8.286 Lecture 4
September 17, 2018

THE KINEMATICS of the HOMOGENEOUS EXPANDING UNIVERSE

Hubble's Law

$$v = Hr \ .$$

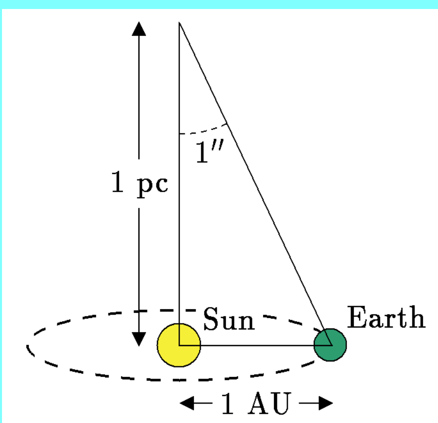
Here

$$v \equiv \text{recession velocity} \ ,$$
$$H \equiv \text{Hubble expansion rate} \ ,$$

and

$$r \equiv \text{distance to galaxy} \ .$$

The Parsec



Georges Lemaître

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UN UNIVERS HOMOGÈNE DE MASSE CONSTANTE ET DE RAYON CROISSANT, RENDANT COMPTE DE LA VITESSE RADIALE DES NÉBULEUSES EXTRA-GALACTIQUES

Note de M. l'Abbé G. LEMAÎTRE

1. GÉNÉRALITÉS.

La théorie de la relativité fait prévoir l'existence d'un univers homogène où non seulement la répartition de la matière est uniforme, mais où toutes les positions de l'espace sont équivalentes, il n'y a pas de centre de gravité. Le rayon R de l'espace est constant, l'espace est elliptique de courbure positive uniforme $1/R^2$, les droites issues d'un même point repassent à leur point de départ après un parcours égal à πR, le volume total de l'espace est fini et égal à $\pi^2 R^3$, les droites sont des lignes fermées parcourant tout l'espace sans rencontrer de frontière (1).

Edwin Hubble

A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE

By Edwin Hubble

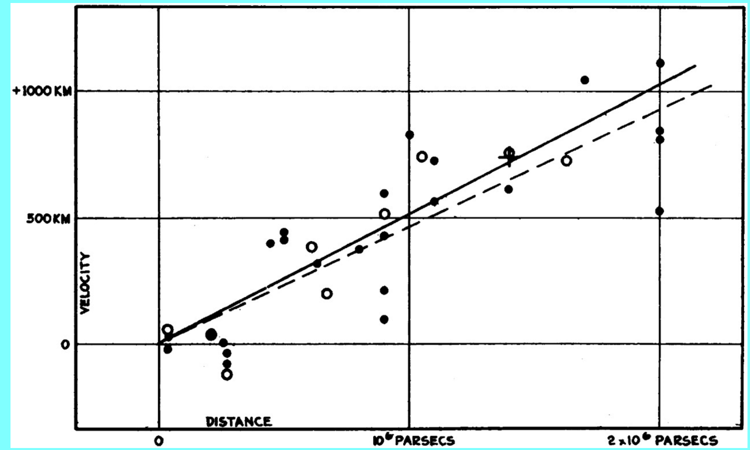
Mount Wilson Observatory, Carnegie Institution of Washington

Communicated January 17, 1929

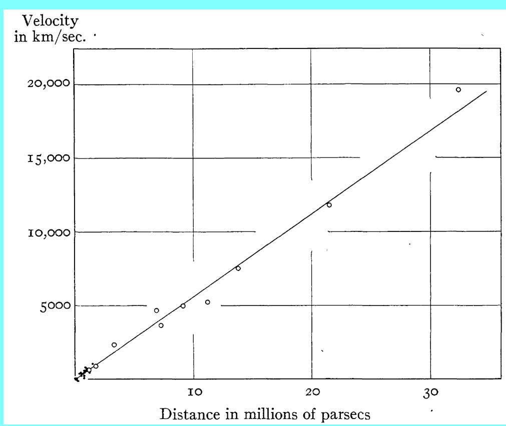
Determinations of the motion of the sun with respect to the extra-galactic nebulae have involved a K term of several hundred kilometers which appears to be variable. Explanations of this paradox have been sought in a correlation between apparent radial velocities and distances, but so far the results have not been convincing. The present paper is a re-examination of the question, based on only those nebular distances which are believed to be fairly reliable.

Distances of extra-galactic nebulae depend ultimately upon the application of absolute-luminosity criteria to involved stars whose types can be recognized. These include, among others, Cepheid variables, novae, and blue stars involved in emission nebulosity. Numerical values depend upon the zero point of the period-luminosity relation among Cepheids,

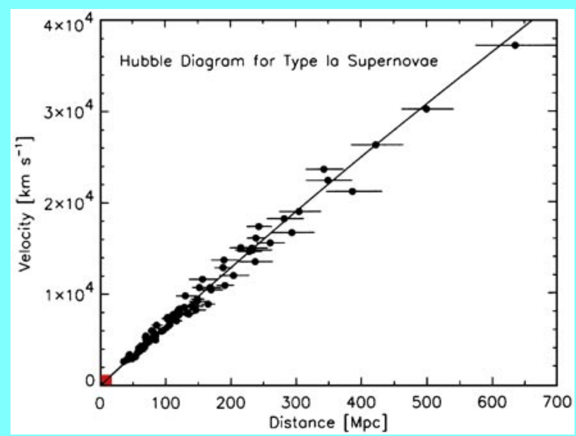
Hubble's Original Data



Hubble-Humason Data, 1931



Supernovae 1a, 2002



Measurements of the Hubble Constant H_0		
Author	Date	Value (km-s^{-1}-Mpc^{-1})
Lemaître	1927	575 – 625
Hubble	1929	500
Hubble & Humason	1931	560
Baade	1952	250
Sandage	1958	75, with a possible uncertainty of a factor of 2
de Vaucouleurs & Bollinger	1979	100 ± 10
Riess et al. (SN 1a & cepheids)	1996	65 ± 6
Hubble Key Project	2001	72 ± 8
Tammann, Sandage, et al.	2001	60± probably less than 10%
WMAP 1-year (with other data)	2003	71 ± 4
WMAP 5-year (with other data)	2008	70.5 ± 1.3
WMAP 7-year (with other data)	2011	70.2 ± 1.4
Riess et al. (SN 1a & cepheids)	2011	73.8 ± 2.4
WMAP 9-year (with other data)	2012	69.3 ± 0.8
Planck 2013 (with other data)	2013	67.3 ± 1.2
Planck 2015 (with other data)	2015	67.7 ± 0.5
Riess et al. (SH0ES collaboration, SN Ia & cepheids)	2016	73.2 ± 1.7
Grieb et al. (BOSS collaboration)	2016	67.6 ± 0.7
Riess et al. (SH0ES collaboration, SN Ia & cepheids)	2018	73.5 ± 1.6
Planck 2018 (with other data)	2018	67.7 ± 0.4
Birrer et al. (H0LiCOW collaboration, gravitationally lensed quasars)	2018	72.5 ± 2.2