WHY DON'T GREEN STARS EXIST?

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ABSTRACT

Blue stars, white stars, yellow stars, orange stars and red stars. You have many colours for stars. But not all colours. There aren't any green stars.

Stellar spectra analysis requires the use of spectroscopes that can easily be constructed by teachers in the classroom with their students. The workshop will consist of the construction of a spectroscope and of simple experimental demonstrations that will answer to the question.

INTRODUCTION

Stars continuously radiate energy that spreads throughout space. The radiation is called electromagnetic because it propagates by the interplay of oscillating electrical and magnetic fields in space at a speed of 299793 km/s.

A perfect linearly polarised electromagnetic radiation would have a profile like the one presented in Figure 1.

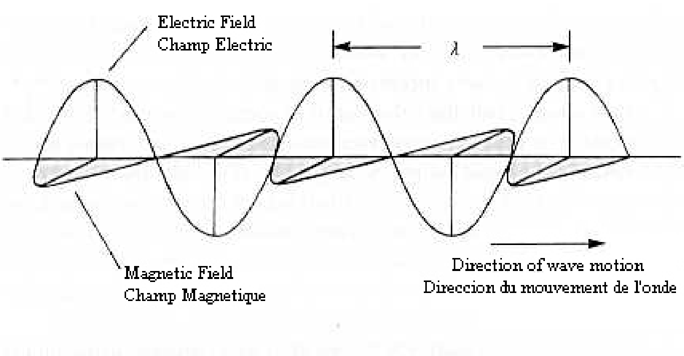

Figure 1. Electromagnetic Wave

Usually the stellar light is not preferential polarised with any orientation, but we can produce an oriented polarisation of sunlight using a *Polaroid* sheet. We can see that the light is polarised by placing another *Polaroid* sheet next to the first one and looking to the light passing through it. When the two *Polaroid* sheets have similar polarisation orientations (light will pass through them) or perpendicular polarisation orientation (light will be block and the sheets will be obscured).

Sometimes molecular clouds function like *Polaroid* sheets any induce some polarisation from the light that comes to us from stars.

Though stars produce light in almost every wavelength of the spectrum the light that arrives to Earth in some bands is neglectable. Adding to this issue, our atmosphere is not transparent to the majority of spectrum wavelengths with exception to visible and radio bands. Only small bands in infrared and near ultraviolet can also be seen from Earths surface, so it is about these wavelengths that we shall concern our attention.

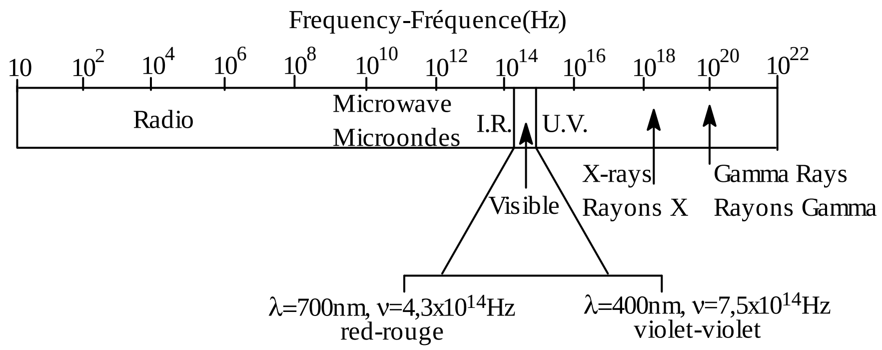

Figure 2. Electromagnetic Spectrum

STELLAR RADIATION

It's common knowledge that the stars are nuclear reactors where huge amounts of energy are permanently being produced. The energy is transported to the surface in the form of photons. Photons are "light" particles responsible for electromagnetic radiation that have a quantified energy of value

$$E = h\nu \tag{2}$$

where E is the energy of the photon, h is Planck's constant (h = 6,626 × 10^{-27} erg.s) and ν is the frequency of the electromagnetic radiation associated with the photon.

Since the photons generated by the stars are responsible for their spectrum, the spectrum will be a sum of al phenomena associated to the production of light since its nuclear generation until it leaves the stellar atmosphere, as we shall now see.

OPACITY

In a star the energy associated to a photon takes typically 1 million years to reach the surface, since it is produced in the parts that are deeper than the photosphere and it will collide with mater that will absorb and afterwards emit it. The absorption's and emissions occur in a very big number since the generation of the photon until it reaches the photosphere.

When light reaches the photosphere, and consequently the atmosphere, it is radiated to the exterior without interactions for the major part of the wavelengths produced or with a continuous small interaction along all wavelengths and we call it this radiation the *continuum*.

The core and the inner parts of a star are opaque (optically thick) to all radiation wavelengths and its atmosphere is transparent (optically thin). A gas may be optically thin or optically thick according to the fact that it absorbs the photons crossing it. As an example, our atmosphere is normally optically thin to visible wavelengths.

Yet, on a foggy day, you won't see far, so it is optically thick. But optically thin doesn't mean invisible. For instance one can use an overhead projector to prove that the flame of a burning candle is optically thin to visible light projecting the candle's shadow with an overhead projector on a wall. The candle will appear, but not the flame. The flame is therefore optically thin to the wavelengths of the projector.

Earth's atmosphere isn't completely transparent. In fact it is opaque to the majority of wavelengths. The only wavelength that reach the ground are visible wavelength and radio wavelength with small windows in the infrared region (Figure 3).

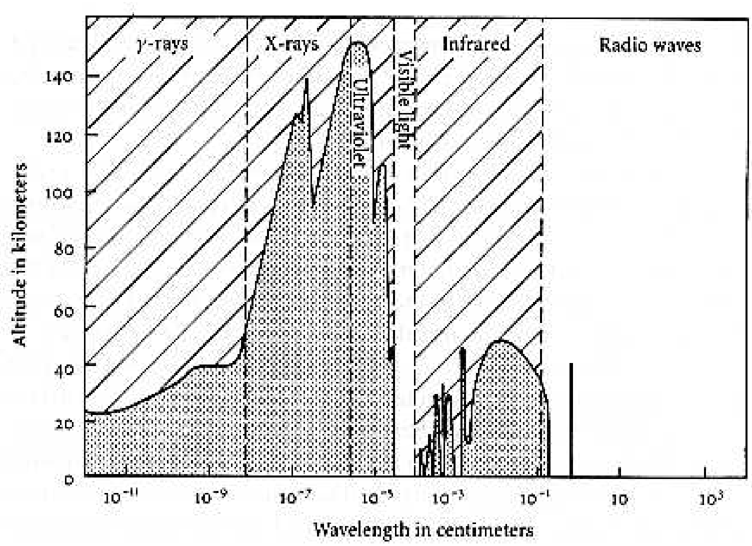

Figure 3. Transparency of earth's atmosphere to the diferente Wavelengths (From Lang,1995)

BLACKBODY RADIATION

During the long period the photons stay inside a star they are thermalized, which means that the photons that are emitted will not have their initial wavelengths. Instead, they will have a distribution of intensities of emitted radiation that obeys a Planck curve, which is only dependent of temperature by Planck's law. For each frequency we will have

$$I_\nu = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT}-1} = B_\nu \qquad (3)$$

$$B_\nu = blackbody\ \ intensity$$

where h is Planck's constant, ν is the frequency, k is Boltzmann's constant ($1{,}34 \times 10^{-16}$ erg/K), c is the speed of light in vacuum, and T is the thermodynamic temperature.

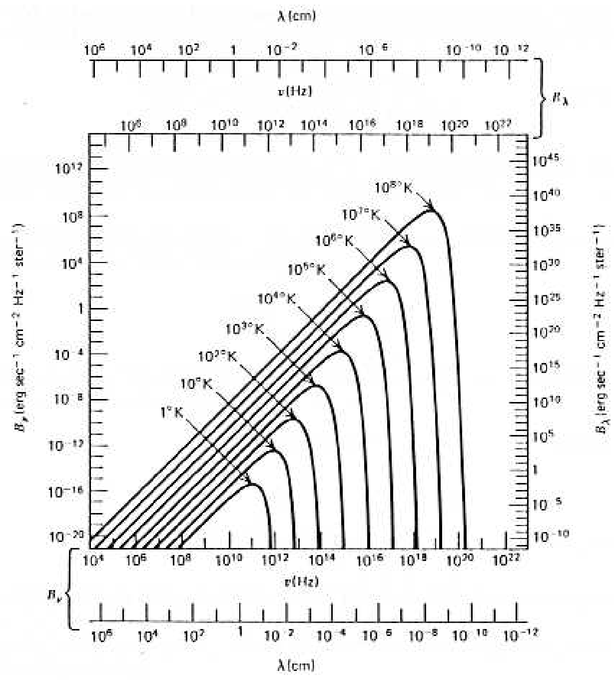

Figure 4. Planck curves at diferent temperatures (adapted. from Rybicki & Lightman, 1979)

We say it radiates like a blackbody. The distribution of blackbody intensity as a function of the wavelength is given in Figure 4. We can understand the colour generated by the blackbody radiation using a simple device built wit three lights, where one is blue, another is red and the other is blue.

All optically thick objects are blackbodies and they have a maximum wavelength (λ_{max}) for emission of radiation associated to their temperature that can be determined by *Wien's displacement law*

$$\lambda_{max} = \frac{0.290}{T} \quad (cm) \tag{4}$$

where T is the thermodynamic temperature. Examples of optically thick astronomical objects are the stars (except for their atmosphere and corona), the planets, asteroids, etc.

Almost all things on Earth radiate like blackbodies (this does not mean they absorb like blackbodies!!). For instance, the common human being is a blackbody. It absorbs ultraviolet and visible light during daytime. Yet, as known, if one wishes to see the radiation emitted by him, one should seek the infrared region with the devices that military use. That is because all energy absorbed by the human being is *thermalised* and then emitted according to Planck's law close to a maximum infrared wavelength of 9.4 μm given by Wien's law (considering a temperature of 37 ºC (310 K)).

Since stellar atmospheres are optically thin, the blackbody radiation will be determined by the temperature at photosphere; so if star should have like the Sun a temperature around 5800K the blackbody radiation should have a maximum wavelength at 4900Å, as shown in Figure 5.

Also shown in Figure 5 are the ultraviolet and infrared absorptions due to the atmosphere as consequence of what has been presented with Figure 3.

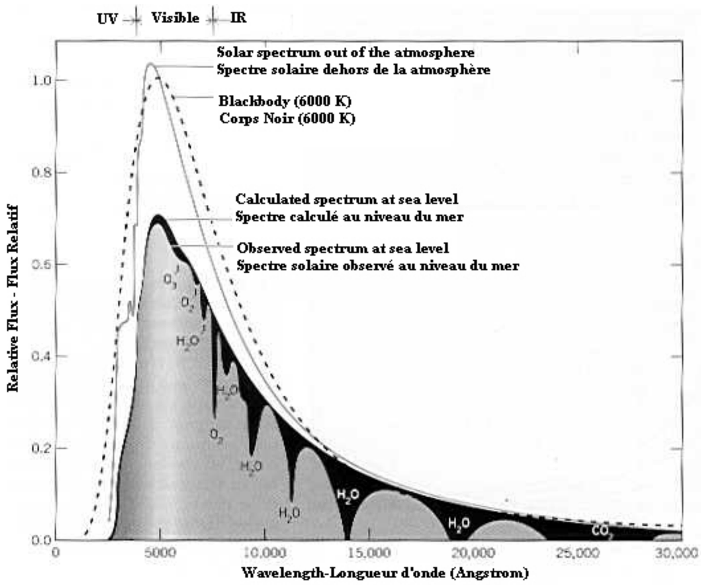

Figure 5. Solar Spectrum (adapted from Zeilik,1997)

Curiously the human eye has evolved to have a curve of visibility that is quite consistent with the visible curve of sunlight that gets to Earth's surface (Figure 6). Note that due to atmospheric extinction the light curve of sunlight reddens near sunset, and so does human eye visibility curve.

The concept of extinction can be demonstrated with an overhead projector leaking only a small beam, filling in small portions of a tall glass with diluted milk; the bigger the column of milk is, redder will be the light that gets to the wall, since blue light is preferentially scattered.

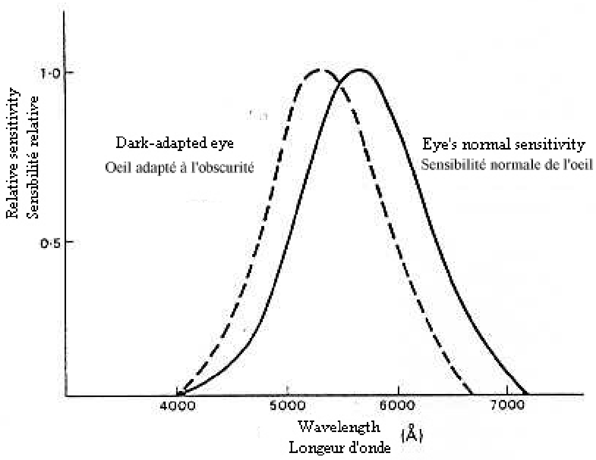

Figure 6. Human Eye's sensitivity to the various wavelengths

ABSORPTION SPECTRUM

When we have a hot atomic gas, it emits a line spectrum (2^{nd} *Kirschoff's law*) associated to the emission of photons due to electronic transitions from a higher state to a lower state of energy. The relation between the energy levels and the frequency seen is given by

$$\nu = \frac{E_H - E_L}{h} \quad (5)$$

where E_H is the higher level, E_L is the lower level and h is Planck's constant.

Viewing an incandescent lamp or an incandescent hot object with a spectroscope will allow us to see a continuous spectrum (1^{st} *Kirschoff's law*).

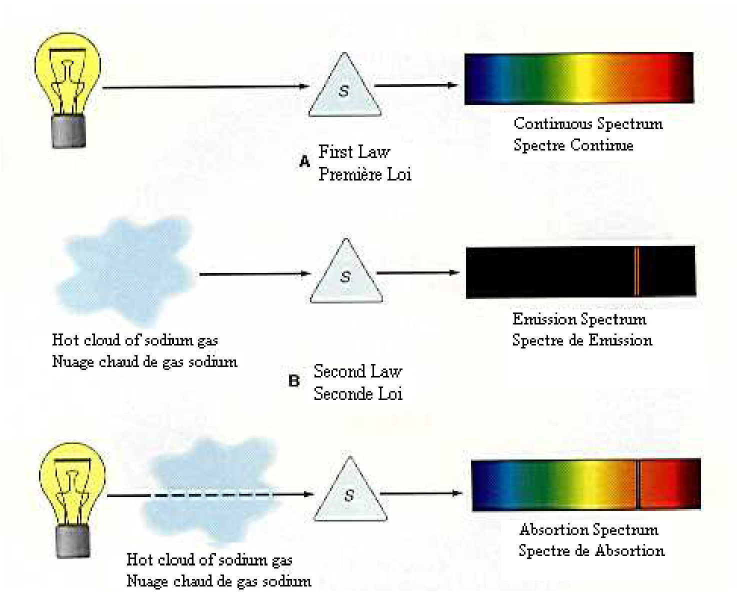

Figure 7. Kirschoff's Laws

If the gas has those emission lines due to transitions between to electronic states, then obviously it can absorb the same energy doing the opposite transition. Then if the gas is put between an incandescent source and a spectroscope, the gas will absorb those same lines from the continuous spectrum of the incandescence source.

This is what happens in a stellar atmosphere. The gas of the atmosphere will absorb the frequencies associated to the spectral lines of the elements that the star is formed of.

Joseph Fraunhofer studied for the first time this phenomenon, in solar spectrum, in 1814; therefore the lines are called *Fraunhofer lines*. With a small portable spectroscope we can see many of the *Fraunhofer lines.* Fraunhofer discovered about 700 lines but that makes a spectrum too complex that people cannot easily understand.

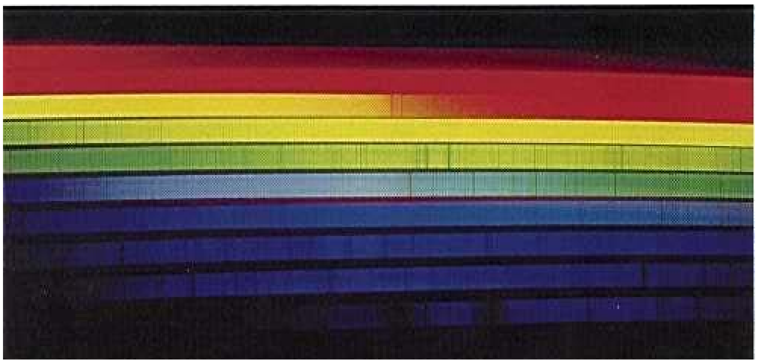

Figure 8. High-resolution spectrum of sunlight (From Lang,1995)

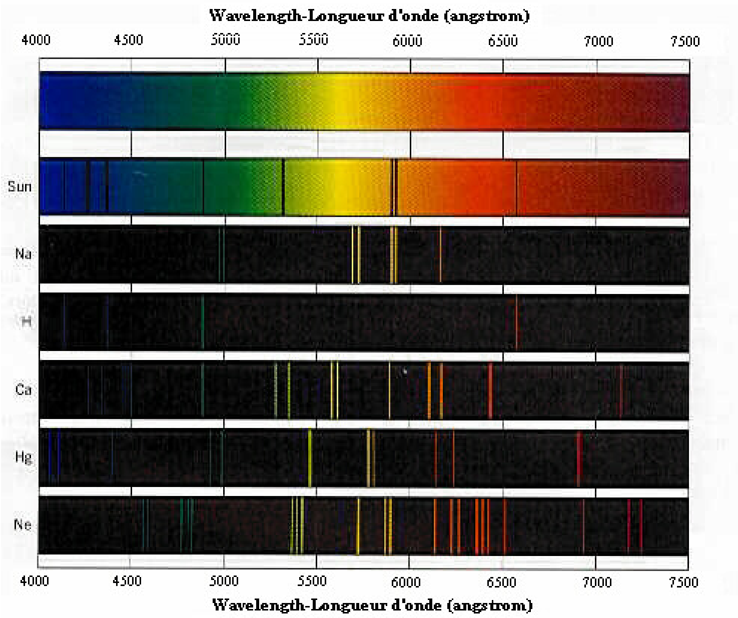

Figure 9. Low resolution spectrum of continuous emission spectrum, sunlight and several emission spectrums of elements (From Zeilik,1997)

Low Resolution Spectrum (Figure 9) however, will allow people to identify the major atomic composition by comparing the atomic emission spectrum with the absorption spectrum.

Simple adaptations can be made to make the simulation not expensive (in black and white).

A low resolution spectrum can be seen using pocket spectrometers, that can easily be made with a tube, a diffraction grating and a paper with a line gap, putting the paper at one edge of the tube and the diffraction grating at the other.

BUILDING A PAPERCARD SPECTROSCOPE

To build a spectroscope using paperboard one needs black paperboard to create an obscure chamber for the reading. The spectroscope assembly can be done using the following sequence:

1) Cut the black paperboard as presented in Figure 10. Don't forget to open a small slit for the light's admission and a rectangle for the scale.
2) Cut the scale presented in Figure 11. This scale must be printed on white paper to insure that the light from behind allows it's legibility.
3) Glue the scale and the diffraction grating to the black paperboard as presented in Figure 12.
4) Assemble the spectroscope by gluing as presented in Figure 13.

The spectroscope is now ready to use.

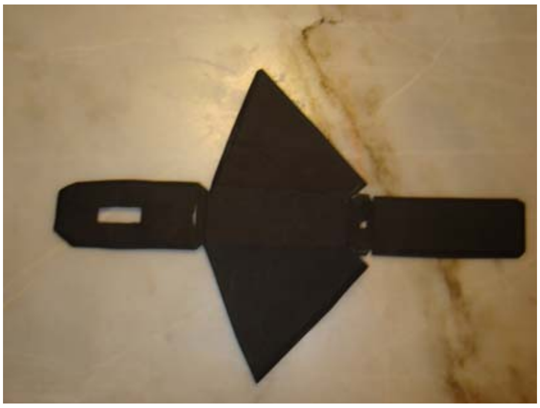

Figure 10. The paperboard prepared to receive the scale and the diffraction grating

Figure 11. Spectroscope Scale

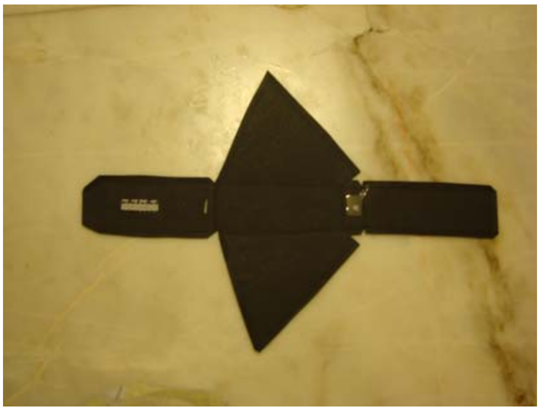

Figure 12. The paperboard after gluing the scale and the diffraction grating

Figure 13. The spectroscope nearly assembled

FINAL NOTES

We have briefly talked about stellar emission, and about the different wavelengths that one can observe from Earths surface. Yet we have not yet discussed why the stars are not green. Well, as we pass from low temperature stars to high temperature stars colour goes from red, to orange, to yellow, to white(?), to blue.

In fact the colour of stars is the sum of all visible radiation it emits. A yellow star has its Wien's maximum in the greens but with big emission of red orange and yellow and only a small amount of blue; since red and green radiation produce yellow, which adds to the "real"(monochromatic) yellow wavelengths, then the star is yellow; the small amounts of all wavelengths that do not contribute to the yellow colors produce white with these wavelengths, that is why the stars are not intensely yellow.

When a star should be green, it becomes white because its maximum is in bluewish green wavelengths. In this case the sum of all wavelengths produce white and not green, and that is why green stars with their colour generated by blackbody radiation cannot exist.

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