Air and Space this Week

Item of the Week

Spectroscopy: Fingerprints of Starlight

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Did you know that stars have "fingerprints of light?" Well they do. And astronomers use a valuable technique, called spectroscopy, to let them measure the chemical composition of light sources and material between light sources and us. Even better, spectroscopy enables an important observation that is showing us how the Universe evolves over time!

Spectroscopy is one of the most important astronomical tools. As Isaac Newton and any other Pink Floyd fan knows, a beam of white light is spread into a colorful rainbow of light when it passes through a prism. But when Wollaston looked at the Sun's spectrum in detail in 1802, he noticed that there were thin dark lines running perpendicular to the color zone boundaries. Others were working on the nature of light, too, and another, Fraunhofer, figured out in 1814 how to systematically study the Solar spectrum and its many lines, cataloging over 570 of them. Around 1850, experiments by Kirchoff and Bunsen (of burner fame) showed that the light of heated elements wasn't white at all, but rather consisted of only a few specific wavelengths, with each element having its own unique-as-fingerprints set of bright lines. They also figured out that the dark lines in the Solar spectrum were similar in origin; the elements in the Sun's outer atmosphere removed those wavelengths passing through that were unique to them.

What a revelation! Armed with spectroscopy, astronomers were confirming the presence of hydrogen, sodium, and other elements in the Sun, and were even able to identify the rough composition of some stars, and classify them accordingly.

But there was one problem. One set of absorption lines in the Solar spectrum could not be matched to any element then known.

On August 18, 1868, Norman Lockyer saw the lines, and imagined that they *had* to be due to a new element. But what to name it? Since it was known in the Sun only, it made sense to name this yet-to-be-isolated stuff something like "sun-ium," or "Ra-ium," or similar. Ra wasn't the only Sun god to pick, what about old Helios, the only god who could drive the Chariot of the Sun? "Heliosium" is hard to say, so Lockyer settled on "helium." But nobody had ever seen it on Earth; the evidence, however strong, was only indirect.

Oh, and BTW, don't eat Helios' cattle, and think twice before letting Junior drive the family chariot, er, car…

Lockyer wasn't the only one thinking about this. There was a total solar eclipse that year, and Pierre Jansson was in India with a good spectroscope. He managed to observe the thinnest edge of the Solar disc, and his spectrogram revealed the same lines Lockyer had been thinking about.

Helium was not detected on Earth in 1882, and was not isolated until 1895. It turns out that helium is the second most abundant element in the Universe, but, because of the configuration of its electrons, it almost never reacts chemically with itself or other elements. Its standoffish nature made it look like helium, if it were a person, thought itself to superior to consort with lesser elements. After all (in its atomic mind), it considered itself “noble.” And, it turns out, there are other, even heavier, noble gases. All of them have a completely-filled outer electron shell, inhibiting any of the sharing or capture/loss of elections that chemical reactions require.

But wait, there’s more!

DO NOT TRY THIS AT HOME! But imagine that you looked like you were about to step onto a street busy with a lot of high-speed traffic. Horns blare, and as you step quickly back to safety, the little physics student in your brain notices that the pitch of the horn had changed as it barely missed you. When the car was coming at you, the horn was higher pitched, but the pitch dropped suddenly. I know you have heard this effect. Glad you are still with us.

Back in 1842, Christian Johann Doppler was thinking about the colors of binary stars, which led him to hypothesize that the colors were caused by the star’s motions with respect to Earth. If the star were moving away, its light would have slightly longer wavelengths, its spectrum shifted redward. If the star were moving toward Earth, its light would have slightly shorter wavelengths, its spectrum shifted blueward.

Doppler was right about the color shifting, but wrong about the color of binary starts (to a degree – it wasn’t enough to make big changes in the tint perceived, but it was enough to detect – some very close binaries were discovered that way. We now know these source-motion-induced frequency changes as the “Doppler Effect.”

Sound is a wave phenomenon involving air pressure, so it is subject to the Doppler Effect, too. The horn you heard when you played in traffic is the example. Sound waves from an approaching source get compressed (higher frequency), and the wavelength of sound waves from a receding source get longer (lower frequency), relative to the wavelength of sound produced by the source when directly alongside (no source speed toward/away from observer).

Doppler was concerned with the effects of source motion on the wavelength of radiation it emits, in the context of binary stars. But the Effect is important not only for them, but for stars in general, and larger collections of stars, such as galaxies.

Spectral lines were the perfect markers to determine Doppler Effect wavelength shifts! Astronomers continued to refine their ability to look at stellar spectra, and began to look at the spectra from galaxies and other large collection of stars. Almost everything they looked at had its light shifted redward to some degree; almost nothing was approaching Earth.

Astronomers were also developing techniques around this time that would allow the distance to the stars, and even nearer galaxies, to be determined.

When an astronomer named Edwin Hubble looked at the distance and the Doppler shift data becoming increasingly available, he noticed an important correlation between distance and degree of red shifting. If the redshift data really did show light sources were receding, and the rate of recession was greater the further the distance from the Earth, one conclusion was inescapable: The Universe was expanding. And if it were expanding in all directions, then everything in the Universe must have been much closer together in the distant past. If you keep up with that line of thought, you end up with all the Universe coming together in a very small space some 13+ billion years ago. The need for subsequent explosive expansion from that point in time in order to produce the observed red shifts is the justification for the "Big Bang" theory of cosmology.

Those little dark lines on the Solar rainbow found by Wollaston and Fraunhofer so long ago turned out to be a major clue to our understanding of our Universe and its evolution.

Personal Note: I had one of my first, and strongest, "aha moments" when I learned the basic principles underlying spectroscopy, so the topic has always been a bit near to my heart. I read a lot about astronomy in my youth, and the book that covered basics of spectroscopy was written in such a way as to "lead" me to learning. Information was presented that had me thinking a step ahead; I came up with what was going on when the topic was set up, before the basics were overtly stated. I felt a sense of ownership; the textbook as information authority confirmed what I had concluded. I no longer have the book, but the lesson it conveyed in education, not astronomy, has stayed with me to this day. I always recommended to museum educators and Docents that a good approach was to lead the audience to recognition of a new idea, then confirm their good reasoning. This very constructivist approach imparts a sense of ownership of the new knowledge leads to much greater retention.

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