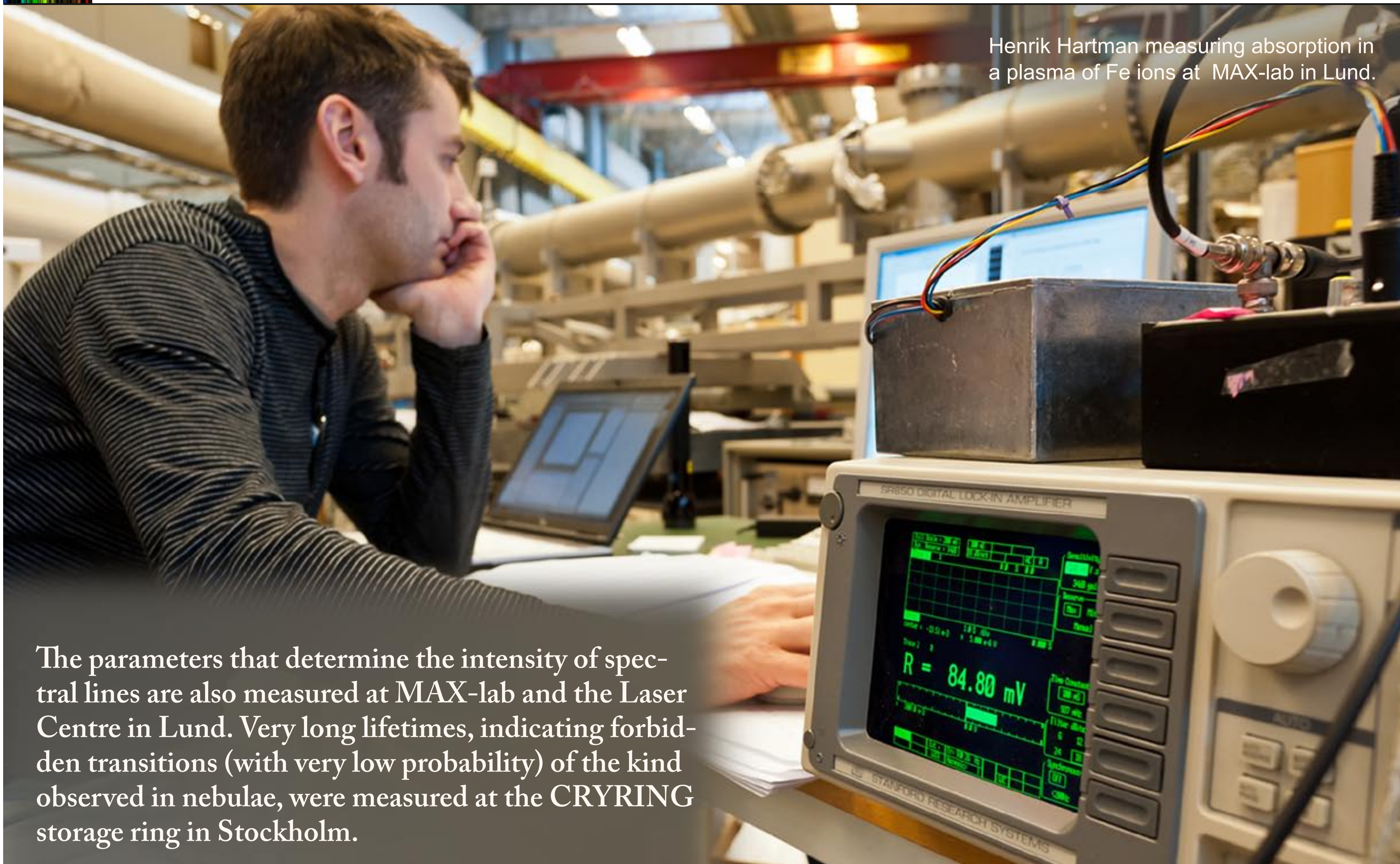
A new high-precision method for spectroscopic measurements is Fourier transform spectroscopy (FTS), which employs an interferometer with very high resolution. The interferogram recorded is a Fourier transform of the spectrum, which is then analysed in a computer.

FTS gives very high resolution, allowing the structure of spectral lines resulting from the spin of the atomic nucleus to be seen.



The figureshows the structure in three lines resulting from Pr^+ (the ion of the element praseodymium).

Intensity measurements

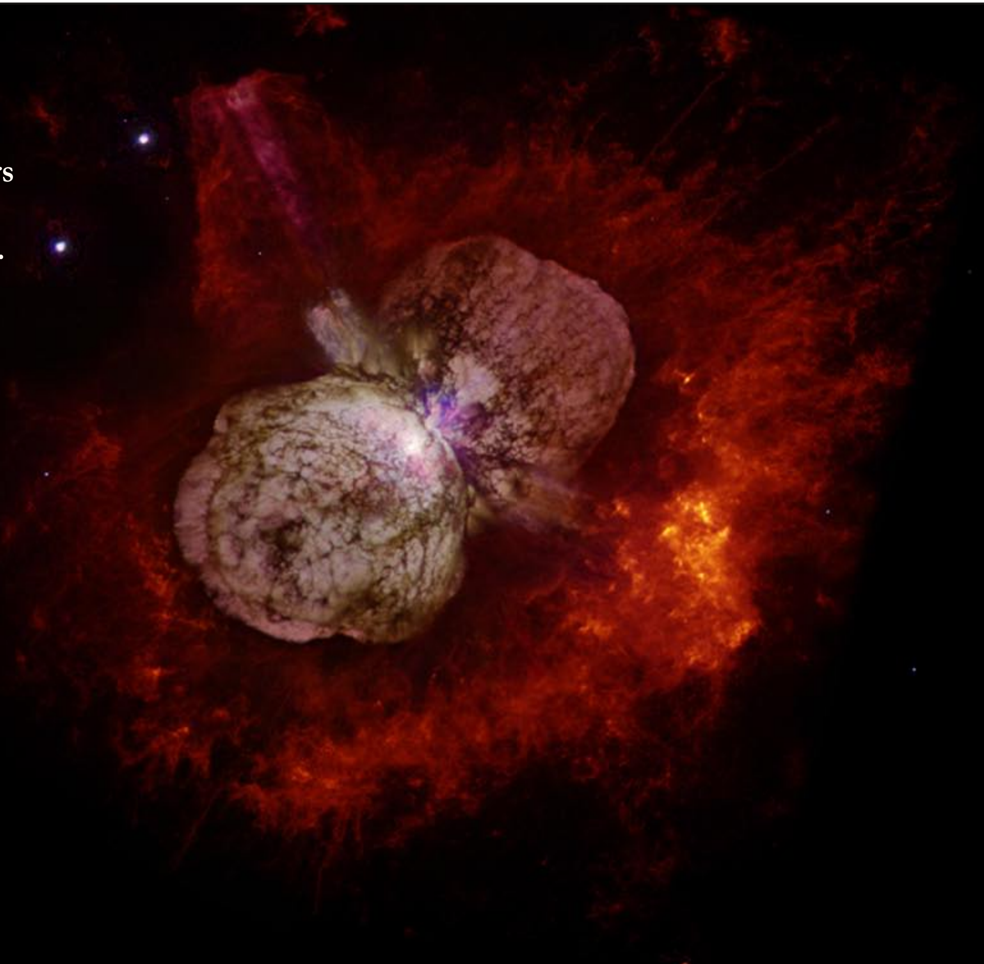


Henrik Hartman measuring absorption in a plasma of Fe ions at MAX-lab in Lund.

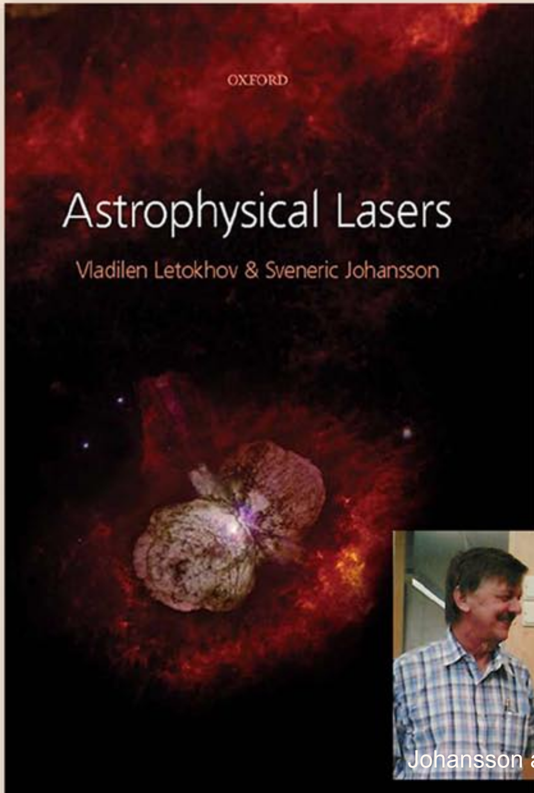
The parameters that determine the intensity of spectral lines are also measured at MAX-lab and the Laser Centre in Lund. Very long lifetimes, indicating forbidden transitions (with very low probability) of the kind observed in nebulae, were measured at the CRYRING storage ring in Stockholm.

Eta Carinae

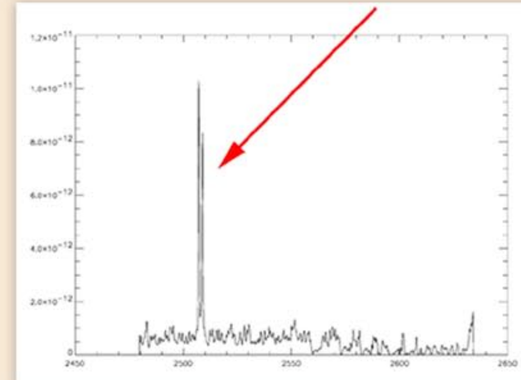
Eta Carinae is one of the heaviest stars in the Milky Way. In 1837 an eruption was observed that was to last for several years, making it one of the brightest stars in the southern hemisphere. Enormous gas clouds were seen, forming two lobes. In the plane between the two lobes are a number of very bright gas bubbles. The line spectrum emitted by these bubbles was analysed in Lund. Observations were made with the Hubble Space Telescope.



A laser star?



Sveneric Johansson and Vladilen Letokhov described their research in the book, *Astrophysical Lasers*, which was published posthumously in 2010, just a year or two after the two physicists had died.



Sveneric Johansson identified a large number of Fe^{+} lines in the gas bubbles around Eta Carinae, two of which were much stronger than the others. However, they were not especially prominent in laboratory measurements.

Sveneric and the Russian laser expert Vladilen Letokhov were able to show that the increased intensity of the two lines was due to stimulated emission, or lasing, in the bubbles.