Observational Astronomy

Subject belonging to the Diploma in Experimental Physics

Universidad de Cantabria, 2009/2010

Introduction to X-rays and AGNs
Summary

I. What are the X-rays? The discovery
II. The X-rays astronomy: an historical perspective
III. Some of the X-rays science
IV. The AGNs
X-rays are a kind of electromagnetic radiation (as the visible light, the infrared, …) associated to waves of very small wavelength, or, conversely, to very high frequency. Therefore, X-rays are related to very energetic phenomena.

**THE ELECTROMAGNETIC SPECTRUM**

- **Penetrates Earth Atmosphere?**
  - Y: Yes
  - N: No

- **Wavelength (meters)**
  - Radio: $10^3$
  - Microwave: $10^{-2}$
  - Infrared: $10^{-5}$
  - Visible: $5 \times 10^{-6}$
  - Ultraviolet: $10^{-8}$
  - X-ray: $10^{-10}$
  - Gamma Ray: $10^{-12}$

- **About the size of...**
  - Buildings
  - Humans
  - Honey Bee
  - Pinpoint
  - Protozoans
  - Molecules
  - Atoms
  - Atomic Nuclei

- **Frequency (Hz)**
  - $10^4$ to $10^{20}$

- **Temperature of bodies emitting the wavelength (K)**
  - 1 K
  - 100 K
  - 10,000 K
  - 10 Million K
X-rays were discovered by the physicist Roentgen in 1895. He was awarded with the Nobel Prize in Physics in 1901 (the first one) because this discovery.

Since very early it was noticed that the X-rays were better absorbed by dense materials, and, almost from the first moment, its medical application was clear.

Besides, X-rays are very suitable to study the structure composition of crystalline materials, since its wavelength is close to the inter-atom distance.
In astronomy, it is common to classify the X-rays attending to their energy:

- **soft X-rays**: from 0.1 keV to 1 keV
- **hard X-rays**: from 1 keV to 10 keV
- **soft γ-rays**: from 100 keV to 1MeV

As a research branch, X-rays astronomy is relatively young. Due to the atmosphere absorption, **rockets/satellites are required** to observe them.

X-rays are *easily* absorbed by the atmosphere (lucky us!), due to the **photo-electric absorption**.
In the 50s, the first experiments were carried out. They just were rockets (“flying” only for a few minutes) that tried to probe whether there was any detectable X-rays source.

Although the Sun is an effective visible light emitter (its temperature is around 6000 K) very early the X-rays emission from the Sun was detected (in 1949 by the V2 rocket).

Where this emission came from? (> $10^6$ K are required!)

From the solar corona:
Estimations made from the solar measurements, suggested that it could be a titanic task to detect X-rays emission from any other star. Hence, subsequent missions tried to measure the X-rays reflected in the Moon surface.

In 18th June 1962, a researching group led by Riccardo Giacconi launched an Aerobee rocket.

It was a low resolution instrument with 3 detectors, that flew higher than 80km for 5 minutes.

Moon X-rays weren’t detected (actually, it wasn’t detected until 1990 by ROSAT satellite), but....
... however, two surprising discoveries happened:

• a source extremely bright in X-rays, but not noticeable at other frequencies. It was (afterwards) located at the Scorpio constellation, and was named Sco X-1: the first extragalactic source detected in the “new” band

• a diffuse radiation from all directions (lately identified as a cosmic radiation from the X-rays background)
After the rockets era, satellites (starting in the 70s) became the best tools to probe the X-rays emission in the universe. Some of the most important ones were:

- Einstein (USA, 1978-1981)
- ROSAT (European, 1990-1999)
- ASCA (Japan, 1992-2000)

Nowadays, there are two major X-rays satellites under operation:

- **XMM-Newton** (from ESA, launched in 1999)
- **CHANDRA** (from NASA, launched in 1999)

And the most important future/planned mission is:

- **IXO** (ESA-NASA-JAXA)
**X-rays mirrors**

This radiation has to have very large incident angle (otherwise, light would cross the mirror, rather than being focalized), and, for that reason, X-rays mirrors are designed as very long focusing “tubes”.

**X-rays detectors**

There are several detection techniques associated to X-rays astronomy, some of the most important ones are: **photo-multipliers** (converting photons into electrons), **CCDs** (already seen in previous lessons), and **calorimeters** (converting photons into heat).
X-rays astronomy provides us with both, images and spectra.
The X-rays science is very much related to the different physical processes producing X-rays. Some of these processes are:

- The **thermal bremsstrahlung** (breaking radiation), produced by the interaction of a free electron with an ion: the electron is deflected (and emits a photon). This kind of emission takes place, for instance, in extended sources, as clusters.

- If the **electron** is not deflected, but **captured by the ion**, the new ion/atom gets rid of energy by emitting photons, including X-rays (mainly at the softer part).
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- The **inverse Compton scattering**, occurring when a (low energy) photon and an electron collide, is another X-rays source. The scattering changes the electron and photon energies.

- When an electron, guided by a given magnetic field, is moving at very large speed (around the magnetic field lines), a **synchrotron emission** appears, with very energetic photons.
**All-sky surveys**

Normally, X-rays telescopes point towards known sources (detected in other frequencies). But, in some occasions X-rays experiments also deal with all-sky surveys, that help to find new sources (not seen in other bands). This was done, for instance, by ROSAT.
Observational Astronomy: Introduction to Asteroids

**Stars**

We already mentioned that the Sun is the most obvious X-rays source in the sky (because its proximity to the Earth). Nowadays (as compared to the early times) **normal stars can be detected as X-rays emitters** (e.g. Proxima centauri).

**Supernovae** are another type of (death) stars that emit X-rays (by heating the ISM)

Crab remnant: optic, X-rays, optic+X+radio
Stars

Influence of the pulsar on the X-rays (Chandra) and Optic (Hubble) emissions
Black Holes (except AGNs)

Some black holes are formed after the explosion of supernovae that arrived to the Main Sequence with very large masses. The explosion could leave a super-dense object (the black hole) producing a gravitation field so intense that even the light can’t escape from it (Schwarzschild radius).

The effect of the black hole can also be seen through its action in the surrounding area (i.e., to a companion star: a binary system).
Binary stars

Sco-X 1 (the first extragalactic object detected in X-rays) is, indeed, a binary system.
AGNs

Many galaxies have a very intense emission of radiation coming from the central region: it could bright more than hundreds of galaxies! When this light is analyzed, one notices that, first, the spectrum differs from a star emission and, second, it brights at all frequencies. The size of these central and bright regions is less than 1 light-day (a few times the distance Sun-Neptune).

Theory (accretion is the most efficient process to convert mass into energy: 10% matter into light) and observations indicate that what is causing this emission is the accretion of matter from a disk into a super-massive black hole (with a mass of $10^8$ the one of the Sun).

Whereas X-rays and radio emission from these objects is roughly direct (from central regions near the black hole), infrared and optical light comes to us after absorption and re-emission processes.

There are several types of AGNs: Seyfert and radio galaxies are low luminosity AGNs, whereas, brighter AGNs are quasars, blazars and BL Lac's.

As AGNs are so bright, they are excellent tracers of the cosmic expansion. By comparing its spectra with a reference one (at lab) the red shift of the lines can be estimated, and, therefore, provide a measurement of the Hubble expansion (related to our Lab work).
AGNs

Not all the galaxies appear as AGNs... but it is believed that all of them host, at the centre, a supermassive black hole. It is the case for the Milky Way (with a black hole with an estimated mass of $10^6$ Suns):
AGNs

X-rays astronomy has played a very important role in confirming the existence of a super-massive black hole at the centre of the AGNs. This confirmation came from the modifications suffered for some spectral lines in the X-rays electromagnetic range. The most important case is the Iron K line (6.4keV at lab). The relativistic effects due to the presence of the black hole, modify the line shape into a more complicate one (gravity affects light significantly!).
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![Graphs showing X-ray spectra of MCG-6-30-15 and NGC 3516]
AGNs

However, the knowledge of the AGNs properties are maximized when a *multi-wavelength analysis* is performed.

<table>
<thead>
<tr>
<th>Band</th>
<th>Emission</th>
<th>Absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio</td>
<td>e- jet</td>
<td>Plasma</td>
</tr>
<tr>
<td>Infrared</td>
<td>Molecular torus</td>
<td>Dust</td>
</tr>
<tr>
<td>Optical</td>
<td>BLR, NLR</td>
<td>Dust</td>
</tr>
<tr>
<td>UV</td>
<td>Disk (BBB)</td>
<td>Dust</td>
</tr>
<tr>
<td>X-rays</td>
<td>Disk corona (&lt;10\ R_S)</td>
<td>Atomic gas</td>
</tr>
<tr>
<td>γ-rays</td>
<td>Inner zone</td>
<td>-</td>
</tr>
</tbody>
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AGNs

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However, the knowledge of the AGNs properties are maximized when a multi-wavelength analysis is performed.
All the different types of the AGNs are now understood in terms of a standard model, that, roughly speaking, tell us that an AGNs appears as a quasar, a Seyfert galaxy, as a radio galaxy..., just depending on the relative position of the objects, with respect to us (as observers).