Worksheet 3:

The Big Bang model – founded by a priest

Edwin Hubble's investigations into the redshift of galaxy spectra were scientifically extremely valuable, opening up completely new possibilities for observational astronomy. But even though Hubble is often called the "father of the Big Bang model", this is not historically justified. Hubble was indeed the one who realised that galaxies further away from us are moving faster. However, he never challenged the concept that this movement is taking place within a vast, pre-existing space.

The idea that space itself is constantly expanding, dragging the galaxies along with it, was first formulated by the Belgian priest and astrophysicist **Georges Lemaître** after studying the results of Hubble's research more closely. Lemaître's own research soon convinced him that a constantly expanding universe must have a **point of origin**. According to Lemaître, at this point, space was extremely small – but the universe was already present in its full diversity. He named this initial state the **primeval atom** – a kind of cell from which everything else was created and that has been constantly expanding ever since.

The term **"Big Bang"** came from the famous British physicist and astronomer Fred Hoyle, who strictly rejected Lemaître's ideas, instead jokingly speaking of a "Big Bang" that created the universe like an explosion. The striking idea of the Big Bang has been around ever since.

The assumption that space is expanding also implies that we should expect redshift in the spectral lines. However, this redshift does not come from the Doppler effect. Instead, the wavelengths themselves expand as they travel towards us because the space they are travelling through expands during their long journey, causing the waves to stretch. The expansion of space therefore creates an apparent recessional velocity – just like the one measured by Hubble. The redshift in the spectral lines caused by the expansion of space is known as the **cosmological redshift**.

1. Look up **Georges Lemaître** on the internet and write down some facts about his life and scientific ideas. Name a few other researchers who were instrumental in developing the Big Bang theory.
2. If we assume that the expansion of the universe follows Hubble's law $v = H_0 \cdot d$, then we can estimate the **age of the universe**. To do this, we need to assume that the value of the Hubble constant has remained essentially constant with a uniform expansion. If we

denote by D the expansion of the universe at the secondary point of today and denote by T the time elapsed since the Big Bang, then from $v = \frac{D}{T}$ we obtain the relation $\frac{D}{T} = H_0 \cdot D$ and therefore $T = \frac{1}{H_0}$.

This means that the age of the universe can be calculated as the inverse of the Hubble constant.

Calculate the age of the universe using the value for the Hubble constant that you found in Worksheet 2. Using the conversion formula $1\text{MPc} = 3.085678 \cdot 10^{19}\,\text{km}$, give your result in "years".

Remark:
This type of calculation can only give us a vague idea of the age of the universe because we now know that the Hubble constant has by no means remained constant over time. The value H_0 that you used is from today. But the rate of expansion of the universe has changed over time. Recently, astronomers have even detected that the expansion is slightly accelerating by performing sophisticated measurements. This surprising discovery is based on research by the three astronomers Saul Perlmutter, Brian P. Schmidt, and Adam G. Riess, who were honoured with the Nobel Prize in Physics in 2011 for their findings.

3. The **value of the Hubble constant H_0** cannot be clearly measured even today. Recent research approaches, attempting to measure the constant, have found strongly divergent values, depending on the choice of method. This has caused headaches for astronomers and is considered one of the greatest puzzles of modern cosmology.

Research this topic on the internet and write down the range of different values that have been found for H_0. Summarize your findings clearly.

