# Worksheet 1:

## Measuring the speed in space – thanks to the Doppler effect

**1.** Using your physics textbook or the internet, look up what the **Doppler effect** means in physics.

**2.** The Doppler effect doesn't just happen with sound. In fact, the same phenomenon can be observed with electromagnetic waves, including light. In astronomy, this is an excellent way to measure the speeds of stars, galaxies, quasars, gas clouds, and other similar objects. If we analyse the light from any of these sources of radiation by spectral decomposition using a prism or diffraction grating, the dynamics of the source can be read from the positions of the spectral lines. From the so-called blueshift or redshift of the spectral lines, we can then calculate the speed at which the source is moving towards or away from the observer.

Using your physics textbook or the internet, look up what the **redshift and blueshift of spectral lines** mean in astronomy.

**3.** Suppose that the light source is emitting light of wavelength $\lambda_S$ and that the source is moving away from us. Then the observer will record a higher wavelength $\lambda_E$, namely

$\lambda_E = \lambda_S \cdot \left(1 + \frac{v}{c}\right)$, where c is the speed of light.

This is the formula[1] of the **redshift due to the Doppler effect**.

Now let us apply this formula to a concrete example.

The galaxy NGC 2276 is around 100 million light-years away from us. The light from this spiral galaxy was analysed by spectral decomposition, and its spectrum was plotted as an intensity curve:

depts.washington.edu/astroed/HubbleLaw/ngc2276_main.html (graph in the bottom right).

The H-alpha hydrogen line is clearly visible in this section of the spectrum. This is not surprising, since many galaxies contain lots of hydrogen gas, which lights up when excited by stars.

Image source: Jschulman555, CC-BY-SA 3.0
commons.wikimedia.org/wiki/File:NGC2276_and_NGC2300.jpg

[1] In fact, this formula is an approximation that only applies at speeds much lower than the speed of light. This is the case in all the exercises below.

If the source is at rest, the H-alpha line has a wavelength of $656.28 \cdot 10^{-9}$ m (or 656.28 nm). But the hydrogen line in the galaxy NGC 2276 is redshifted because the object is moving away from us.

Below, you will calculate this galaxy's **recessional velocity**:

**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, $c = 299{,}792{,}458 \frac{m}{s}$.

Using the graph, determine the wavelength of the H-alpha line of the moving source (highest spectral line). This is the observed wavelength $\lambda_E$. We already know the emitted wavelength $\lambda_S$ – it's 656.28 nm.

Note:
In the spectrum of the galaxy NGC 2276, the wavelength is shown in Ångström along the x-axis, which is a very uncommon unit outside of astronomy. You can use the conversion formula: $1Å = 1 \cdot 10^{-10}\,m = 0.1nm$.

**b)** Use the formula derived above to calculate the speed at which the galaxy is moving away from us. Give your result in kilometres per second (km/s).

 