

# STARLIGHT'S STORY

## WHAT CAN THE LIGHT WE SEE IN THE NIGHT SKY TELL US ABOUT THE UNIVERSE?

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**A**stronomers are constantly challenged with the task of studying objects that exist many light years away. Typically, the only information an astronomer has about an object is the light coming from that object. As a result, astronomers have used extensive knowledge of light's properties to develop clever methods for studying the light emitted from distant celestial bodies. Recent technology has made these methods even more useful. Knowledge of light's properties equips astronomers with certain tools that assist them in their search for answers. Two of these tools, spectroscopy and the Doppler Effect, rely on simple properties of the light spectrum—often in the visible light range—as the basis for explaining many perplexing phenomena that the universe presents.

Spectroscopy is the study of the spectrum of light in order to understand properties of the source of the light. It developed as a tool for astronomers through the slow accretion of knowledge about light's behavior. For many years it was known that light would produce a rainbow when passed through a prism. Isaac Newton further examined light's properties and interactions with prisms in the 1660's. He discovered the prismatic effects of light; as white light (like that coming from the sun) passes through a prism, it exits the prism as a rainbow. Placing a second prism in front of the rainbow of light which exited the first prism then converts the rainbow back into white light. The resulting rainbow was considered a spectrum of light. A spectrum is now known more generally as certain wavelengths on the electromagnetic radiation.

Visible light is a small band of wavelengths on this larger spectrum. Newton's observations signified the beginning of serious scientific inquiry into the properties of light and color. In 1802, William Hyde Wallaston further examined prisms and discovered that the rainbow created by passing light through a prism had gaps or lines in it. He incorrectly concluded that the lines were the natural borders of colors. Nevertheless, this observation led to further inquiry into the properties of light and the light spectra. A few years later, Joseph Von Fraunhofer expanded the study of light by studying the spectra of certain flames, the sun's light, and light coming from stars in the night sky. In the mid-1800's Gustav Kirchhoff and Robert Bunsen examined and mapped the light spectrum emitted by the burning of certain elements, and they concluded that each element emits a specific spectrum. This chain of discoveries took place from the 1660's through the 1820's. An accurate description of how the properties of atoms and their electrons would cause the specific emission spectrums and lines on the sun's light spectrum wouldn't be found for another 50 years. Regardless, the examination of spectral lines became a tool for scientists which we now call spectroscopy. (Tyson, 2001)

A few years after Kirchhoff and Bunsen mapped their spectra, Christian Doppler began studying how the pitch of sound changes when the noise source is moving relative to the observer. He discovered that when the source of sound is coming towards the observer, the pitch of the sound is perceived to be higher

by the observer. Conversely, if the source is moving away from the observer, the pitch is perceived to be lower by the observer. He

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conducted experiments with musicians on flatbed railroad cars and observers in fixed positions describing the notes they heard. Although his experiments were conducted with sound, he knew that light was a wave, like sound, and consequently could exhibit the same property. This property of waves became known as the Doppler Effect (Tyson, 2001; Giancoli, 2009). The observed upward shift of frequency (which matches the shift in pitch because specific pitches correspond with certain frequencies) can be easily conceptualized when examining the trough of each wave. When a source is moving towards the observer, each emitted trough appears to be closer to the preceding trough than if the source was stationary, compressing the waves together in front of the source. The converse of this is also true, as waves appear to stretch if a source is moving away from the observer. The shift in frequency of a wave is proportional to the velocity of the source with respect to the observer. This proportionality is especially important to astrophysicists, as it allows them to calculate the velocity of a moving body if they examine the shift in wavelength/frequency.

Over time, scientists developed a greater understanding of the light spectrum. Perhaps the most useful discovery for astronomers was light's relationship with energy—visible light is a band of wavelengths on the electromagnetic radiation spectrum. As a result, scientists discovered that each wavelength of light corresponds with a frequency and more importantly a specific energy. This greatly helped to form an understanding of spectroscopy, as scientists eventually came to realize that excited electrons of a particular atom would jump up and down energy levels, and these jumps would release a specific amount of energy. These discrete amounts of energy emitted by excited electrons corresponded to certain colors or bands on a spectrum. Thus scientists could learn about objects that emitted lights by examining an object's emission spectrum (Kaler, 2010).

The study of absorption spectra is another type of spectroscopy which made it possible to perform spectroscopic examination of objects that do not emit light or energy. When energy goes through a gas, the electrons of the gas need certain packets of energy to jump up energy levels. Thus certain packets of energy are absorbed by the atoms of the gas. The effect of this

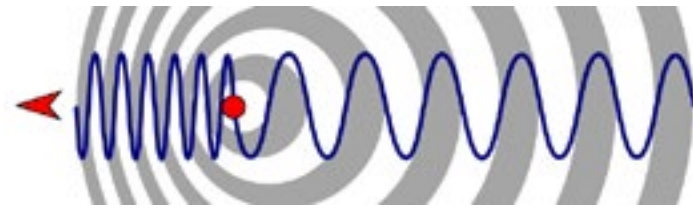


Figure 1 The Doppler Effect: When an object emitting waves is in motion, the waves emitted in the direction of motion appear “compressed” and the waves emitted antiparallel to the motion appear “stretched” to an outside observer. The “compression” occurs because each wave trough is closer to the preceding trough than it would have been if the source was stationary. The “stretching” is the same principle, except each trough is further away from the preceding trough.

is an absorption spectrum, which has unique lines for each element just as the emission spectra of different elements had specific, identifiable lines. The emission spectrum of an element is the reverse of the absorption spectrum (Kaler, 2010). With both emission and absorption analysis, astronomers could learn about both objects that emit light as well as objects that light passes through.

Once spectroscopy and the Doppler Effect were backed by scientific evidence and reasoning, they became particularly effective tools for astronomers to use in order to describe and predict certain aspects of our universe. They are effective because they can be used to get a better understanding of almost anything we can see in the universe; with these tools the light we see contains information about its source—it tells a story. Once it was determined that certain elements emitted/absorbed certain wavelengths of light, an astronomer could analyze the light they see from a star and determine components of that star (Tennyson, 2011; Harwit, 1998). This is true because the hot, energy producing center of a star will emit radiation that will pass through gas

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clouds that make up the outer layers of a star, and the observed light from a star can be examined as an absorption spectrum of the gas that composes the outer layers of stars. Furthermore, the emission spectrum from the center of stars can give scientists clues as to what is fueling stars (Kaler, 2010). This knowledge about the chemical makeup of stars, both at the core and of the outer layers, will tell an astronomer about the type of star they are examining. Astronomers use this information to categorize stars into types based on their temperature, age, composition, and more traits.

The Doppler Effect is a tool that helps explain and describe the movement of celestial bodies. The shift of the frequency of light coming from distant stars due to the Doppler Effect can be analyzed and the movement of distant celestial bodies can be determined due to the proportionality between the shift and the source's velocity. This data can in turn be used to help astronomers form an accurate model to describe the shape and properties of our universe. Another use of the Doppler Effect is the search for exoplanets, or planets orbiting stars other than our own (Perryman, 2011). It is well established that two objects in space orbit around their common center of mass. This is due to Newton's universal law of gravity (many people will recognize the equation  $F=Gm_1m_2/r^2$  from their basic physics classes). Exoplanets orbiting around stars cause the star to wobble slightly. Our sun, for example, wobbles at a speed of approximately 3 meters per second due to Jupiter's pull (Kaler, 2010). This wobble, which is very minute considering the size of a star (the radius of

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our sun, for example, is approximately 695.5 billion meters), can be detected by advanced instruments because the light coming from the star is Doppler shifted, and its velocity can be measured. The discovery of a star's wobble can lead astronomers to determine an exoplanet's existence and orbit patterns.

Both the Doppler Effect and spectroscopy are very important in the study of exoplanets. The exploration of exoplanets began in the late 1980's, when modern measurement methods could first detect the shift of light coming from stars that wobbled due to the orbits of exoplanets (Campbell, Walker, & Yang, 1988). Since the initial research, astronomers have discovered nearly 500 exoplanets (Perryman, 2011). Astronomers, armed with cutting edge technology can now learn even more about these exoplanets, including chemical composition, without needing to send exploratory missions into space. Examination of the absorption spectrum of an exoplanet's atmosphere, which is visible at certain times during the exoplanet's orbit, can tell astronomers the atmospheric composition of an exoplanet. The methods used to obtain such knowledge are in a sense simple spectroscopy or measurements of Doppler shifts, with more complicated processes used to isolate the absorption spectrum or the shift from the brightness of a star or another factor that doesn't allow a simple spectroscopic or Doppler calculation of light.



To this day, these tools are being used to change the way astronomers think about the universe. Professor Saul Perlmutter, of the University of California, Berkeley, won a Nobel Prize in physics in 2011 for his research teams' examination of Doppler shifted light coming from supernova explosions in distant parts of the universe (Palmer, 2011). His team, along with a competing research team, found evidence that distant supernovae were accelerating away from us. This result was not expected, as it was previously thought that these far away objects were slowing down. Professor Perlmutter and his team's results are causing many astronomers to change their views on the universe. They proved experimentally that our universe is not only expanding, but is accelerating outward as well.

Looking forward, there are many applications for the discoveries made with our two tools and many unexplored areas that they can help to understand. A major product of the discoveries made with the two tools is increased aid in the search for extraterrestrial life. Since the discovery of exoplanets, astronomers have found new ways to understand the composition of these exoplanets; such information can be gathered from more advanced applications of these simple spectroscopic principles. In the case of Tau Bootis, an exoplanet discovered nearly 15 years ago, astronomers can tell when the exoplanet is right next to its star (from our point of view) and the light they see contains a "fingerprint" of the planet's atmosphere because light passes through its atmosphere. This technique still uses principles of spectroscopy, but it is in a more advanced form that relies on powerful telescopes and technology to pick apart the fingerprint from the rest of the light coming from the star (Mann, 2012). By achieving a greater understating of distant exoplanets and their atmospheres, scientists can determine if such exoplanets are hospitable for life as we know it, thus facilitating the search for extraterrestrial life.

From simple observations of rainbows formed by the sun's light through a prism to the analysis of light coming from supernovae explosions at the edge of the observable universe, science has come a long way. The future of astrophysical inquiry into the universe is bright with analyzable light. The Doppler Effect and spectroscopy are two important tools, each with their own subset of more advanced tools. Both of these tools are, and will continue to be, absolutely essential for astrophysics. So long as humans have not achieved intergalactic transportation, the only way to study the composition of far-away exoplanets or stars is through the light that they emit. Astronomers cannot play with planets, stars, nebula, galaxies, or any other celestial body in a lab. They can only interpret the

light that travels to them. Luckily, with spectroscopy and the Doppler Effect as tools, they can know a great deal about an object from the light it emits.

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