

# Laboratory Exercises in Astronomy — Hubble's Law

ANEURIN EVANS, *University of Keele*

**C**OSMOLOGY is that branch of astronomy which deals with the structure and evolution of the universe as a whole. It is a remarkable fact that a vital clue to the nature of the universe is revealed by a very simple observation: the sky becomes dark after the sun sets. In a stationary universe of infinite extent, uniformly strewn with stars, our line of sight would always end at the surface of a star, and the whole sky should therefore appear bright like the sun. Why, then, is the sky dark at night? This contradiction is known as Olbers' paradox. It is resolved nowadays as being due to the expansion of the universe, distant sources receding from us at speeds so high that the intensity of light received from them is greatly reduced.

Thus, from this simplest of astronomical observations can be deduced the expansion of the universe, a phenomenon which manifests itself in the motion of galaxies away from the observer, no matter where in the universe he is situated.

Although this general recession of the galaxies had been known since about 1920 from the observations of V. M. Slipher and others, the discovery of the expansion of the universe is invariably associated with the name of Edwin Hubble. In 1929, he was able to show that the galaxies seem to be receding with velocities that are proportional to their distances from us. Hubble's law can be written as

$$V = H \times D,$$

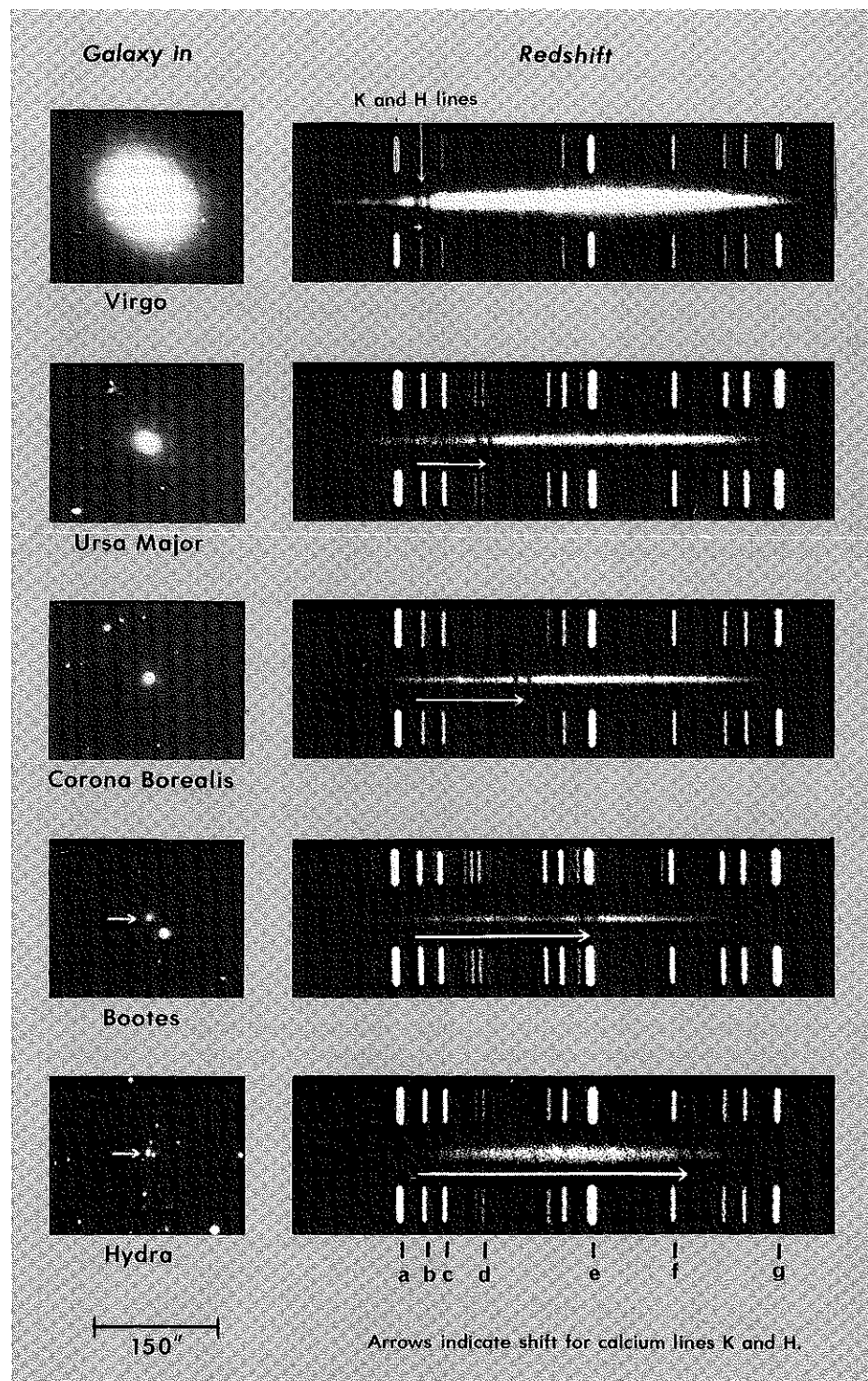
where  $V$  is the recessional velocity in kilometers per second, and  $D$  is the distance of the galaxy in megaparsecs (one Mpc. equals one million parsecs or 3.3 million light-years).  $H$  is called Hubble's constant and is expressed in kilometers per second per megaparsec; it is a measure of how rapidly the cosmic expansion is proceeding at the present time.

In his pioneering studies, Hubble found that  $H$  was about 540 — that is, a galaxy one megaparsec distant would be receding at 540 kilometers per second; a galaxy at two megaparsecs would recede at 1,080 kilometers per second, and so on. Although Hubble's law is now firmly established, his numerical value for  $H$  was much too large, because he underestimated the distances of galaxies. A currently accepted value, reported by Allan Sandage and G. A. Tammann in 1976, is about 50 kilometers per second per megaparsec, less than a tenth of Hubble's original estimate.

The aim of this laboratory exercise, which is based on one used at the University of Keele in England, is to verify Hubble's law and to determine the Hubble

constant. For this purpose, we need a sample of galaxies for which we shall determine recessional velocities and distances. Such a sample is conveniently provided by the accompanying Hale Observatories photographs of five galaxies and their spectra. All five objects are members of clusters of galaxies. The

recessional velocity of each galaxy is found by measuring the displacements of spectral lines toward the red end of the spectrum. We shall determine the distances by using the fact that galaxies of the type shown all have approximately the same linear diameter, which we shall take here to be 0.03 megaparsec (about 100,000 light-years),



Images and spectra of five galaxies are in this diagram adapted from Hale Observatories photographs. Wavelengths of comparison lines are in the text.