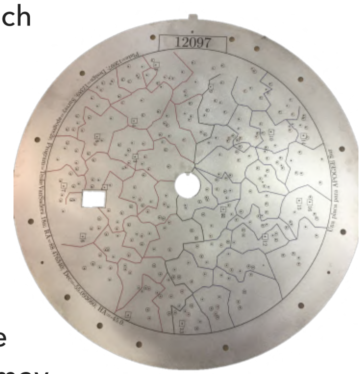
Mapping our Milky Way

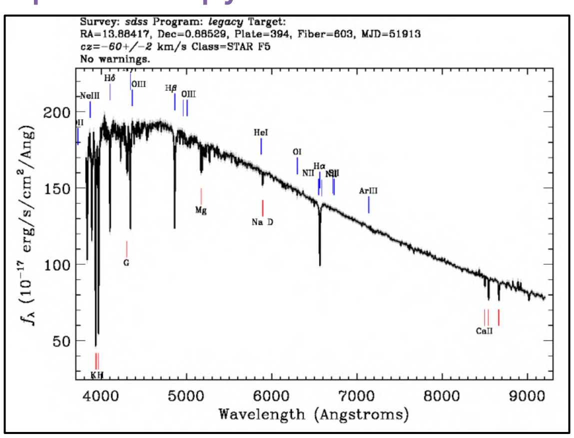
Your Piece of the Sloan Digital Sky

Apache Point Observatory Galaxy Evolution Experiment (APOGEE) is an ongoing survey being performed by Sloan Digital Sky Survey (SDSS). Their goal is to learn about the history, evolution and composition of our galaxy; the Milky Way.

In order to study our Galaxy, APOGEE measures a spectrum for each of some 200,000 stars in our Galaxy. This document explains what a spectrum is, and how it can be used to obtain the chemical composition and motion of a star. In order to be able to gather such large numbers of spectra, APOGEE makes use of aluminium plug plates, such as the one you have now. Using imaging (or photographs of the sky), APOGEE astronomers determine which stars they would like to study. The sky is then tiled, or divided, into thousands of circular areas, each corresponding to an area of sky that is roughly 6 times the diameter of the full Moon. The positions of the stars are carefully measured and 300 holes are drilled in the corresponding place in a plate. Doing this allows observers to plug 300 optical fibres to a single plate. The optical fibres take the light from the stars to the APOGEE spectrograph, 300 at a time. A star may be observed multiple times, using multiple plates, but each hole in your plate corresponds to a unique star in the sky. The light from each star is then analysed using **spectroscopy.**



Spectroscopy

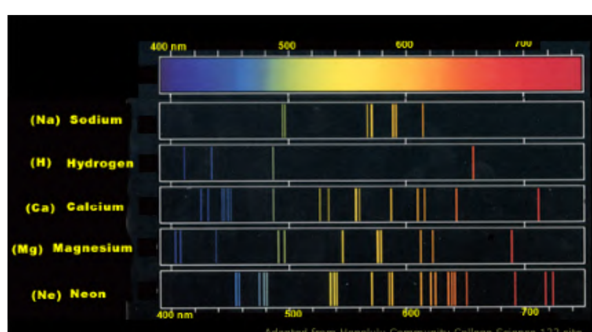


Spectroscopy is the process of spreading the light from an object out into its constituent colors by measuring the amount of light in each wavelength. The process results in a spectrum (plural: spectra). This process occurs frequently in nature, for example when droplets of water spread the light of the sun into a rainbow! The spectrum of a star is shown on the left. It can be seen that there is a distribution of light over a range of wavelengths, with dips in the light at specific wavelengths. This shows that light with these specific wavelengths has been absorbed by gas or dust.

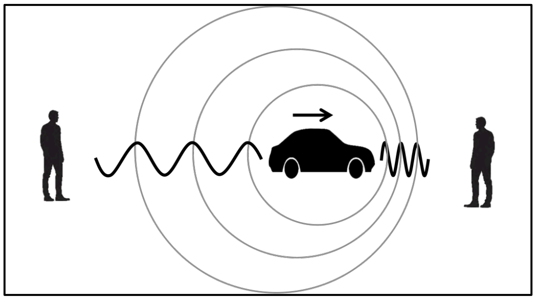
The wavelength of light that is absorbed or emitted by gas or dust is determined by the chemical composition of the gas or dust. Each element has a unique 'fingerprint' of spectral lines.

APOGEE creates spectra for each of the stars in our galaxy; these can then be analyzed to find out the chemical composition of the stars.

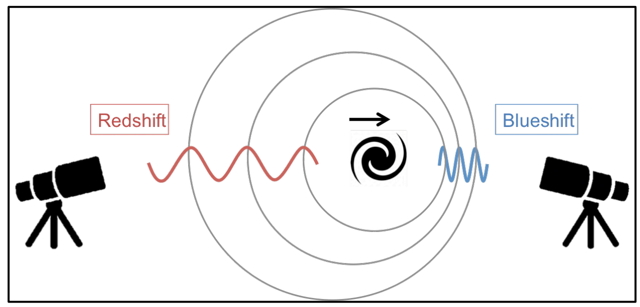
Spectra can also be used to investigate the motion of stars in our galaxy. This is done using **Doppler shift.**



Doppler Shift



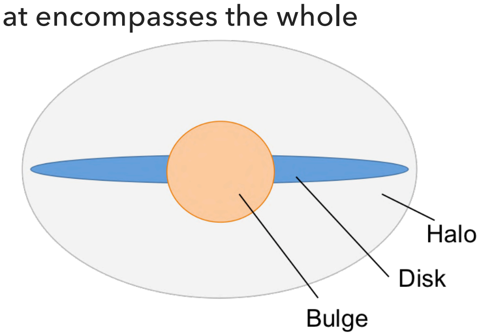
Doppler shift is the effect that you can hear when a fast car passes by you. As it moves towards you, the sound waves in front of the car are compressed (making the pitch higher), whereas when it moves away from you, the sound waves are stretched out, making the pitch lower.
The same effect can be seen with waves of light: if an object is moving quickly towards you then the wavelengths will be compressed. Similarly, if a star is moving away from you at a velocity comparable to the speed of light then the wavelengths will stretch out. These effects are called blueshift and redshift, respectively. Everyday objects such as cars do not move fast enough for us to see a shift in the wavelength of their light. Stars, however, do move fast enough relative to Earth that we can measure a shift in wavelength.



This shift is measured using spectra. Astronomers know where the spectral lines from a star would be positioned if the star was at rest, and Doppler shift affects all wavelengths equally; therefore the Doppler shift can be measured by comparing the observed spectra with the emitted spectra. From this shift in wavelength, the velocity of this star can then be calculated.
Once the velocities and composition of the stars has been worked out, the next step is to work out what part of the galaxy each star is in.

Components of a Spiral Galaxy

The Milky Way is a spiral galaxy. An example of a spiral galaxy can be seen to the left. The image is of the galaxy Messier 81 (Bode's Galaxy). This galaxy lies about 12 million light-years away in the constellation Ursa Major. We do not have a photo of the Milky Way because we are inside it!
Spiral Galaxies consist of a central bulge, a disk (containing the spiral arms) and a halo. The stars in the disk cover a wide range of ages as star formation occurs in the disc. The bulge contains primarily old stars, as no star formation occurs in the bulge. The halo is a very large, diffuse group of stars that encompasses the whole galaxy. The stars in the halo are the oldest stars of all.
The ages of all of these stars are determined using spectra, as the element abundances in a star allow astronomers to estimate the age of the star.



The image above is an infrared map of the Milky Way. The disk can be seen as a plane along the center, and the bulge is wider, brighter area in the middle. It can be seen that there are darker smudges and swirls in the disc; these are clouds of dust in the arms. Dust is one of the reasons that **infrared** is used when imaging the Milky Way.

Measuring in infra-red

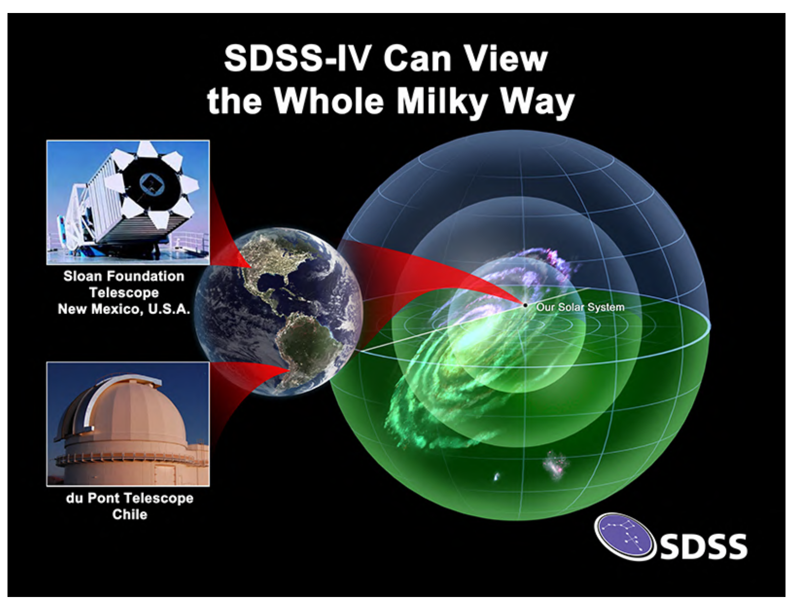
Infrared light has a wavelength too long to be seen by the human eye, but can be detected by specialized cameras. Dust in the Milky Way will obscure stars that are behind it, like a sand storm might obscure the road in a desert. Although dust will block the visible light from stars behind it, the infrared light does not get absorbed by this dust so can still be detected from earth. Therefore astronomers can use infrared telescopes to see all of the stars in our galaxy.

Now that we know infrared can be used to see past the dust in the galaxy, there is one last barrier to seeing our whole galaxy. When only observing from one position, we can only see the night sky from horizon to horizon. The earth is blocking our view of half of the night sky, and therefore it is blocking our view of the rest of the Milky Way. To get around this issue, APOGEE has begun observing from a second location, in the opposite hemisphere of the globe.

Observing the whole galaxy

APOGEE began by observing only from the Apache Point Observatory in New Mexico, this is in the northern hemisphere of the globe. In order to observe the whole of our galaxy, APOGEE is now also using the du Pont Telescope in Chile (in the southern hemisphere).

Using spectroscopic telescopes at these two locations allows astronomers to create spectra for all of the stars in our galaxy, and therefore calculate the chemical composition and velocities of these stars. Estimating the distance to stars is trickier. For nearby stats, APOGEE can use **parallax** measurements from satellite telescopes such as Gaia.



Parallax

There is a simple experiment that you can do to experience parallax. Have a friend hold a pencil upright about an arms length away from your face. Take note of what objects are at the other end of the room, behind the pencil. While the pencil remains still, lean your body to the left, and then to the right. Keep swaying back and forwards. The pencil should appear to be moving much faster than the objects far behind it. When you are leaning all the way to the left, the pencil will line up with a different object in the background than when you are leaning all the way to the right.
The same principle is used to find out the distance to a star, but instead of you leaning left and right, this effect is due to the earth orbiting the sun. In June (for example), astronomers will take note of the position of a given star, lets call it *star A*, against the field of distant stars behind it. The astronomers will then wait six months until December and observe the position of *star A* against the same field of distant stars again. At the time of this second observation in December the earth has completed half of its orbit, so will be at the other side of the sun than it was at in June. This means that *star A* will appear to be in a different location than it was in June. This difference in position can be used to work out the parallax angle, labeled *P* in the diagram below. We know the distance from us to the sun, this distance is referred to as one astronomical unit (AU) , therefore once astronomers know the parallax angle *P* trigonometry can be used to calculate the distance from us to *star A*.