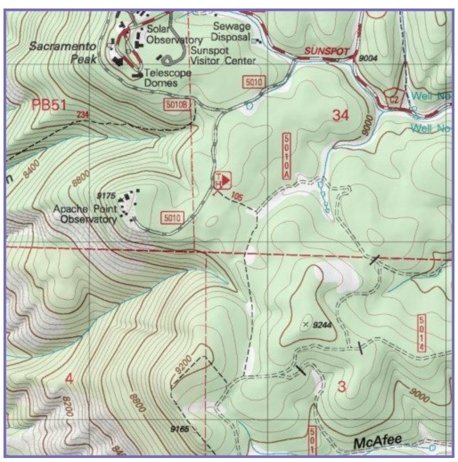
Mapping the Universe in Three Dimensions - Your Piece of the Sloan Digital Sky

The Sloan Digital Sky Survey is now in its 4th generation of mapping the night sky in three dimensions. Why do scientists care so much about mapping the universe? How DO you map objects in space, and what does this aluminum plate with all the holes in it have to do with it? With your own piece of the SDSS survey in your possession, keep reading and exploring to discover what modern astrophysics and engineering are doing to uncover the secrets of the universe from here on Earth.

A Different Kind of Map

Our familiar understanding of a map, whether we use a phone, GPS unit, or a large paper versio, is as a tool for getting from point A to point B. It tells us what lies in between points A and B and sometimes describes the terrain, but if we want to get a sense of the land elevations and geographic features, we need more information. This information is found on a topographic map.

Google Maps

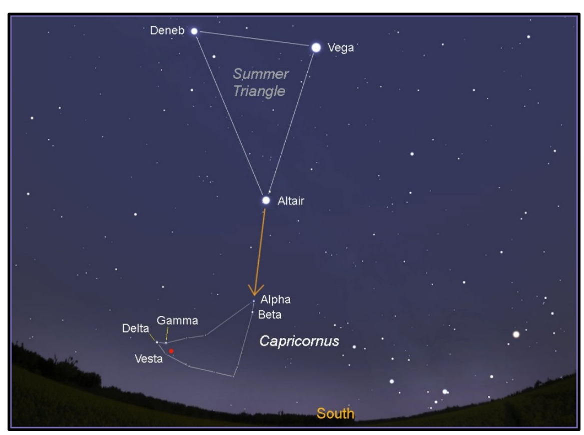


In order to describe the additional dimension of elevation on a two-dimensional surface, we need elevation information at many points. Points of equal elevation are connected to one another; these connections create contour lines that reveal information from which geologists can see the geography of an area and infer its geologic history.

The same types of maps exist in astronomy. If you want to know where in the sky to point a telescope, a two-dimensional view is all you need. If, however, you want to know where objects are actually placed in three-dimensional space, you need to collect distance information, and then you need to devise a way to display that information.

Making a Three-Dimensional Map of Space

In the same way that cartographers measure elevation information to create a topographic map on Earth, astronomers need distance information to stars and galaxies to make three-dimensional maps of space. The Sloan Digital Sky Survey (SDSS) is concerned with a specific kind of map, one that reaches out beyond our Milky Way to the large-scale structure of the universe itself. For this we need a long distance measuring tool called **redshift**.

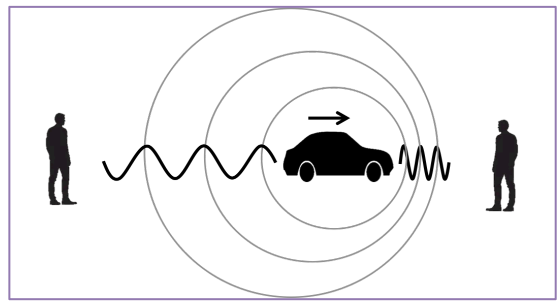


Stellarium

Redshift

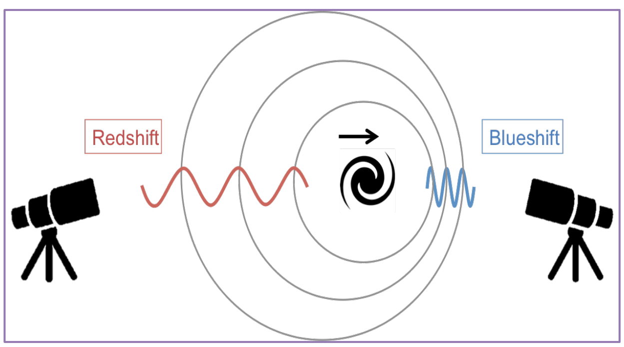
When light from astronomical objects is observed, the wavelengths are often measured as being longer than expected. Red has the longest wavelength in the visible spectrum, so this effect is called redshift. There are two ways to think about redshift: **Doppler shift** and **Cosmological Redshift.** These two effects both lengthen wavelengths that are emitted from an astronomical object, but in two very different ways.

Doppler Shift



Oriel Marshall

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, making the object appear more blue, similarly, if an object is moving away from you at a velocity comparable to the speed of light then the wavelengths will stretch out, making the object appear more red. Everyday objects such as cars do not move fast enough for us to see a shift in the wavelength of their light. Galaxies, however, do move fast enough relative to Earth that we can measure a redshift.



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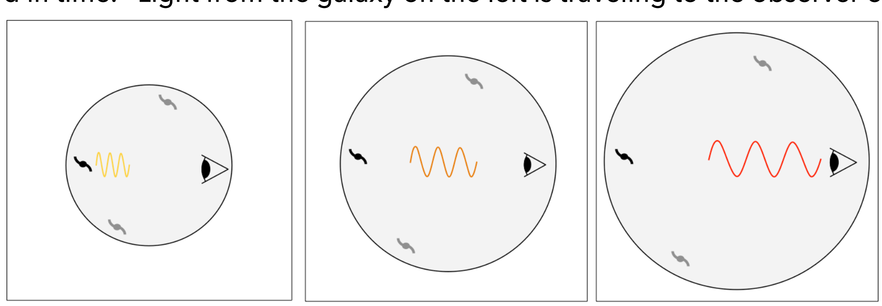
Cosmological redshift

The other effect that can cause wavelengths to be lengthened is **cosmological redshift,** this is an effect due to the expansion of the universe. The Universe is expanding isotropically. This means that, on a large enough scale, everything in the universe is moving away from everything else. In 2D, this is analogous to an infinite rubber sheet being stretched, with the galaxies represented by coins glued onto this sheet. As the sheet expands, all of the coins will move away from each other.
The diagram below shows a section of the universe (the grey circle) containing 4 galaxies. The galaxy on the right is drawn as an eye, as it represents the Milky Way (the galaxy we are observing from). From left to right, each panel is an arbitrary step forward in time. Light from the galaxy on the left is traveling to the observer on the right. As the Universe expands, the wave of light lengthens as a consequence. This effect is called **cosmological redshift** because the wavelength of the light increases due to cosmological expansion.



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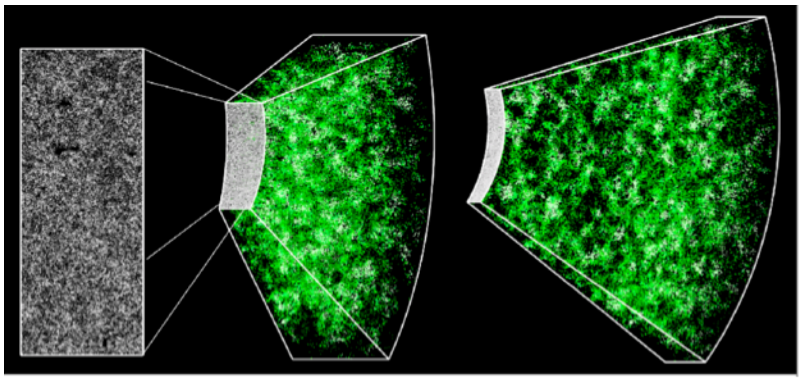
From Redshift to Distance

Cosmological redshift is a function of time because the longer the light has been traveling for, the more the wavelength will have been stretched by the expansion of the Universe. Therefore, if we know the redshift of an object, and we know how fast the Universe is expanding by, we can then work out how long the light from that object has been traveling for in order to reach us.   As the speed of light is a constant, we can then work out how far away the object is from us.

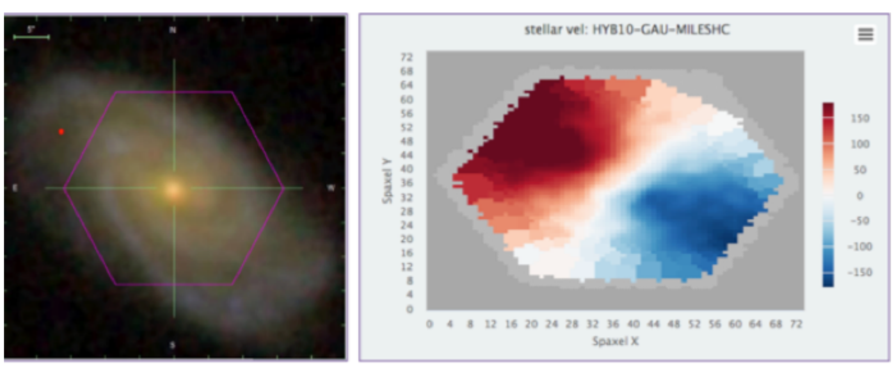


Jeremy Tinker, New York University

The above image shows a black and white, 2D image of a section of the Universe. The white patterns show the distribution of stars and galaxies within this image. Redshift has been used to make this 2D image into a 3D image (seen in green), showing the distribution of the stars and galaxies more accurately.

Mapping Velocity Curves of Galaxies

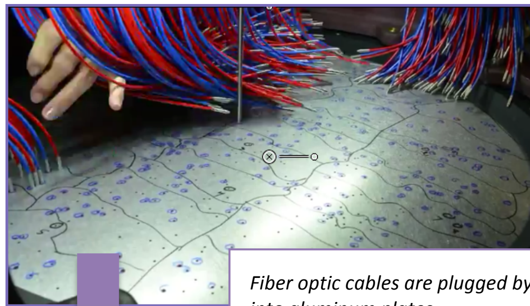
Doppler shift can also be used to study the Universe. Looking at Doppler shift in a galaxy allows astronomers to map its rotational velocity.
If one side of a galaxy is more red and the other is more blue, this means that the red side is moving away from us and the blue side is moving towards us. MaNGA (Mapping Nearby Galaxies at APO) uses Doppler shift to make velocity maps of galaxies.



Sloan Digital Sky Survey

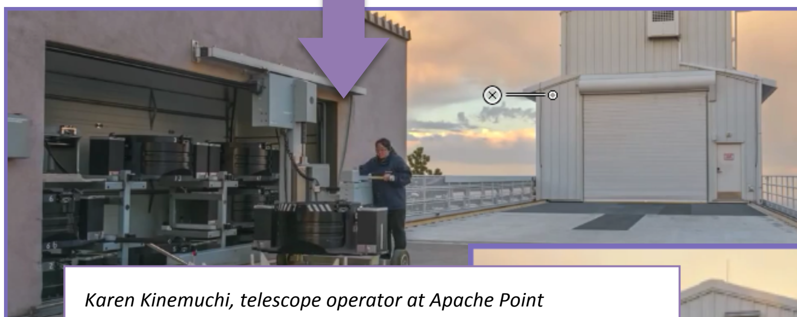
The images above are of a spiral galaxy (Manga ID 1-284485). The image on the left shows a photo of the galaxy, the image on the right shows the velocity map of the same galaxy. The blue areas are blueshifted, so are moving towards us. The red areas are redshifted, so are moving away from us. From this information, astronomers can tell how a galaxy is rotating.

Measuring Redshift on a Massive Scale

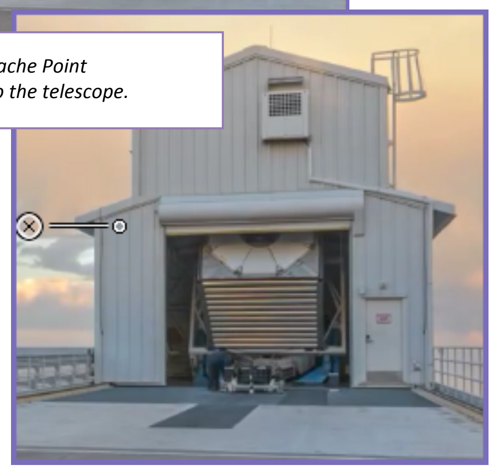


Fiber optic cables are plugged by hand into aluminum plates.

The first step in building these 3D maps of the cosmos was to take detailed color images of about 1/4 of the night sky, as visible from the Earth. The first generation of the SDSS (SDSS-I) achieved this between 2000-2005, using one of the largest and most powerful digital cameras at the time, which was designed and built exclusively for the survey. This camera is now located in the Smithsonian Air & Space museum. As a result of the SDSS-I's imaging, we now have a composite color image of the sky that contains about 200 million galaxies. Targets for the spectroscopic study are chosen from these images.

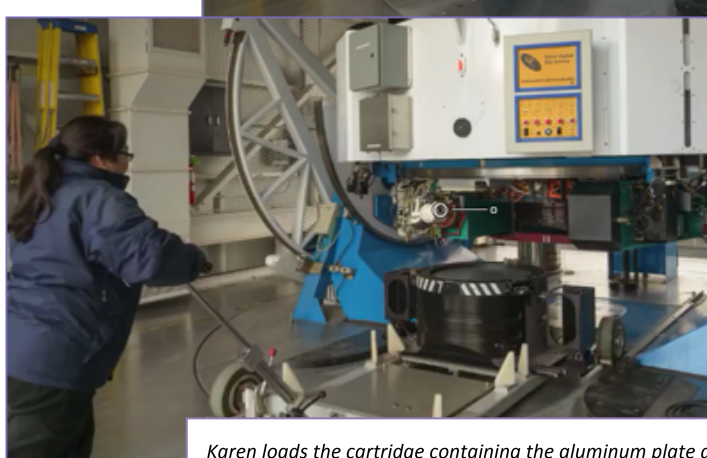


Karen Kinemuchi, telescope operator at Apache Point Observatory, transports a plate cartridge to the telescope.



Astronomers and engineers took advantage of this extremely accurate sky map when they designed a spectroscope that allowed them to capture light from not one but one thousand stars and galaxies at a time. The aluminum plate you've received has 1000 holes, each drilled to match the position of a star or galaxy in the 2D image. When the plate is installed on the back end of the telescope, an individual fiber optic cable attaches to each of these holes and guides the light from individual objects to the spectrograph. In this way the SDSS-III can obtain spectra for 1000 objects in only 45 minutes! Multiple plates can be used each night. This makes for a busy crew of people plugging fibers into holes!

With redshift information calculated for each spectroscopic target, astronomers are now able to place objects in three dimensions and look for patterns in the distribution of galaxies, galaxy clusters, and mysterious objects called quasars. To learn more about galaxies, quasars and the data astronomers recorded about your piece of the SDSS sky, go to the Voyages website at voyages.sdss.org



Karen loads the cartridge containing the aluminum plate and fiber optic cables into the spectrograph that is attached to the back end of the telescope.