RADIATION FROM THE STARS

The March equinox marks the beginning of the spring season in the Northern Hemisphere and in this day Earth's two hemispheres are receiving the sun's rays equally. Did you know that solar radiation includes among others X-rays and gamma rays? Let's find out more...

1. Spectrum and light

If you have ever seen a photo of a star or a galaxy, you might have heard or read the words "spectrum" and "X rays" or "Gamma rays". These photos are usually colorful, showing beautiful object, such as stars and galaxies, or phenomena, as Planetary nebulae or Supernovae [**Figure 1**].

Figure 1. Different colors represent different wavelength, typically ranging from X rays to radio waves.

So, what is a spectrum? What are these rays? And why are they of interest for the Sun and the other stars and astronomic objects?

1.1 Rays

X rays and Gamma rays are two classes of photons, thus they are both light.
The difference between the two is their origin, and this reflects onto their characteristic energies. We are going to look at atoms [**Figure 2**] and nuclei [**Figure 3**] to understand heuristically these phenomena, and why are they important.

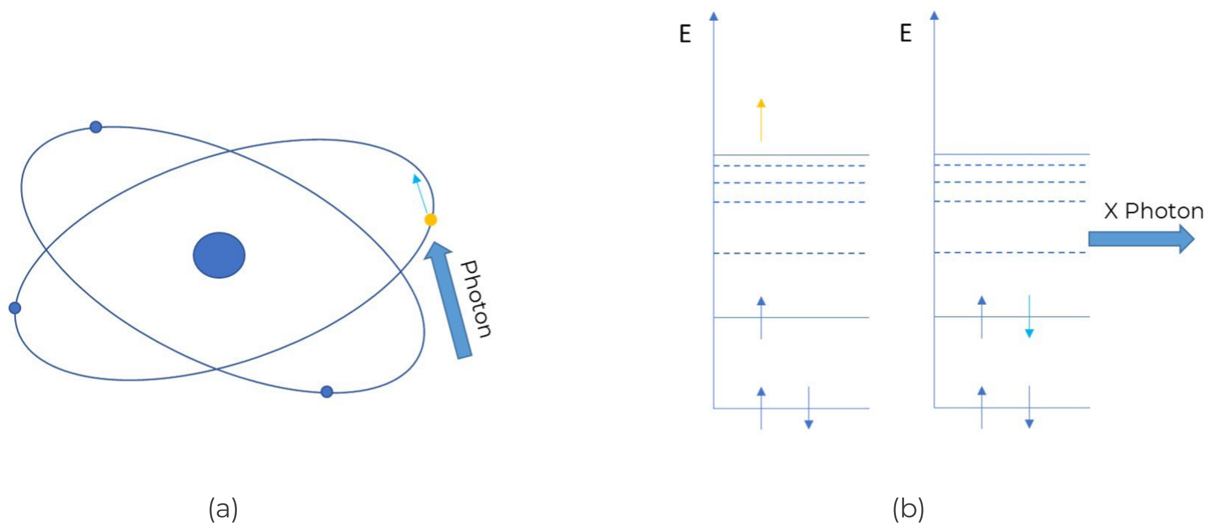

Figure 2. (a) is a Bohr-like representation of the atom.
(b) is the representation of the atomic energy levels.. One of the atomic electron is removed, leading to an ionized state.
When another external electron fills the hole left by the outgoing electron, it emits X rays to fit the energy level.

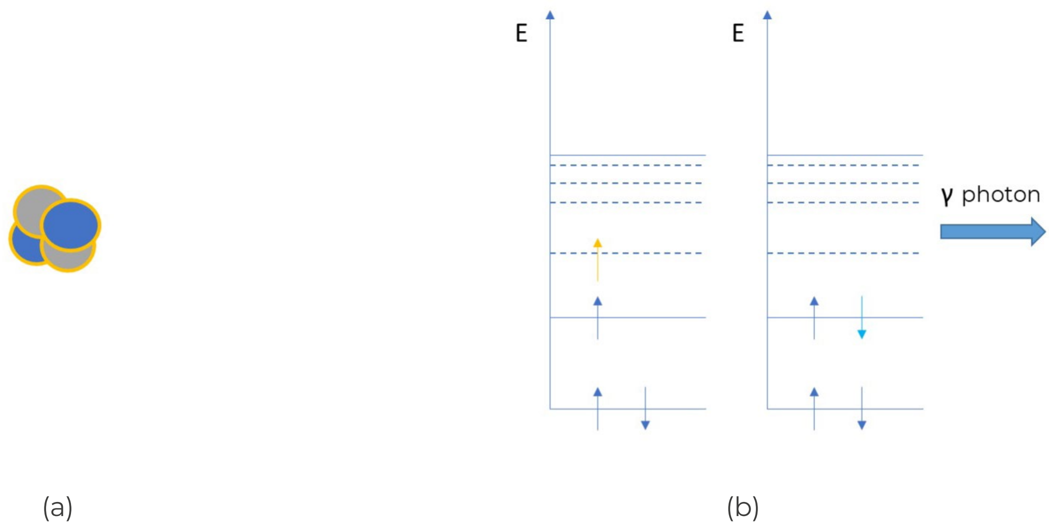

Figure 3. (a) is an Hard spheres representation of the nucleus, and
(b) are the nuclear energy levels. Gamma rays come from de-excitation of the nucleus, being in an excited state.

We will use the Bohr model for the atom and the Hard Spheres model for the nucleus, that are powerful models, allowing for an easy-to-visualize approach, although providing correct and interesting results for what we are interested in.
X rays come from atomic events [**Figure 2b**], involving the electrons into an atom. We divide the events in two cases: when an electron is moved to a higher energy level, the atom is said to be excited. When one (or more) electrons are instead extracted from the atom, we refer to it as an ionized atom [**Figure 2a**].

Gamma rays come from nuclear events, involving the energy levels characteristic of any nucleus [**Figure 3b**]. Inside the nucleus there are protons and neutrons, generically addressed as nucleons. In the case of a nucleus, we are considering the de-excitation of a nucleus [**Figure 3a**] and not the extraction of a nucleon, since this will fall into the class of nuclear reactions.
Nuclear events have many times more energy than atomic events, so X rays are known to be less energetic, although some X ray can be more energetic (also said to be harder) than some extremely soft gamma rays.

1.2 Spectrum

When we talk about a spectrum, we are referring to something that comes to our Detector from an object, named Source. Speaking of X and Gamma rays, we are referring to a source of light.
The spectrum is a histogram that shows, for any selected energy interval, the number of detected photons [**Figure 4**].

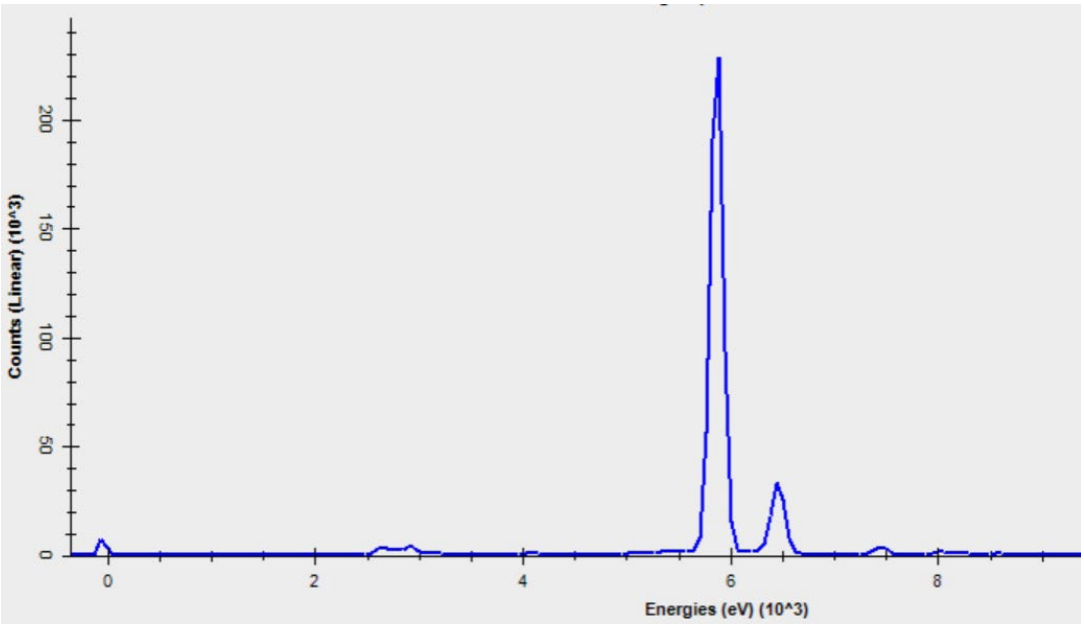

Figure 4. Spectrum from a Fe^{55} source obtained with our DANTE Digital Pulse Processor coupled with an SDD detector.

From these histograms, several aspects of a star or an object can be deduced, as its nature, its temperature, its composition, or its distance from the Earth.

2. Stellar Spectrum

The stellar spectrum shows some peculiar characteristics that make it identifiable quite easily, while some features are not straightforward, and we won't explore them here.
The stellar spectrum spans from the radio waves to the Gamma rays, named from lower energy, equivalent to longer wavelength, to higher energy, or shorter wavelength.
The law linking energy and wavelength for a photon comes from classical electromagnetism and energy quantization:

$$E = \frac{(h\,c)}{\lambda}$$

Where h is the Plank constant, c is the speed of light in vacuum and λ is the wavelength. We can see that, reducing the wavelength, the energy increases and vice versa.
The most energetic parts of the spectrum come from X rays and Gamma ray [**Figure 5**], which provides us the information about the composition of the star and some insights of processes ongoing into it.
If you look at the visible and neighbor regions, that are infrared and ultraviolet, you can see black bands called absorption bands. These bands depend on the materials composing the outermost layers of the star.
The spectrum exhibit also a maximum of energy emission, that means that the photons are emitted with that energy more that with any other energy, that depends on the temperature of the star.
The brightness of the star, that is the number of photons incoming considering all the energies, depends on distance and dimensions of the star.
There is also the Magnitude, that is an index of the brightness in the visible range, that is linked to the total brightness, being a portion of it.

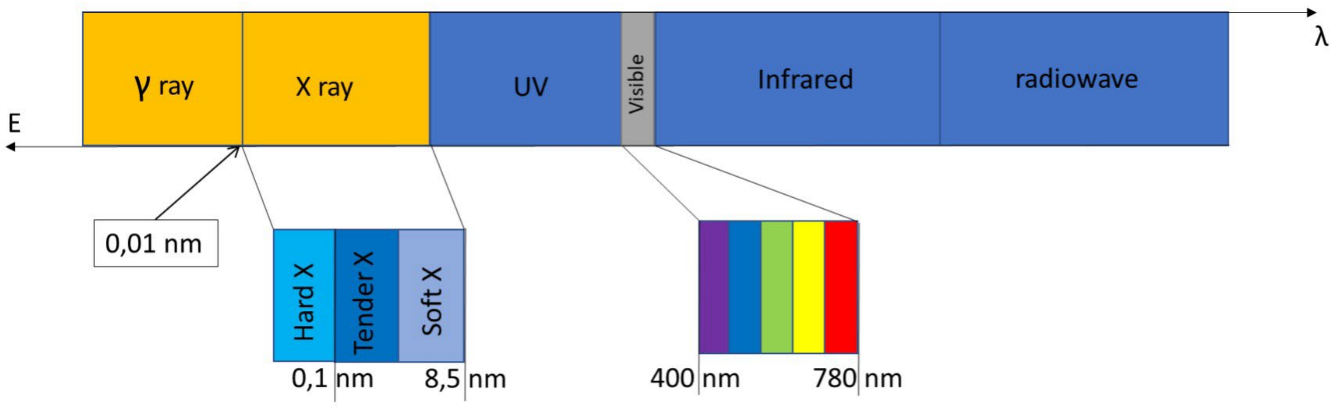

Figure 5. Electromagnetic spectrum. The axes are oriented in opposite directions, meaning that Energy and Wavelength are inversely proportional. Visible, X ray and Gamma ray are highlighted.

3. Solar X rays

The X rays emitted from the Sun allow us to understand what elements it is composed by and what is its dimension.
It is composed mainly by hydrogen and helium. Comparing it with stars of similar mass, dimension, and elemental abundance, we can esteem the age of the Sun and the expected life.
The Sun is the closest star to us, so it was exploited for the most extensive studies about them. Being the most studied, its structure is particularly detailed, although not free of doubts and unknowns. We know about the sunspot cycle, about the Photosphere, producing most of the light coming out of the Sun, and we know about the Chromosphere and Corona.
The Solar Corona [**Figure 6**], when imaged at X rays shows strongly inhomogeneous zones, suggesting that its physics is complex. It is optically-thin, meaning that light from the layers behind it can pass through it; that's one of the reasons we cannot see it by naked eye.
For what previously said, the X rays coming from the Sun originates from the elements (hydrogen and helium), mostly in ionic form due to the extremely high temperatures inside it. For this reason, X rays are produced starting from electrons in excited states, which needs lower energies to be extracted, therefore will emit softer X rays. The excitation due to extreme temperatures is the reason why some stars, much hotter than the Sun, do not show x ray emission from hydrogen. In these cases, hydrogen is completely ionized when present, and without electrons it is not able to produce X rays.

Figure 6. Solar Corona during a Solar Eclipse.

4. X rays from Supernovae

X rays are not produced just in stars. When instabilities in astronomical objects leads them to contract, expand and explode, a number of phenomena can happen, and an example is the famous Supernova.
When these disruptive events take place, a huge amount of matter is ejected into nearby space. This matter is composed by several elements, ranging from hydrogen to iron, which are ejected at different speeds because of their masses. Then, when an image of the after event is made, we can see the distribution of these elements all around the center of the explosion.
The false-color representation of the spectra in different positions allow to create these stunning views of space objects [**Figure 1**].

5. Gamma rays from Stars

Gamma rays, instead, give us information about the nuclear reactions that happens in the star. Most of all nuclear reactions, that are mainly fusion or radioactive decay here, happen to produce Gamma rays of a specific, well-defined energy. This allows to understand the types of reactions and the elements produced by these.