Prof. dr. J.S. Kaastra

X-ray diagnostics in space:

Lines in the universe

X-ray diagnostics in space: lines in the universe

Inaugural lecture spoken by

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Mr. Rector Magnificus, dear colleagues, acquaintances, friends and family,

The hardest word in the title of my lecture, X-ray diagnostics, is better understood than the simple words space and universe by many. That is all literally far away. And what should we do with lines? I hope to show this afternoon the line here.

X-rays

Everyone is familiar with the blessings and dangers of X-rays. Sensitive tissues, such as unborn children, we prefer to screen off for these rays. However, diseased tissue can be literally brought to light by the irradiation with X-ray light. We speak of X-ray light, because in fact it is nothing but light, albeit very energetic, hundred to a thousand times stronger than ordinary daylight.

One can use X-ray light in different ways. In medical technology radiation is transmitted through a body part. A part of this radiation is retained in the body and of what remains one makes a picture. Thus, one makes, in fact, an image of the shadow. In technical terms it is called an absorption measurement. One can also take an image of the radiation emitted by an object. This is called emission, but on Earth, under normal circumstances, it does not occur.

And that brings us to space. It is common for an astronomer to talk about a beautiful starry sky. And anyone can imagine something with that. However, looking at x-ray eyes to the sky, we see besides the sun, moon and stars, especially a lot of very unusual sources.

I want to take you this afternoon to that wonderful world. To reassure you, the Earth's atmosphere is thick enough to hold all extraterrestrial x-rays. Otherwise life would be unbearable here. But because the atmosphere acts as a shield, we can not watch the X-ray sky from Earth. That is only possible with the help of a satellite in space. And so this brings us to the field of space research, a special art.

The measurement of X-ray radiation

Let me start with some technical issues. The satellite must have a lot on board. First of all, the radiation needs to be collected, and more preferably, of course, displayed on a camera. An ordinary telescope contains mirrors, in which the incident light moves approximately perpendicularly to the mirror and then is directed to the focal point of the telescope in which the image is created. The amount of light that is collected depends almost exclusively on the surface of the mirror.

However, X-ray light has such a high energy, that at normal incidence, the radiation is not reflected but is absorbed in the mirror. Only if the radiation bounces off the mirror at a small angle, just as some may bounce a stone on the water, one can focus the radiation. An X-ray mirror is thus almost parallel to the light beam that needs to be collected, and therefore there are many smoothly polished mirror parts required in order to get an acceptable signal.

But that's not all. The light must be absorbed, and most preferably broken down into the X-ray colors it contains. All light has wave properties besides also particle properties. Both of these properties are used in order to unravel the light into its colors.

Gratings can be placed in the light beam so that the light of different wavelengths is deflected at different angles. Now, by putting a stretched detector behind the grating, one can determine the wavelength of the light from the spot where the light lands. This is accomplished by the grating spectrometers on the XMM-Newton and Chandra satellites, made by my employer SRON, on which I'll speak later.

An alternative method makes use of the particle properties of the light. Each light particle, also known as photon, can be detected separately. It is now the art to determine the energy of that photon, in addition to the registration of the arrival of the photon. There are several techniques for this.

Until recently the most modern technology was the CCD chip, known for example from your photo camera. The energy of a photon can be determined with an accuracy of 2 to 30%, but unfortunately in a large number of cases, the number is more often close to 30% than to 2%. It will come as no surprise that the heroes of the basement of SRON are hard at work developing a new type of detector. More on that later.

Why do we want the X-ray light from stars and other sources to be splitted in colours? The reason is very simple: it tells us a lot about what is happening in those sources. In the universe a small dozen different processes are at work that make X-ray light. Each process has its own characteristic distribution of light on the different colors, and especially the so-called thermal processes emit very much light in very narrow color bands.

Spectral lines

Thus we come to speak about the lines, or the spectral lines. These are made by atoms. One can imagine a simplified atom as a core around which a number of electrons turn in different orbits, similar like planets orbit around stars. The difference is that there are a limited number of orbits available for the electrons, and there can be only one electron in a particular orbit[1] at a time.

The lowest energy state is the most popular, just as in the human world where everyone wants to be dormant rich. Where it often lacks a Balkenende norm[2] in society, atoms have a B-standard, the Bohr-norm, because the atomic model of Bohr predicts the energy of the track.

In nature energy is preserved. Now when an electron is changing orbit, it thereby releases energy. That energy is transferred to another electron, or it is emitted as light. Because the electrons can only have certain orbital energies, the energy of the emitted radiation also can have only certain values, and thus we only see most of the radiation at specific wavelengths, and these are the spectral lines that are previously mentioned.

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[1] The Dutch word for orbit is the same as the word for job ("baan")

[2] Dutch regulation that says that no one in public service should earn more than the prime minister, at that time Balkenende

The relative strength of the spectral lines contains a wealth of information on what is going on with the atoms, and thus in what happens in the region where the atoms are. Time does not allow me to present this extensively. I will do so during my regular lectures in Leiden. I just want to make a list of what kind of information one can get from those lines.

First, there is of course the amount of matter in the source. The more material, the more radiation to a certain extent. Furthermore, one can determine therefrom the temperature and density of the gas, the chemical composition, the presence of dust, of highly accelerated electrons or atoms, magnetic fields, turbulence, or if the gas is shocked, and how long ago that was, how quickly the gas is moving, and so on.

Required professional skills

I hope I have enough advertised the diagnosis that can be achieved with X-rays. But you have to wait for the applications. Because it is not easy to retrieve the properties of the gas that emits radiation from the observable data. Various expertises are required, and for example SRON has that expertise all in-house.

It is my pleasure to be accompanied here by four of my colleagues, who all represent different expertises.

First there is the instrument connoisseur, here represented by Cor de Vries, one who knows the ins and outs of all parts of the instrument, and knows the calibration sometimes literally with pinpoint precision.

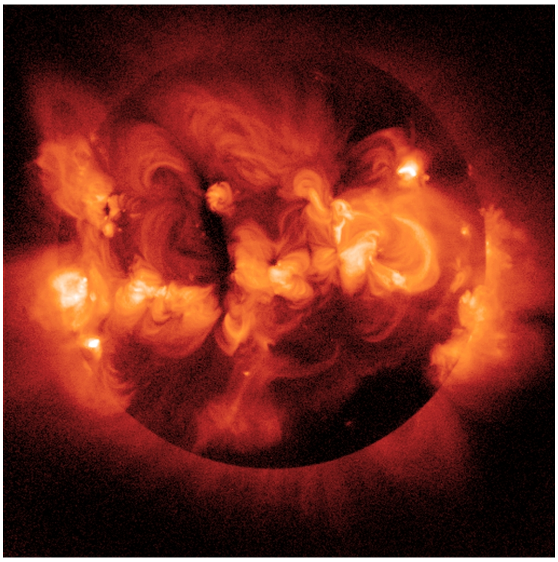
Then you need specialist knowledge of computers and large data files, because obviously we do not look through a telescope but everything is sent by the satellite to the earth where the data should be processed. For that we have here Jelle de Plaa.

Furthermore, someone is needed like Ton Raassen, with thorough knowledge of atomic physics, because the formation of spectral lines can be very complicated, and if you thought that area has solved all problems you are wrong.

And finally there is the astronomer, represented here by Elisa Costantini, trying to find out from the clutter of information what is happening in the X-ray source.

And around it is a whole army of people who support the overall process, from cleaners to directors, but I want to especially mention the enthusiastic postdocs, PhD students and students with their youthful zest embarked on a journey of discovery through the universe.

The beginning of X-ray research from space



The sun in X-rays. Yohkoh image – Greg Slater

It is now slowly time to consider the kind of heavenly bodies that we study. Let's start close to home, our sun. The sun is the oldest known X-ray source, as such detected by Herbert Friedman in 1949 with the aid of a V-2 rocket. In Utrecht a very long time important research of the sun occurred, which is best known by Minnaert. Kees de Jager also came from this group. He started in the early sixties in Utrecht with space research. Van der Hulst did the same in Leiden.

Soon the Utrecht space research focused on X-rays of the sun, and SRON has made important contributions to it. To understand the X-ray spectra of the sun, however, you need knowledge of atomic physics. For that reason, De Jager hired in 1970 Rolf Mewe, someone who had experience with spectroscopy. Rolf is one of the few people in the world that has set up from scratch a model for the prediction of the X-ray radiation. Throughout his career, then, until his sudden death at the age of 68, he has expanded that model. I've learned a lot of Rolf and am grateful to have had the opportunity to work with this sympathetic colleague.

Such cooperation moreover only started when I was already several years working at SRON in Leiden, after my PhD defense. Johan Bleeker, the driving force behind the Leiden space research and later successor to De Jager as Director of SRON, had as specialty X-rays from supernova remnants (exploding stars). His doctoral candidate Fred Jansen was studying that topic, and Fred and I could really douse the encyclopedic knowledge of Rolf in the field of spectroscopy. This way years of collaboration grew.

We can use the models for X-rays that have been developed by Rolf and me, together with a number of other colleagues, for the X-ray study of the universe. Virtually everything in the universe can emit or absorb X-rays. I will not extensively elaborate on this here, but I limit myself to two types of sources: Black holes, and clusters of galaxies.

Black holes

Time for the second topic, black holes. What is a black hole? An eleven-year-old expressed it this way: "A black hole is a hole. If you fall into it, you can not get out." That is indeed a concise summary. It's a hole in space, and beyond the horizon is no turning back.

But what many do not know is that a black hole looks far from black. Due to the strong gravitational force gas is sucked from long distances to the vicinity of the hole where it is brought in through a massive vortex in the form of a disc. During this process it is so strongly heated that it emits X-rays. The region near the black hole is exceptionally clear, up to ten billion times brighter than sunlight.

I confine myself here this afternoon to the heaviest black holes that exist in the cores of galaxies, which are one million to ten billion times more massive than our sun. Our own Milky Way is home to such a monster. That keeps, at least now, rather quiet.

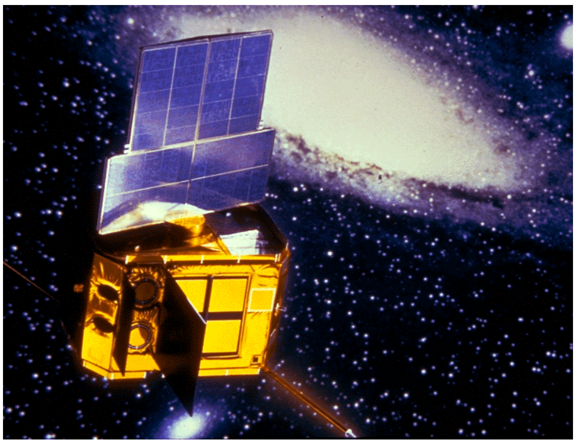
The black holes where I want to speak about with you are particularly active. That activity should be fed just like with the monsters in nature. Sometimes the gas between the stars of a galaxy is considerably shaken. This may be due to a nearby passage or even a collision with another galaxy.

The gas and stars that orbit neat and graceful in regular orbits around the nucleus of the galaxy containing the "pit" of the black hole, are distorted by the extra gravity of the passing or colliding system and can therefore end up in orbits that come very close to the black hole. And that leads up to much gas into the rotating disk around the hole, which is eventually swallowed by the black hole. That may involve amounts of a solar mass per year.

As I said earlier, the gas is then heated and will emit X-rays, especially in the area close to the black hole, at typically ten times the distance to the edge or horizon of the black hole. Ultraviolet light is also emitted near the center, but that happens usually ten to a thousand times farther away from the hole. Infrared and radio waves come from even greater distances. If one wants to study the environment so close to the black hole, then the X-rays are the tool to use.

EXOSAT

As some of you may know, I came to work after my PhD in Utrecht at SRON in Leiden, and I'm glad I picked up the thread – the line – after twenty years here. I was involved in the analysis of data from the EXOSAT satellite, an ESA mission that flew in the early eighties of the last century. One of the subjects I studied were active galaxies, so that are those galaxies with an active black hole in the center.



The EXOSAT satellite. Image: ESA

For its time EXOSAT was very advanced - my current colleagues will smile. It had a real X-ray imaging mirror on board, but the detector was simple and only by inserting filters one could deduce some very rough spectral information. There was also a detector with proportional counters on board, with which a spectral resolution of up to 20% could be achieved, but without an imaging mirror. All that was within one degree of the direction of view was included in the signal, which therefore contained a lot of noise.

This lack of imaging capability also brought risks with it. I like to tell you an anecdote about it, for education and entertainment. In 1989 I spent a month in Japan, to work with the Japanese Ginga satellite, that possessed an enlarged edition of the proportional counter of EXOSAT.

Another guest was working on the data of NGC 6814. That was a source that was found to exhibit periodic signals, and it hummed in the high-energy world therefore with models to explain that, like a star that has come too close to the black hole and thereby was periodically plowing through the disk, every time leaving a puff of gas until it would eventually be swallowed.

I was also with Nico Roos well advanced with such a model, but we have fortunately never published. Well, why fortunately? It appeared that within half a degree next to NGC 6814 another source was present in the field, and that was a cataclysmic variable, a kind of binary where the regular orbital motion of the star generates a periodic signal. The puzzle was solved because someone took the effort to study the field with an imaging X-ray telescope. End of story.

What I want to demonstrate here is that the combination of imaging power, spectral resolution and time-resolving power, is the ideal mix to do astronomical research and preferentially everything as good as possible. EXOSAT was still far away from that.

What this satellite did discover was the so-called soft excess in active galaxies. The first generation of X-ray satellites had already established that the spectrum of such sources was dominated by a rather boring power law spectrum. EXOSAT now found an excess, extra soft x-rays, which we now think is the direct emission from the disk that rotates around the black hole.

Prejudices

It took quite a while until everyone was convinced that this component really existed. Besides the European EXOSAT satellite at the same time there was also an American X-ray satellite in space, and the vain creatures had baptized him Einstein. If Einstein did not see it, it could not be true.

This kind of prejudice I'll still see in my field of work, sadly. For example, when comparing data from our own Dutch RGS detector with the German pn detector. Then, by definition, the German instrument is right.

Or when using different spectroscopic tools – where some people do not want to abandon the ubiquitous XSPEC - it almost seems like a similar kind of mass delusion as with Windows from Microsoft.

And then there's the big crowd that although correctly learned during science class to work with meters, Joules and kilograms, but because "everyone" in astronomy still does so, simply falls back on centimeters, grams and ergs. It is time to write an article with Rhenish rods, Frisian pondematen and nautical knots. And then see who can still unravel that.

EXOSAT also had seen strong variability in the X-rays from active galaxies on time scales of minutes to days. The stronger the source, the longer was the time scale. This was one of the best evidence for the existence of black holes in these systems.

Again, it took some time before many people dropped their prejudices, that is, when one could see with the Hubble Space Telescope the movements of stars around black holes in nearby galaxies. Here is the prejudice that something is only "real" if you do see it in visible light with the naked eye - with or without a telescope. But X-rays are just as real as visible light or radio waves.

The relationship between time scale and luminosity of the active galaxies was described by Paul Barr and Richard Mushotzky. With the first one I had written a paper about the EXOSAT data of the active galaxy NGC 5548, a source that will come back this afternoon a few times.

EUVE

I had already indicated that EXOSAT had its limitations. A big step forward was the American EUVE satellite. This had a number of grating spectrometers and delivered the first large-scale high-resolution spectra of all kinds of X-ray sources. That was at very long wavelengths, and the question is whether you should now call this radiation "soft" X-ray radiation or Extreme Ultraviolet radiation, but with data from this satellite Rolf Mewe and I have really developed our spectroscopic code and could test it with observational data. We have also observed the aforementioned source NGC 5548 been with EUVE, but you needed weeks of observing time to catch a rather noisy signal.

Chandra and XMM-Newton

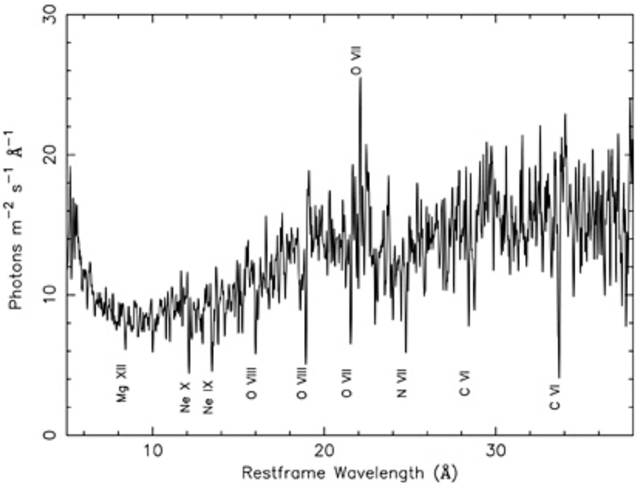
The real birth of the high resolution X-ray spectroscopy was the launch of the Chandra and XMM-Newton satellites in 1999. Both work at this moment perfect. It was a kind of repetition of moves: as with Einstein and EXOSAT around 1980 also now NASA and ESA had their own competing satellite. The US Chandra satellite is very good at making sharp images and the European XMM-Newton satellite is the most sensitive.

SRON had accumulated in the course of the years experience in the making of X-ray gratings, with which the X-ray light can be separated in colors. With this experience in one house they then tried to have a high resolution grating spectrograph being placed on both Chandra and XMM-Newton.

There was competition, but the SRON bars came out as the best design and could be placed on both satellites. A great result, but a financial disaster, because it concerns a "free" delivery (free for NASA and ESA). A good solution was luckily found by renting on Chandra a former rival, the Germans, as paying subcontractor. A marvel of diplomacy of Bert Brinkman.

Winds of black holes

We now return back to the active galaxies. The SRON grating spectrometer on Chandra delivered the first high-resolution spectrum of an active galaxy, measured in 1999, namely that of the aforementioned source NGC 5548.



The first X-ray spectrum of NGC 5548, measured with the Chandra LETGS spectrograph in 1999. The lines are caused by absorption through the wind.

When Rolf and I looked at that first spectrum we were disappointed. It seemed like it only consisted of noise. That was because we tried to squeeze together the detailed information of the spectrum on a sheet of A4 paper. But after closer examination of details we saw somewhere something like oxygen lines. And a trained spectroscopist knows that when you see one line, you should see other lines, and indeed, the one after the other line could be identified. It turned out that we had seen a strong wind that blows away gas with velocities of hundreds of km/s, away from the black hole. The wind betrayed himselves by absorbing the underlying radiation.

This marked the beginning of a new branch of sport, investigating winds of black holes. It has brought many wonderful results. We have observed NGC 5548 even longer in 2002, and the details that were visible led to deeper understanding of these sources.

But one always wants more. More means more observing time, and so together with a large group of colleagues I have studied the system Markarian 509 in 2009. Because one can see how the wind reacts to changes in the brightness of the active nucleus one can determine how far the wind is away from the black hole and how much matter and energy it carries away. This campaign was very successful and resulted in 15 publications. But do all sources behave the same?

Satellites such as XMM-Newton, by the nature of their orbit, do not always see all parts of the sky, and thus our earlier source NGC 5548 was not observed for a number of years. But we could well see it again in 2013, and we have again set up an extensive observing campaign with an entire space fleet of six satellites. The flagship was obviously XMM-Newton, but also the Hubble space telescope joined, Chandra was present and also three other satellites.

When the first data was received we were stunned. It seemed like our RGS spectrometer was broken - a signal was hardly seen. Closer inspection revealed that the RGS was alive and well, but the source was thirty times weaker than normal.

The combined data showed that we had found a new kind of gas flow close to the black hole. A thick gas jet with a speed of 5000 km/s flying outwards blocks at this moment the bulk of the soft X-ray light of NGC 5548. It provides a shadow through which gas that is behind it is shielded from the X-ray radiation and is therefore less highly ionized.

Cartoon of the gas streams and winds in NGC 5548. Credit: Renaud Person

Such gas in the shadow of the current can be easily accelerated by ultraviolet light to winds with hurricane force. That process is supposed to work in the brightest active galaxies, and here we have thus seen it for the first time, completely unexpected.

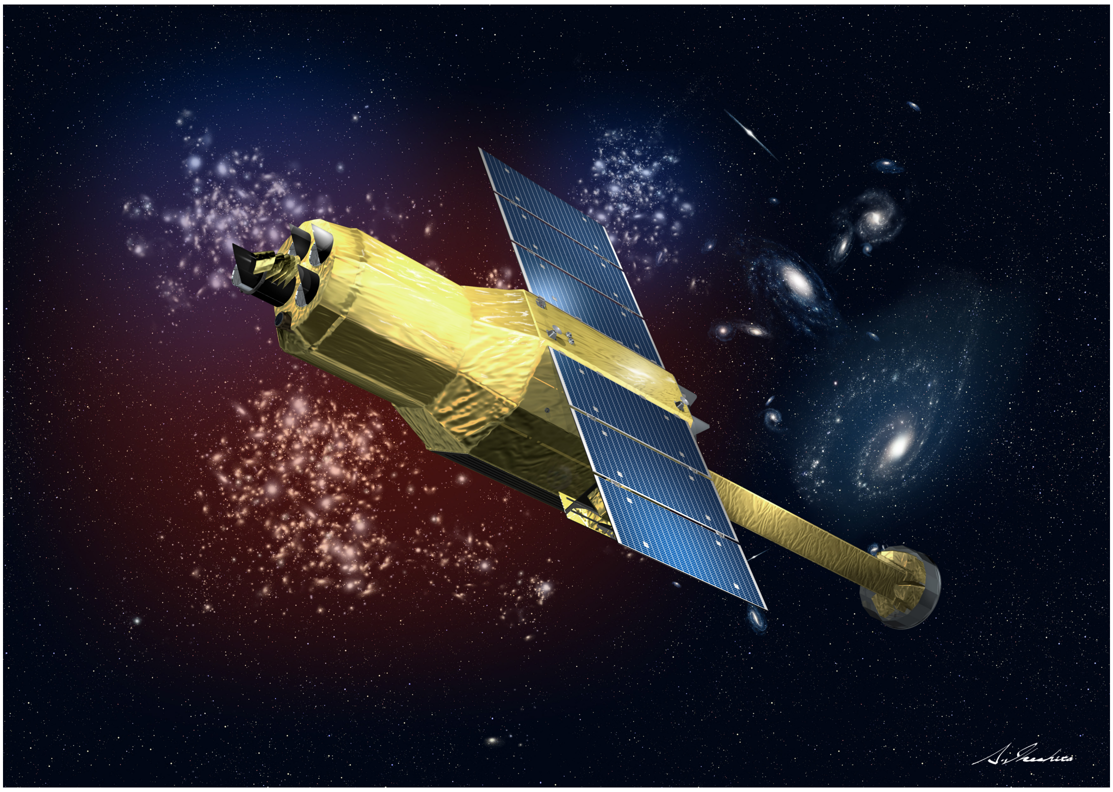
That brings me to another point. Funding agencies now require mostly from researchers who apply for grants that the results of the study are predicted in detail. One would almost think that it has little use to perform the proposed program if the results have already been set in advance. And it leaves no room for unexpected discoveries as the above finding.

The researcher must also now show the social importance of the research - read: can you make money? No, esteemed funders, knowledge is power, and money does not buy happiness.

So back to the black holes. Some colleagues suggests the existence of UFOs. These are not flying saucers, but Ultra Fast Outflows - very fast gas flows - very hot gas with speeds up to three-tenths the speed of light. If they really exist they carry so much energy that they strongly influence the development of the black hole and the surrounding galaxy energy - they blow so strongly that the growth of the black hole will be severely curtailed. To demonstrate the existence of these a new satellite is needed.

ASTRO-H

Such winds will be found by ASTRO-H, a Japanese satellite with a revolutionary new detector on board, if they exist. SRON also contributes to this Japanese satellite which will be launched over a year.



ASTRO-H

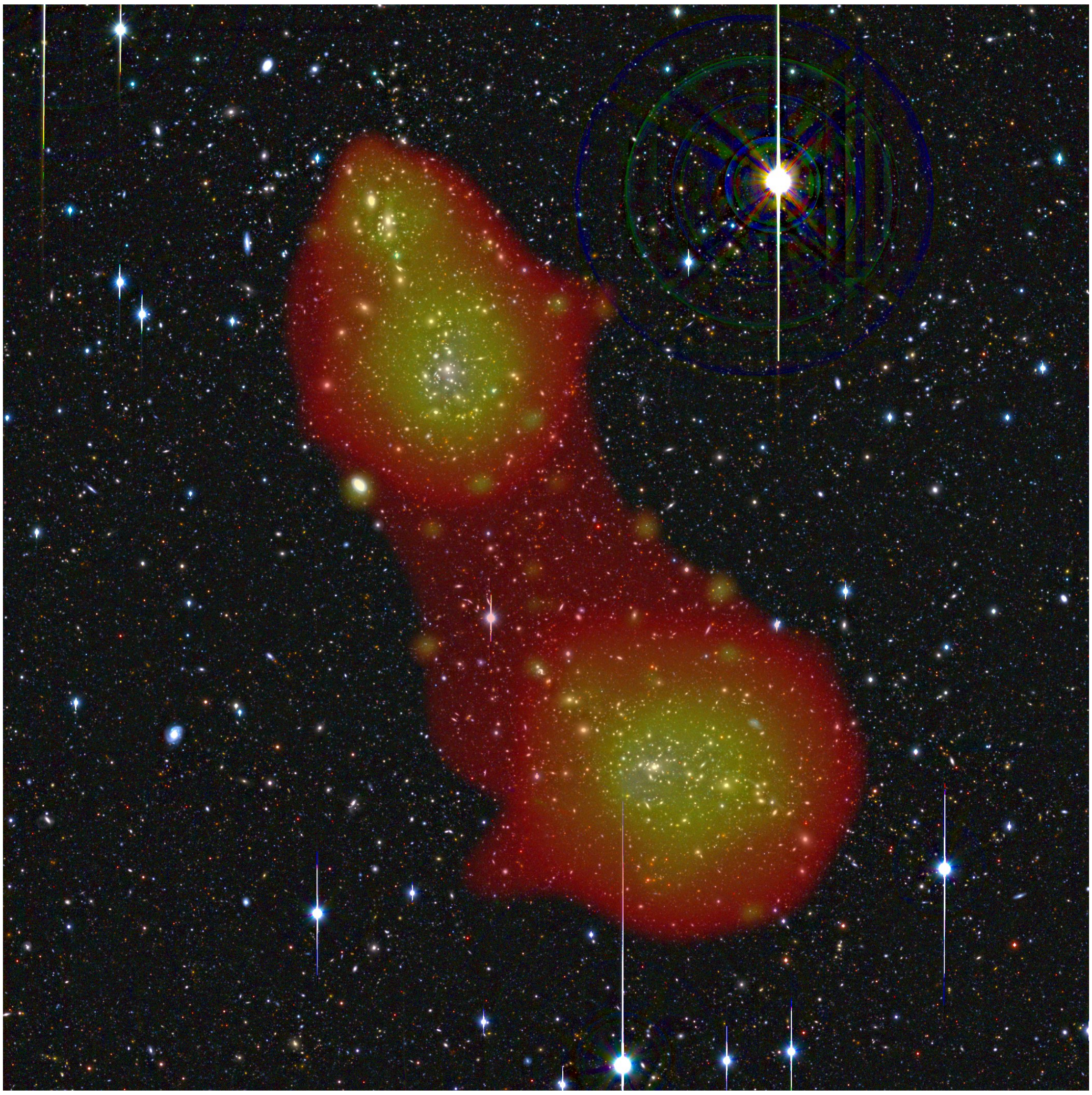
The innovation of the detector of ASTRO-H is that the X-ray light does not have to pass through a grating in order to separate the colors, but that the detector measures the energy of each incoming photon very accurately. The light output is much greater than for a grating, but above all, for the first time, very good spectra from spatially extended sources can be made, that are sources, which for example have a dimension of a degree in the sky.

Clusters of galaxies

That brings us to the third part of this afternoon, clusters of galaxies - large groups containing hundreds to thousands of galaxies, which are embedded in hot and tenuous gas that emits X-rays. What will ASTRO-H bring us here? I expect here together with three Leiden PhD students, two postdocs, other colleagues at SRON and nearly two hundred colleagues abroad to be able to develop new lines of research.

What do we want to do using ASTRO-H in this area? Many clusters contain at their core an extra large galaxy, which in turn contains a supermassive black hole.

Unlike active galaxies we discussed earlier, those with the strong winds and high luminosity, the black holes in these types of cluster galaxies far more insidious: you never see them but they emit huge amounts of particles at high speeds. These particles spray in directed currents along the axis of the hole outwards and influence their environment to millions of light years away.



The pair of clusters Abell 222 and Abell 223 in regular light (photo) and X-ray light (yellow and red). Credit: Norbert Werner.

Eventually they dump their energy away from the black hole, which in turn creates heat. Would the rarefied gas in the cluster without that extra heater be cooling further and further by emitting X-rays, the cold gas that would form would eventually produce stars or might fall into the black hole. Again, there is feedback between the growth of the black hole and its surroundings. How that heating and cooling is happening exactly, can be excellently studied by ASTRO-H.

Although clusters are very old, they are still far from mature. Still these days, there are individual galaxies and groups of galaxies falling onto the clusters, attracted by the strong gravitational field. Clusters also can sometimes collide.

Such interactions cause - how could it be otherwise - strong shocks, where cluster gas is heated will emit more X-rays. The shocks also accelerate electrons and accelerated electrons can produce special X-ray lines. Because ASTRO-H is studying that radiation, we will learn more about what happens in this kind of large-scale shocks. In addition, the radio radiation that my colleagues in Leiden study with the LOFAR telescope provides important supplemental information.

New stars in the galaxies of the cluster are constantly being born and other stars end their lives. Massive stars explode as supernovae and can thereby emit large amounts of gas. That gas is enriched with all the chemical elements that the star produced through nuclear fusion in his life or during the last breath. Less massive stars like the sun eject at the end of their long lives also their chemically enriched outer layers, but in a less violent manner.

Every generation new stars produce heavier elements like carbon, nitrogen, oxygen, and iron, all essential building blocks for life on Earth. Eventually the universe will therefore contain more and more heavy elements. It has long been known: most of the atoms in your body once were made in stars. The elements formed by the dying stars eventually ends up in the space between the stars. This enriched gas can turn into new stars, or ultimately end in the hot gas of the cluster.

Clusters have a very large mass. Because of the assoiciated strong force of gravity the hot gas in the cluster can not escape. If we now measure the X-ray spectrum of a cluster with ASTRO-H, we do cosmic archeology: we see the end result of billions of years of evolution of the cluster. From the relative amounts of the elements we even can deduce things like how many stars of which type were present at whcih timepoint. Each type star has its own unique "DNA" imprint, his own chemical production.

Athena

ASTRO-H will open the above research field, starting in 2015. But technology does not stand still. ESA last year decided to build a new X-ray satellite to be launched in 2028. This mission is called Athena, the Greek goddess of wisdom, and - the story is monotonous - SRON also is involved in the construction of the main instrument, thanks to fifteen years of investment in the technology behind that instrument. Add to that the fourteen years to the launch, and maybe even fifteen years or more successful observations. You see, we have to hold the line for almost a lifetime in space research, but the results are great.

High energy astrophysics, and in particular the X-ray spectroscopy, is still fully in development. Therefore, I am glad I can give this beautiful course here in Leiden, a university with a very old tradition that holds the freedom of research of paramount importance and covers a wide range of fields, including astronomy, where it is a leader in the world.

Writing skills

In the current research environment one gets nothing for free. Proposals for large facilities such as a space telescope requires a lot of money, and in addition to the knowledge and skills to design it, first in a very tough competition the proposal has to be judged better than that of competitors.

That competition also occurs in writing proposals for observations with such an instrument, and writing proposals for getting money for the appointment of PhD students and postdocs to do research. In all these cases - obtaining instruments, observation time and manpower - the demands is excessive - seven to ten times more requested than the available resources or time permit is fairly common.

Proposals must therefore be particularly strong, and the average applicant usually gets nothing, while on the other hand, the committees that evaluate the proposals spend a lot of time on reading proposals that may eventually not be honored. Waste of time and effort on a large scale. It does not matter whether the competition is national, European or global.

I have often experienced the process - as submitter and reviewer, and I necessarily spent a significant portion of my time on these issues, on average perhaps one day a week. ***I came to the firm conviction that the alpha qualities of the researcher are more important than the beta qualities.*** Of course, the proposal should be meaningful and good, but only those proposals that have a clear storyline, are understandably written even for non-experts, grammatically correct, without striking misspellings, typographical correct and easy readable, only those proposals have markedly increased chance of success.

I will therefore continue to stress to all my students to meet these conditions, even when writing scientific articles, and not hide behind excuses like "that somebody else will do that for me" and "oh, if science is only correct ". How do you expect the reader takes the work seriously when the author apparently did not take the trouble to themselves to first read their own brew? Training is also extremely important here.

Genealogy

That brings me to the final part of this afternoon.
I want to take you to the genealogy. This is a fascinating area of research, and as some of you know I keep some of my spare time to do that. No, you do not have to fear for endless stories about my ancestry. But I want to point out an interesting parallel. This is done as follows.

Any research, even astronomical research, builds on results obtained in a long series of years by many researchers. That research is recorded in the literature.

But equally important is what is not always written down, the process of the researcher in a broader sense. Someone trained the researcher and taught him or her a way of thinking and working. The hand of the master is visible in the work of the student, although students also develop their own style from that accrued basis and may also transfer that further on their students. Furthermore, often the specific research area of the teacher forms the foundation for the research of the student.

Just as in the family genes and uses of are passed and from generation to generation and evolve, so too one can perceive a continuous line with researchers.

Mathematicians of the North Dakota State University have set up a project, the Mathematics Genealogy Project. They try to reconstruct the family history of mathematicians, from teacher to pupil. But their database currently contains more than mathematicians alone. Many of you will be able to retrieve their scientific pedigree there. I will illustrate this by showing my scientific ancestry.

I enjoyed my education - and I've enjoyed it - at the Astronomical Institute Utrecht. My co-supervisor Jan Kuijpers has introduced me in the plasma physics of the sun with his great enthusiasm and openness to both theory and observations.

However, my official supervisor was Max Kuperus, who made school in plasma physics. He was PhD student of Kees de Jager. This still scientifically active 93 year old scientific pioneer has started the Utrecht branch of SRON, my employer, established from his interest in the sun.

But during lunches and coffee breaks at observatory Sonnenborgh in Utrecht still many stories about Minnaert, the promoter of De Jager, were told. Minnaert made the spectroscopic examination of the sun in Utrecht fmous. It will come as no surprise that he was one of nearly 100 PhD students from the spectroscopist Leonard Ornstein.

Ornstein in turn was promoted by Lorentz in Leiden, one of the largest Dutch physicists, Nobel laureate and also very socially involved. The work of Lorentz is still one of the pillars of the High Energy Astrophysics, the profession that I'm going to teach here in Leiden

Via Rijke and Uylenbroek we arrive at Jan Hendrik van Swinden, in 1766 in Leiden promoted on the topic of gravity, and then professor in Franeker and later in Amsterdam. He also showed in addition to his scientific work a great social commitment. I have no time to elaborate on this, but he was involved in the introduction of the metric system in the Netherlands.

Via Lulofs, Odé and Serrurier we arrive at Burchard de Volder. He got his PhD in Utrecht as a philosopher and became a professor in that field here in Leiden. He did not keep strictly to the curriculum and developed the Leiden experimental physics. His most famous student was by the way Herman Boerhaave.

The promoter of De Volder, Johannes de Bruyn, was since 1652 the first supporter of the scientific philosophy of René Descartes in Utrecht. Further back in time, through Berckringer we arrive onto Martin Schoock, who was the last follower in Groningen of the philosophy of Aristotle. He made Descartes out for quack and adventurer.

This Schoock was earlier in 1636 one of the first professors at the University of Utrecht that was established that year. The first rector of that university and colleague of Schoock was by the way Bernardus Schotanus, a Frisian astronomer and lawyer, to whom the motto of Utrecht University fitted well: "Sol iustitiae illustra nos" (Sun of righteousness illuminate us). In Utrecht they believe nowadays that they can live without the sun. I therefore follow the example of Schotanus, who moved to Leiden after five years.

We now continue with the teacher of Schoock. Via Renerius and Van Kerckhoven we leave philosophy and arrive at theology. Van Kerchoven was promoted in Geneva byThéodore de Beze, better known as Theodorus Beza. Beza was one of the most famous leaders of the Reformation, and close associate of Calvin and his successor.

Both reformers were again disciples of Melchior Wolmar, in turn a disciple of Jacques Lefèvre, a famous philosopher and theologian at the Sorbonne. He had studied with Georgius Hermonymus. He was from Sparta in Greece and since 1476 he was the first professor of Greek at the Sorbonne and among others teacher of Erasmus.

Through the Sorbonne, we return to the Sorbonnelaan in Utrecht, where SRON is located and where I would like to continue to work a long time on the days that I am not in Leiden. I hope to have made clear that science has a long tradition, it is international, and that different disciplines interact and stimulate each other.

In the list of teachers outlined above we get through linguistics, theology, philosophy, mathematics and physics to astronomy. Many of my predecessors showed besides passion for their profession also a great social commitment and broad perspective on science and society. A university like Leiden shows that width in all its aspects. I also hope to teach my undergraduate and PhD students this broad vision.

Acknowledgments

With the above I come at the end of this lecture. I want to thank all who contributed to the realization of my appointment, in particular Prof. Huub Röttgering, and with him the Leiden colleagues who have called me welcome in an extremely pleasant way.

I thank the SRON organization and colleagues over the years who have given me the room to do X-ray spectroscopy and also provided the opportunity to conduct the line of my scientific career as it has proceeded.

I am of course also indebted to my teachers, especially late Professor Henk van Bueren who gave taught me high energy astrophysics, and awakened my interest in galaxies and clusters.

It is impossible to mention here individual names, but I have sharpened my knowledge through collaboration with dozens of colleagues, students and postdocs here and abroad. The support of friends and family was also indispensable.

I am particularly grateful to my parents for the opportunity they gave me to follow such a particular study. Finally, I thank my family who has to live with the many foreign missions, and in particular for the support of my wife Christine, who with her Dutch common sense puts me and us with both our feet back on the ground.

I have spoken.