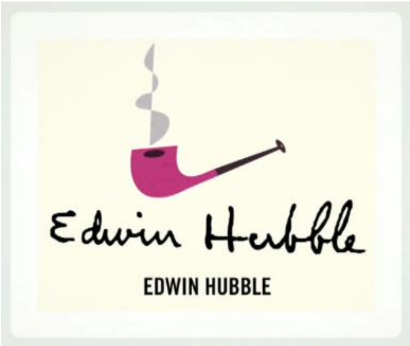
Worksheet 2:

Edwin Hubble's law



In 1929, the American astronomer Edwin Hubble (1889-1953) showed that the redshift in the spectrum of a galaxy is related to its distance from the Earth. His key conclusion was as follows: the further away the galaxy, the more the spectral lines of its spectrum are shifted towards higher wavelengths.

Hubble interpreted this redshift as the effect of a relative velocity between the observer and the galaxy. His findings were famously summarised by **Hubble's law**.

Today, we know that redshift in the spectra of galaxies actually results from the expansion of the universe. This is primarily true for very distant galaxies. It is widely agreed that Hubble's research and his law were extremely important inspirations for the development of modern cosmology.

Below, you will follow in the footsteps of Edwin Hubble by investigating the **relationship between the spectral redshift of an object and its distance** using a few selected galaxies as examples.

Exercises:

1. The following video gives a short overview of the development of the universe and some historical notes about the development of the Big Bang model: www.mediatheque.lindau-nobel.org/videos/31583/this-mini-lecture-introduces-you-to-fundamental-theories-of-the-origin-evolution-and-structure-of-the-universe-2012.

   Watch the video as an ideal introduction to this topic.

2. Attached to this worksheet, you will find profiles of 14 galaxies from our immediate cosmic neighbourhood. As a general rule, figuring out the distance of a galaxy is very difficult for astronomers. Some methods use the luminosity or size (angular diameter) of the galaxy. The ratio of the pulse duration and the luminosity of variable stars (Cepheids) and the brightness (photometric) curves of supernova explosions are also used to measure the distance. All methods have one thing in common – there is a lot of uncertainty in the results.

   The distances given for these 14 galaxies are averages of the values calculated by each method, so you will notice that the standard deviations are large when you look at the profiles. In astronomy, large distances are often stated in parsecs (Pc) or megaparsecs (MPc). You can use the conversion formula: 1 parsec = 3.26 light-years.

For each galaxy, a small section of its spectrum is shown. The H-alpha hydrogen line, i.e. the red line in the spectrum, is clearly recognizable in each case. This hydrogen line usually has a wavelength of 656.28 nm – however, it appears at higher wavelengths in the spectra of these galaxies. The line is redshifted. Edwin Hubble thought that this redshift was caused by the galaxy's recessional velocity, which he used the Doppler formula to calculate.

a) Show algebraically that:

the Doppler formula $\lambda_E = \lambda_S \cdot \left(1 + \frac{v}{c}\right)$ can be rewritten as the velocity formula $v = \left(\frac{\lambda_E}{\lambda_S} - 1\right) \cdot c$, where c is the speed of light, $c = 299{,}792{,}458 \frac{m}{s}$.

b) Determine the wavelength of the H-alpha line in each of the 14 galaxy spectra. Write the values that you find into the table below, together with the distance of each galaxy.

	Galaxy	**Distance in MPc**	**Wavelength of the H-alpha line in nm**
1	NGC 1357		
2	NGC 1832		
3	NGC 2775		
4	NGC 2903		
5	NGC 3034		
6	NGC 3147		
7	NGC 3227		
8	NGC 3368		
9	NGC 3623		
10	NGC 3627		
11	NGC 5248		
12	NGC 6181		
13	NGC 6217		
14	NGC 6643		

c) Copy this table into a spreadsheet program and calculate the recessional velocity of each galaxy in another column using the formula $v = \left(\frac{\lambda_E}{\lambda_S} - 1\right) \cdot c$.

Next, plot the velocity as a function of the distance in a graph (x-axis: distance in MPc, y-axis: velocity in km/s).

Plot a regression line (trend line) for these points as a straight line through the origin and write down the equation of this line.

d) Edwin Hubble modelled the relationship between the distance and velocity of the galaxies that he studied with the formula: $v = H_0 \cdot d$, where d is the distance of the galaxy and H_0 is known as the Hubble constant.

What value did you find for the Hubble constant based on your own measurements? Give your result in the following units:

$$\frac{km}{s \cdot MPc}$$

