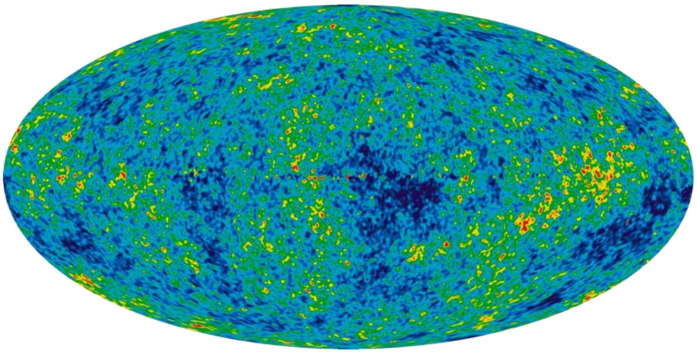
# Evidence for the Big Bang

## *Cosmological Microwave Background (CMB)*

Crucial evidence for the Hot Big Bang (HBB) model includes precise measurements of the remnants of the very early Universe through the so-called cosmological microwave background (or **cosmic microwave background**). The HBB model predicts that high-energy (gamma) electromagnetic radiation produced around t ≈ 300 000 years should still be observed today, but owing to the expansion of the Universe should be red-shifted down to the millimetre wavelength (microwave) region. The thermal intensity of the spectrum fitted perfectly to a black-body curve corresponding to a temperature of 2.73 K.



Although the temperature of the CMB is almost completely uniform at 2.7 K, there are very tiny variations in the temperature of the order of $10^{-5}$ K, which appear on the maps in Figure 15 as cooler blue and warmer red patches. The key findings of WMAP were that a more accurate age of the Universe could be established as 13.7 billion years ± 0.2 billion years.

## *Hydrogen and Helium Abundances*

Hydrogen and helium account for nearly all the matter in the Universe that we observe today. The relative abundance, by mass, of these elements in the Universe is 25% helium and 73% hydrogen, with all the other elements amounting to 2%.

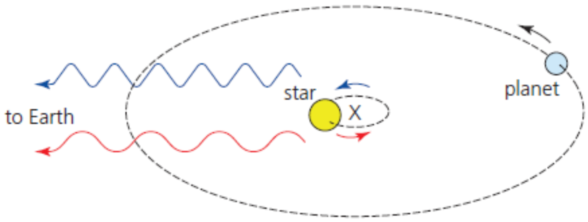
The HBB model predicts that primordial **nucleosynthesis**, the process by which the lightest elements such as H and He formed, began approximately 100 s after the Big Bang. Owing to the immense temperatures and pressures, nuclear fusion reactions converted hydrogen into helium. Then, owing to the rapid expansion of the Universe, temperatures dropped below those required to sustain fusion. As a result, nucleosynthesis lasted only for about three minutes. All the heavier elements, including those of which the planets and you and I are made, were created later by long-lived fusion processes inside stars and were dispersed across the interstellar medium by supernovae.

## *Quasars*

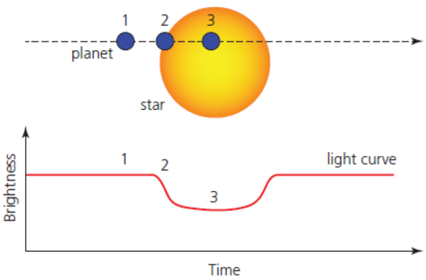
Quasars are distinguished by extremely large red-shifts and are therefore believed to be some of the most distant objects in the known Universe. Optically, quasars are very faint and star-like, but application of the inverse square law reveals them to be amongst the brightest objects in the Universe. One quasar may emit hundreds or even thousands of times the entire power output of our Galaxy.

## *Exoplanets*

An exoplanet (or extrasolar planet) is a planet that orbits a star other than the Sun. They are much fainter than the star they orbit and so are lost in its glare and very difficult to detect directly. Most have been found using indirect methods that involve tiny but measurable effects of the exoplanet on its parent star.




The Radial Velocity Method: The radial velocity method in the search for planets looks for periodic variation in Doppler shift in the star's spectral lines as the star 'wobbles' as a planet moves around this point (affected by the gravitational attraction between the planet and the star.




The Transit Method: This works by detecting a dimming in the star's brightness as an exoplanet moves across its disc, perpendicular to our line of sight – called a transit. The decrease in observed brightness allows the radius of the exoplanet to be calculated if the radius of the parent star is known. If the star has a radius rstar and the planet has radius rplanet, the fractional drop in brightness will be:

$$\frac{\pi r_{planet}^2}{\pi r_{star}^2} = \frac{r_{planet}^2}{r_{star}^2} = \left(\frac{r_{planet}}{r_{star}}\right)^2$$