

# Hubble's Law

2008/03/13

# Our Purpose

- \* Verify **Hubble's Law**:

$$V=H \times D$$

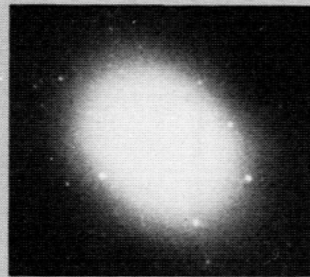
where  $V$  is the **recession velocity** in kilometers per second, and  $D$  is the **distance** of the galaxies in megaparsecs.  $H$  is **Hubble's constant**.

- \* Determine the Hubble constant.

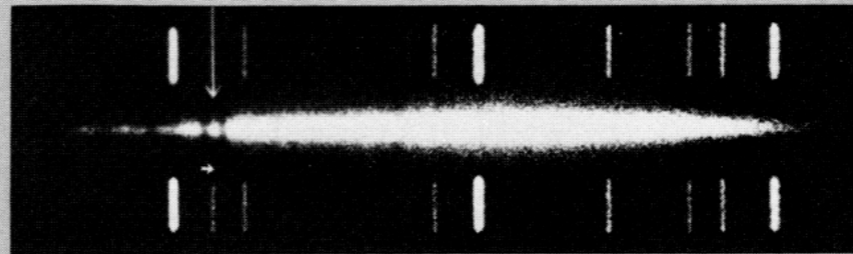
# Method

- \* We need a sample of galaxies to determine the recessional velocities and distances.
  - \* Use Hale Observatory's photographs of five galaxies and their spectra.
- \* 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** of galaxies by using the fact that galaxies of the type shown all have approximately **the same linear diameter -- 0.03 Mpc**, which is the diameter of our own galaxy.

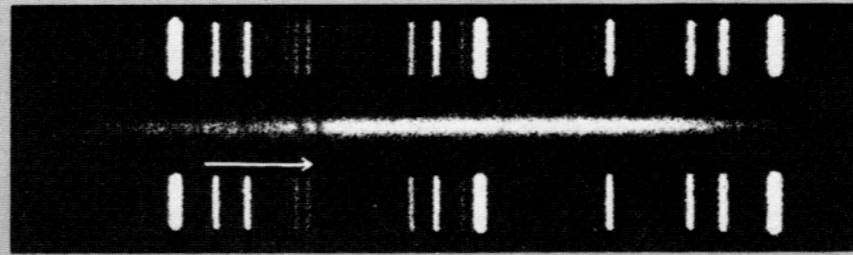
K and H lines



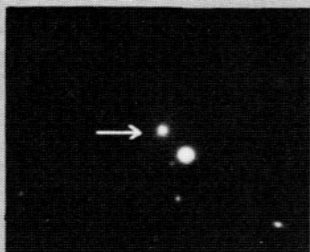
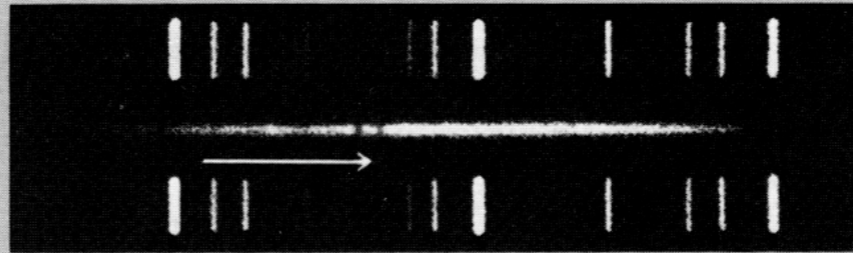
Virgo



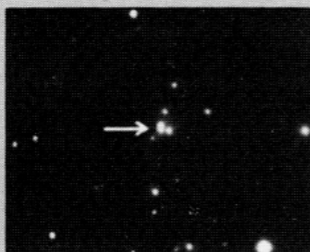
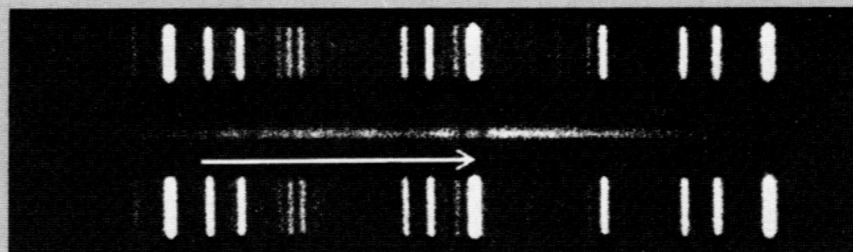
Ursa Major



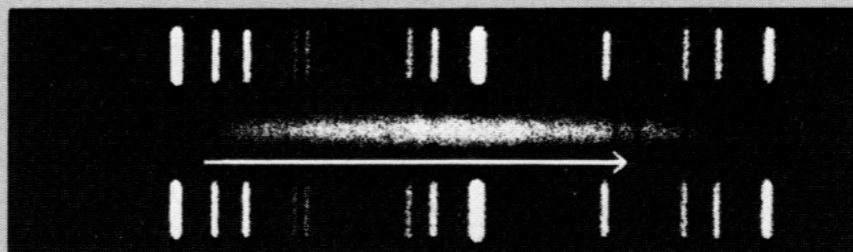
Corona Borealis



Bootes



Hydra



a b c d e f g

150"

Arrows indicate shift for calcium lines K and H.

# Procedure

- \* Each galaxy's spectrum is flanked above and below by a **comparison spectrum** of bright lines.
- \* The seven labeled comparison lines have the following wavelengths in angstroms:

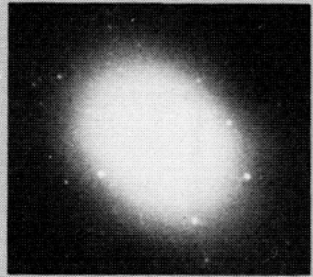
a	3888.7	e	4471.5
b	3964.7	f	4713.1
c	4026.2	g	5015.7
d	4143.8		

- \* Note the two dark notches in each galaxy's spectrum; from left to right, they are the K and H absorption lines of ionized calcium.

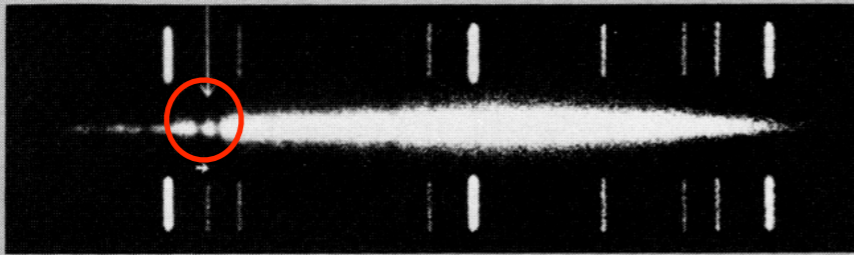
Galaxy in

Redshift

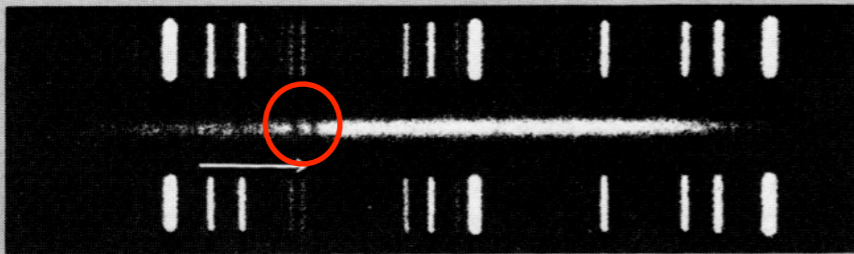
K and H lines



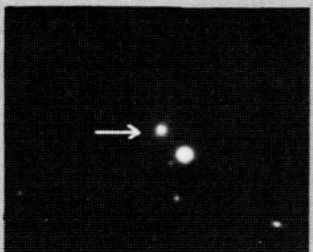
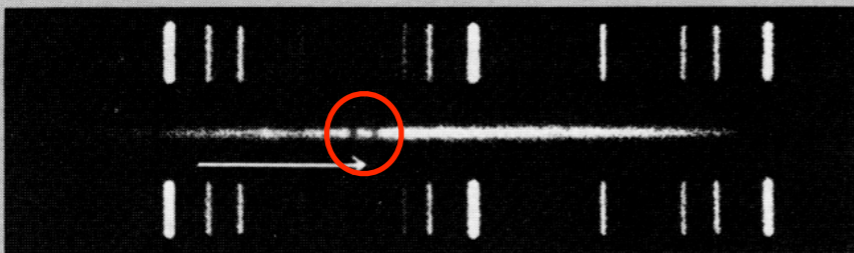
Virgo



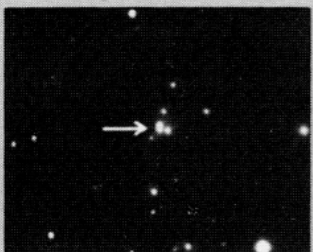
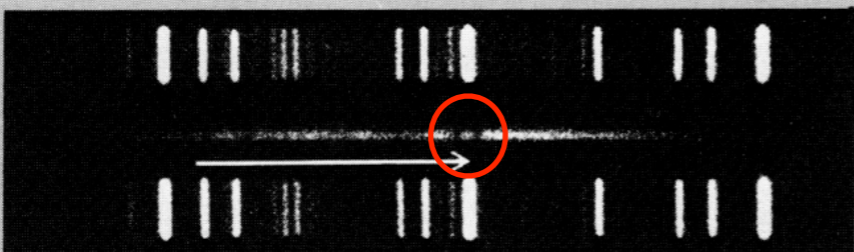
Ursa Major



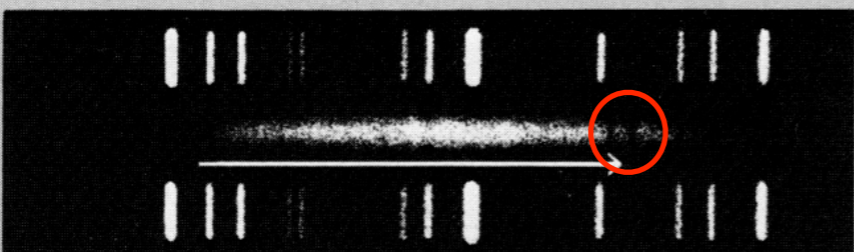
Corona Borealis



Bootes



Hydra



a b c d e f g

150"

Arrows indicate shift for calcium lines K and H.

\* The displacement of the K and H lines in each case is indicated approximately by the length of the horizontal arrow.

# Scale of spectrum

- \* In a comparison spectrum, measure the distance between two widely spaced lines.
- \* Find the difference in wavelength between the same lines from the above list, and divide by the measured distance to obtain the spectrum's scale.
- \* Because these are grating spectra, the scale should not depend on which pair of lines is selected.

# Observed wavelength

- ✱ For each galaxy, measure the distance from the **red shifted K and H lines** to the same **identified comparison line**.
- ✱ Multiply every distance by the average scale value just determined, to obtain  $\Delta\lambda$ , the wavelength difference in angstroms.
- ✱ Add  $\Delta\lambda$  to, or subtract from, the comparison-line wavelength to find the observed wavelength,  $\lambda'$ , of the red shifted galaxy line.

# Velocities of Recession

- \* The rest wavelength ( $\lambda$ ) of K and H lines are 3933.7 and 3968.5 angstroms.
- \* The recessional velocity  $V$  corresponding to the red shifted wavelength,  $\lambda'$ , is given by:

$$V = c(\lambda' - \lambda) / \lambda$$

- \* Calculate  $V$  for each of the five galaxies, doing this for both K and H lines, and average the result.

# Galaxy distances

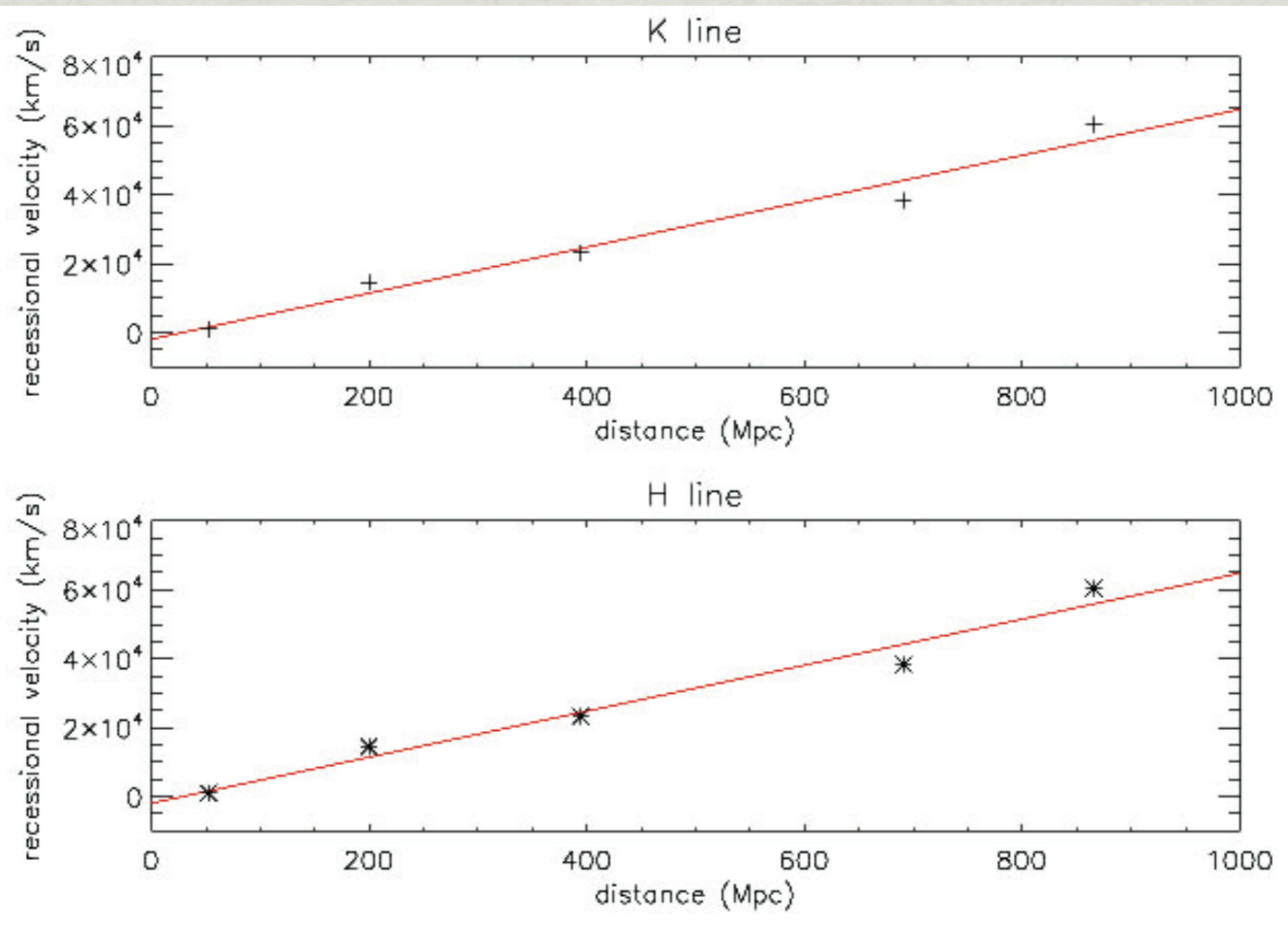
- \* The photographs of the five galaxies are all in the same scale.
- \* First, measure each galaxy's **diameter**. For a noncircular image, measure the longest and shortest diameters and average.
- \* The scale of the photograph is given by the bar bottom, which is equal to 150 seconds of arc.
- \* Next, convert the angular diameters to radians by dividing them by 206,265.
- \* The **distance D** in Mpc can be calculated from

$$D=0.03/d$$

where  $d$  is the diameter in radians.

# Hubble Diagram

- \* Plot the five galaxies, using **distance** as the horizontal scale and **recessional velocity** as the vertical.
- \* **Fitting** these five point with a straight line. Note that it would pass the origin.
- \* The Hubble constant,  $H$ , is this line's **slope**.
- \* What value of  $H$  do you get? How does it compare with the general accepted value?



For K line:

$$a = -1950.7 \pm 3743.7, \quad b = 66.75 \pm 7.01$$

For H line:

$$a = -2002.1 \pm 3716.9, \quad b = 66.86 \pm 6.96$$

# Age and size of the Universe