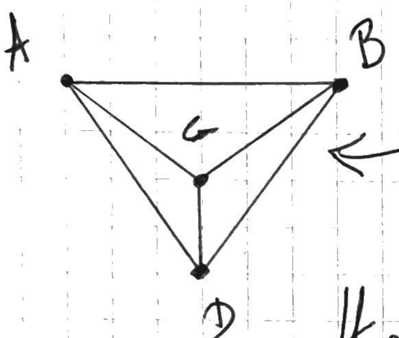
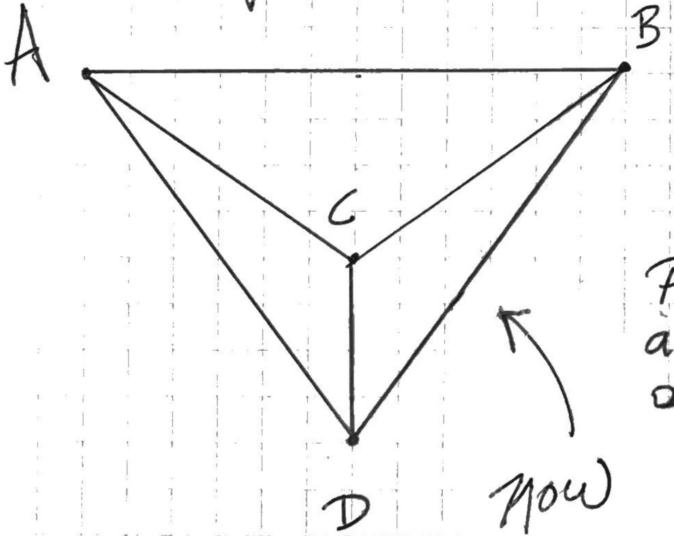
1(a) Cut out ruler at bottom



5 billion years ago

after t = 5 billion years



Now

1(b) FILL IN THE BLANKS IN THE TABLE

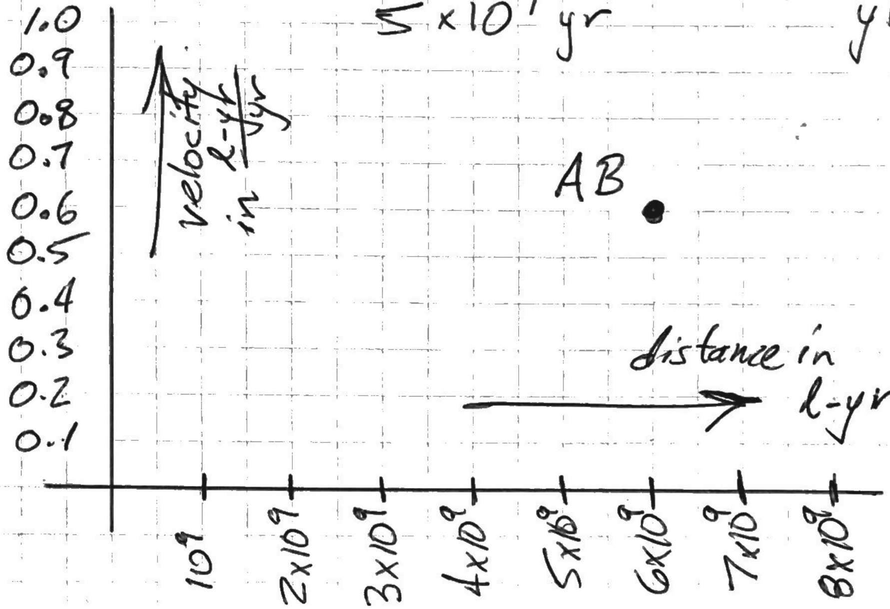
	AB	AC	AD
after	6×10^9 l-yr		
before	3×10^9 l-yr		
difference	3×10^9 l-yr		
velocity	$0.6 \frac{\text{l-yr}}{\text{yr}}$		

use $V = \frac{d}{t}$

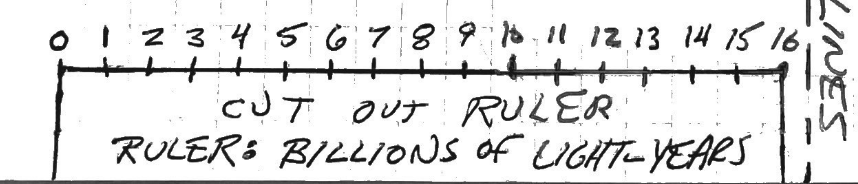
EXAMPLE AB

$$\frac{3 \times 10^9 \text{ l-yr}}{5 \times 10^9 \text{ yr}} = 0.6 \frac{\text{l-yr}}{\text{yr}}$$

1(c) Put AC and AD on the plot



CUT OUT RULER ON DOTTED LINES



Pages 3 and 5 of Hubble's 1929 paper.

2) Use Hubble's value for $H_0 = \frac{60 \text{ km/sec}}{\text{Megaparsec}}$ to get the age of the universe. $T = \frac{1}{H_0}$. Just units conversion.

individual distances are estimated for only 24. For one other, N. G. C. 3521, an estimate could probably be made, but no photographs are available at Mount Wilson. The data are given in table 1. The first seven distances are the most reliable, depending, except for M 32 the companion of M 31, upon extensive investigations of many stars involved. The next thirteen distances, depending upon the criterion of a uniform upper limit of stellar luminosity, are subject to considerable probable errors but are believed to be the most reasonable values at present available. The last four objects appear to be in the Virgo Cluster. The distance assigned to the cluster, 2×10^6 parsecs, is derived from the distribution of nebular luminosities, together with luminosities of stars in some of the later-type spirals, and differs somewhat from the Harvard estimate of ten million light years.[2]

The data in the table indicate a linear correlation between distances and velocities, whether the latter are used directly or corrected for solar motion, according to the older solutions. This suggests a new solution for the solar motion in which the distances are introduced as coefficients of the K term, i. e., the velocities are assumed to vary directly with the distances, and hence K represents the velocity at unit distance due to this effect. The equations of condition then take the form

$$rK + X \cos \alpha \cos \delta + Y \sin \alpha \cos \delta + Z \sin \delta = v.$$

Two solutions have been made, one using the 24 nebulae individually, the other combining them into 9 groups according to proximity in direction and in distance. The results are

	24 OBJECTS	9 GROUPS
X	-65 ± 50	$+3 \pm 70$
Y	$+226 \pm 95$	$+230 \pm 120$
Z	-195 ± 40	-133 ± 70
K	$+465 \pm 50$	$+513 \pm 60$ km./sec. per 10^6 parsecs.
A	286°	269°
D	+40°	+33°
V_0	306 km./sec.	247 km./sec.

Hubble's value for what he called K and is now called H_0 or "Hubble's Constant"

For such scanty material, so poorly distributed, the results are fairly definite. Differences between the two solutions are due largely to the four Virgo nebulae, which, being the most distant objects and all sharing the peculiar motion of the cluster, unduly influence the value of K and hence of V_0. New data on more distant objects will be required to reduce the effect of such peculiar motion. Meanwhile round numbers, intermediate between the two solutions, will represent the probable order of the values. For instance, let $A = 277°$, $D = +36°$ (Gal. long. = 32°, lat. = +18°), $V_0 = 280$ km./sec., $K = +500$ km./sec. per million par-

corrected for solar motion. The result, 745 km./sec. for a distance of 1.4×10^6 parsecs, falls between the two previous solutions and indicates a value for K of 530 as against the proposed value, 500 km./sec.

Secondly, the scatter of the individual nebulae can be examined by assuming the relation between distances and velocities as previously determined. Distances can then be calculated from the velocities corrected for solar motion, and absolute magnitudes can be derived from the apparent magnitudes. The results are given in table 2 and may be compared with the distribution of absolute magnitudes among the nebulae in table 1, whose distances are derived from other criteria. N. G. C. 404

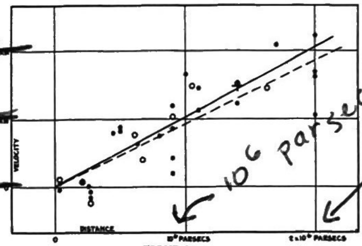


FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution combining the nebulae into groups; the cross represents the mean velocity corresponding to the mean distance of 22 nebulae whose distances could not be estimated individually.

can be excluded, since the observed velocity is so small that the peculiar motion must be large in comparison with the distance effect. The object is not necessarily an exception, however, since a distance can be assigned for which the peculiar motion and the absolute magnitude are both within the range previously determined. The two mean magnitudes, −15.3 and −15.5, the ranges, 4.9 and 5.0 mag., and the frequency distributions are closely similar for these two entirely independent sets of data; and even the slight difference in mean magnitudes can be attributed to the selected, very bright, nebulae in the Virgo Cluster. This entirely unforced agreement supports the validity of the velocity-distance relation in a very

Use 1 Megaparsec = 3.1×10^{19} km.

Use 1 year = 3.2×10^7 seconds.

I've started you out:

$$T = \frac{1}{H_0} = \frac{1}{\frac{60 \text{km/sec}}{\text{Megaparsec}}} = \frac{1 \text{ Megaparsec}}{60 \text{km}} \text{ seconds} =$$