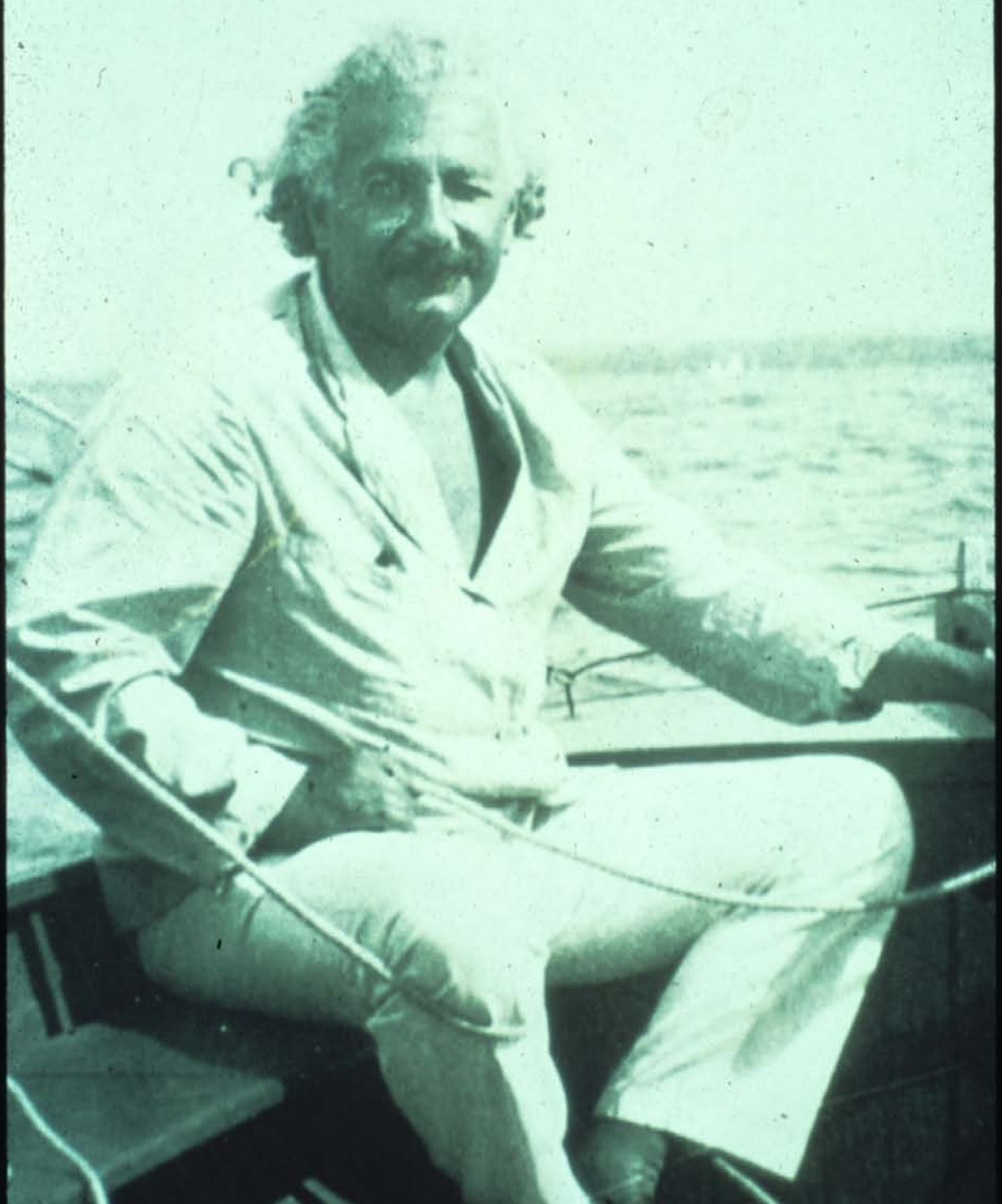
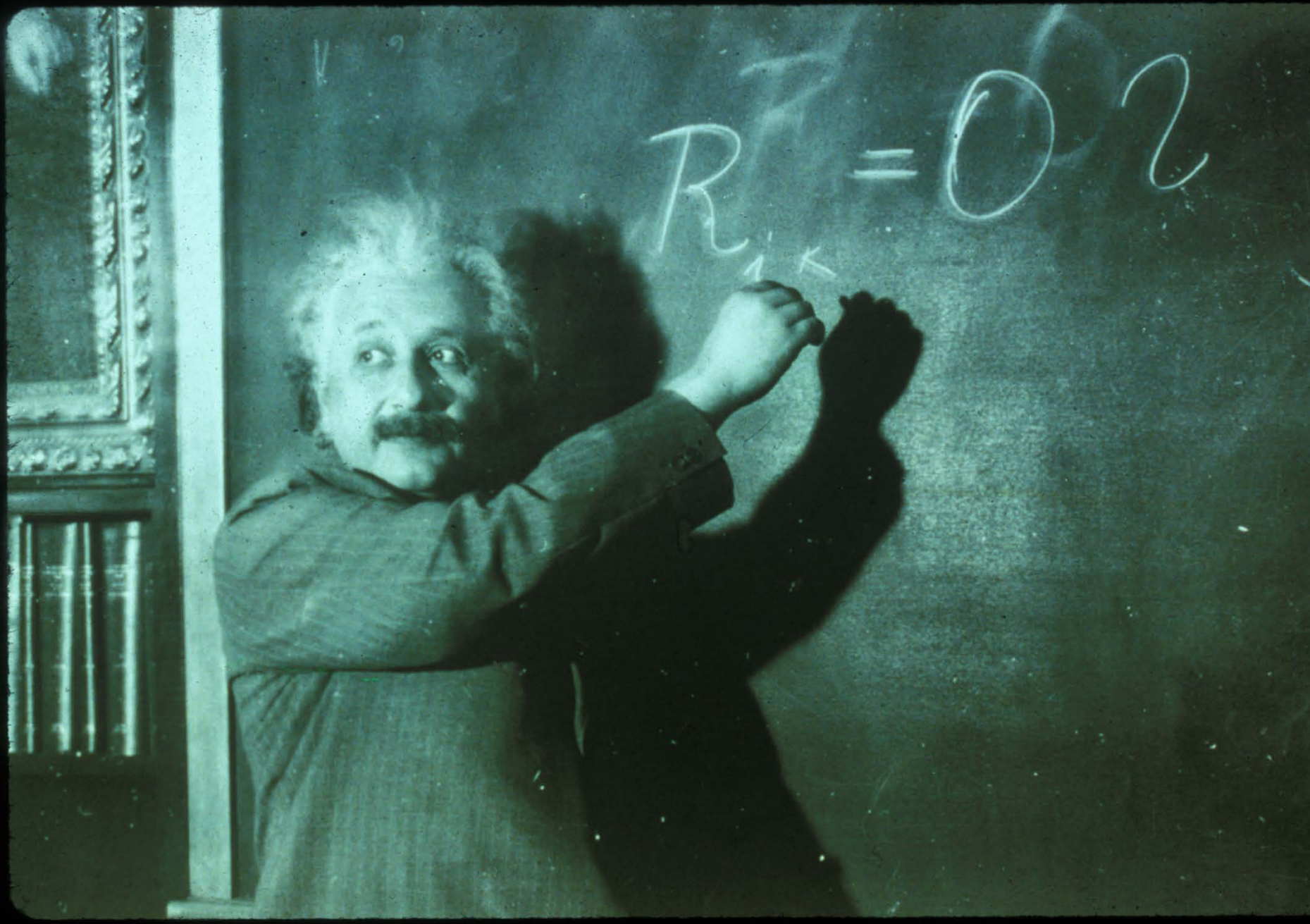
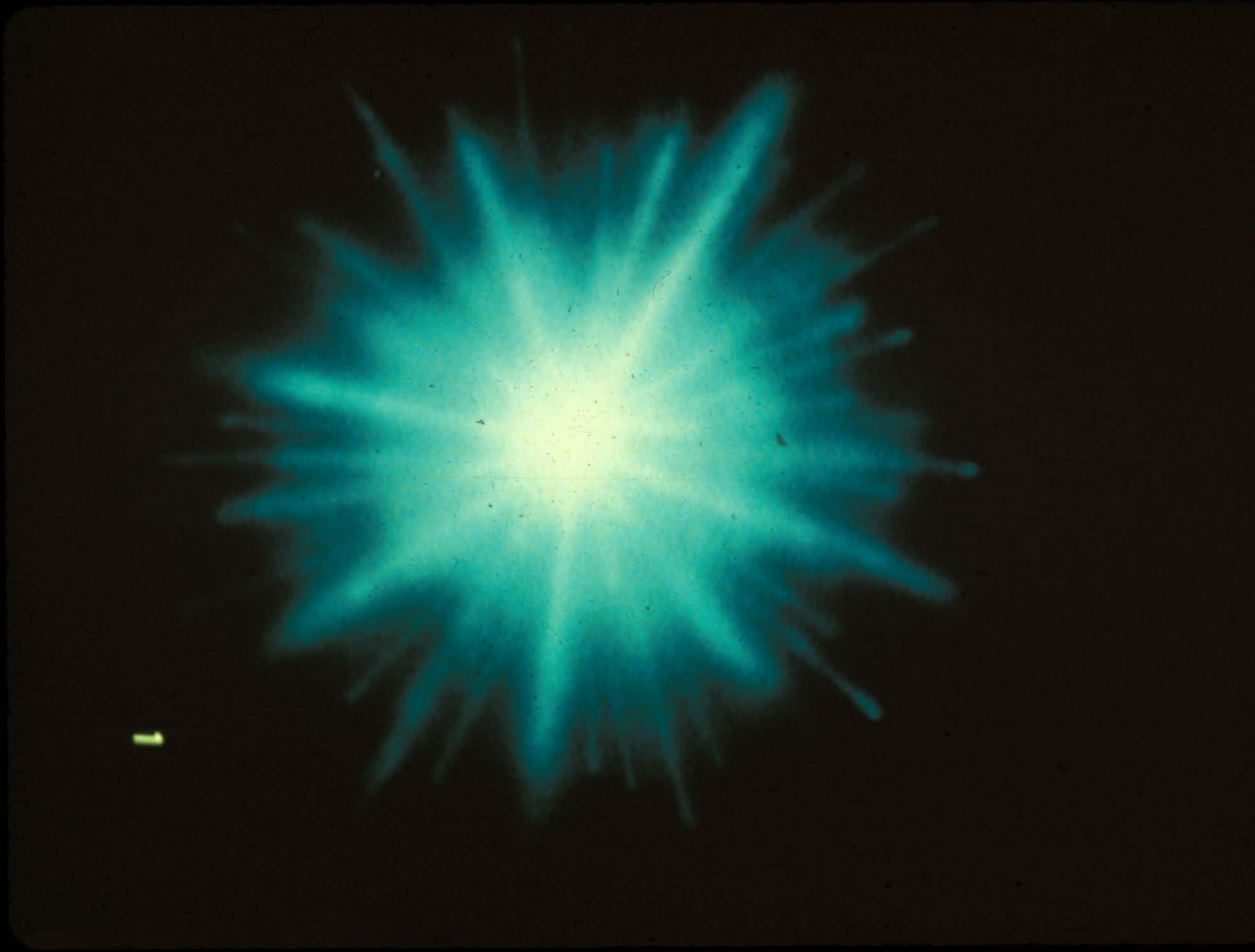
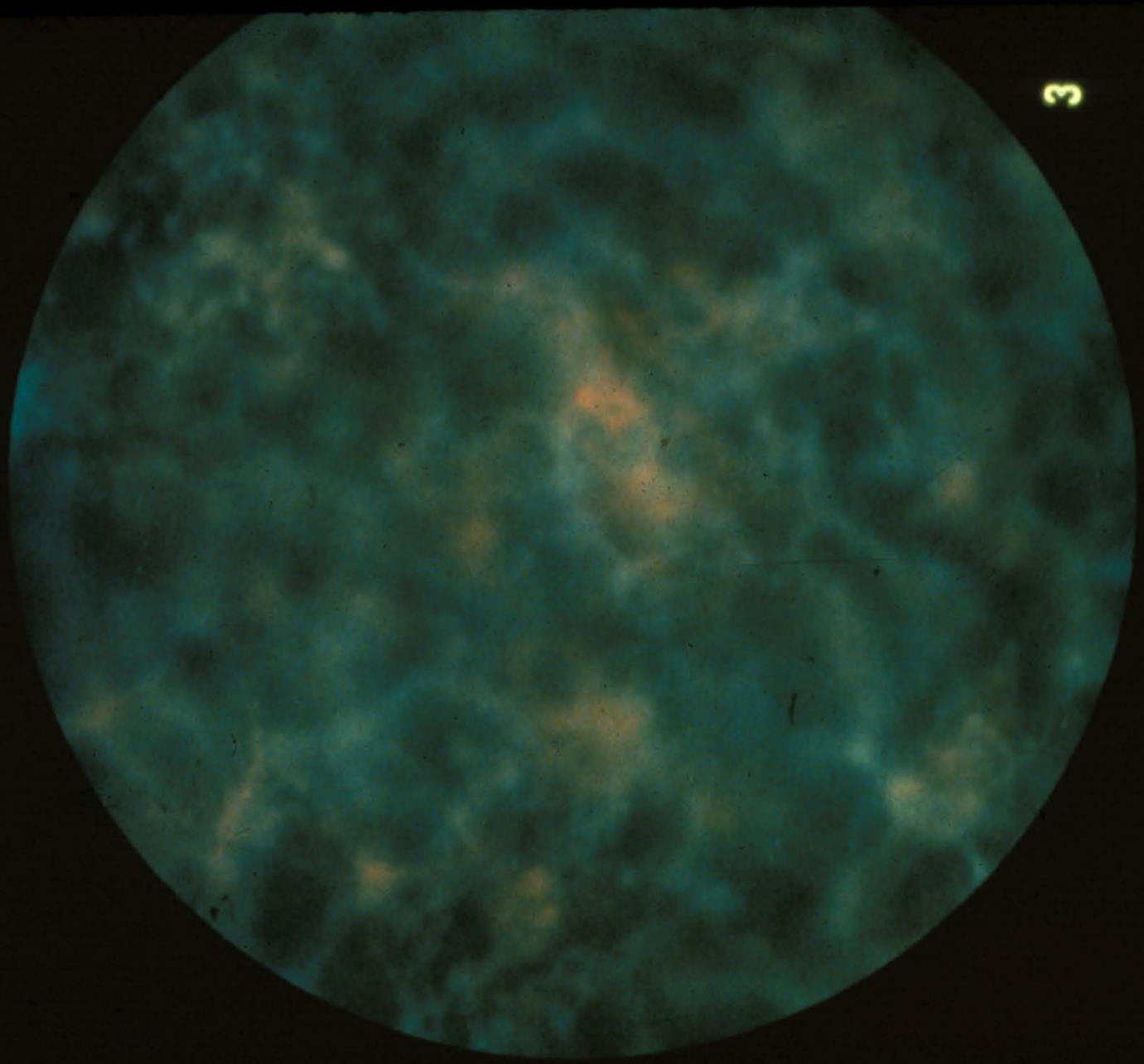
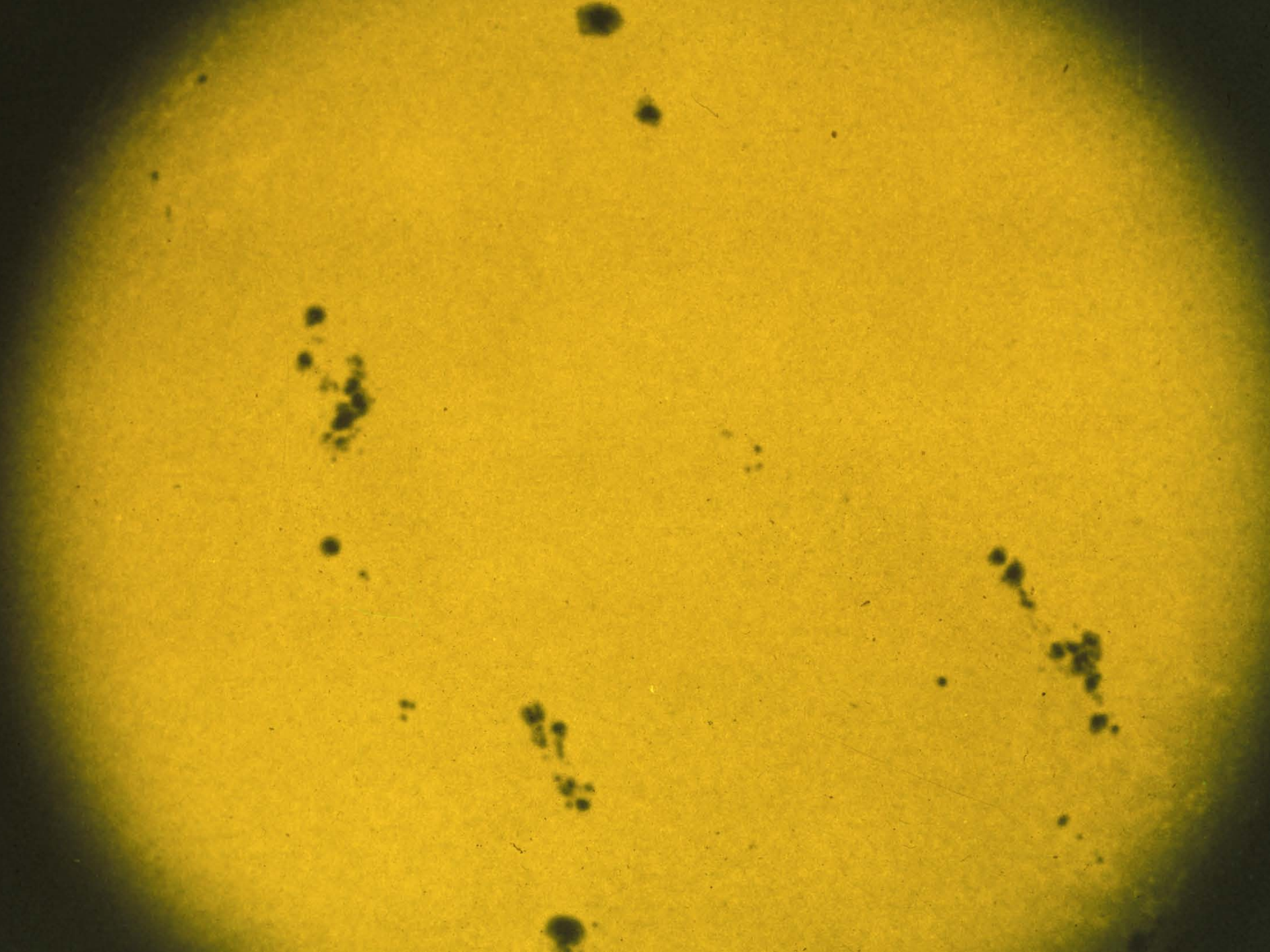
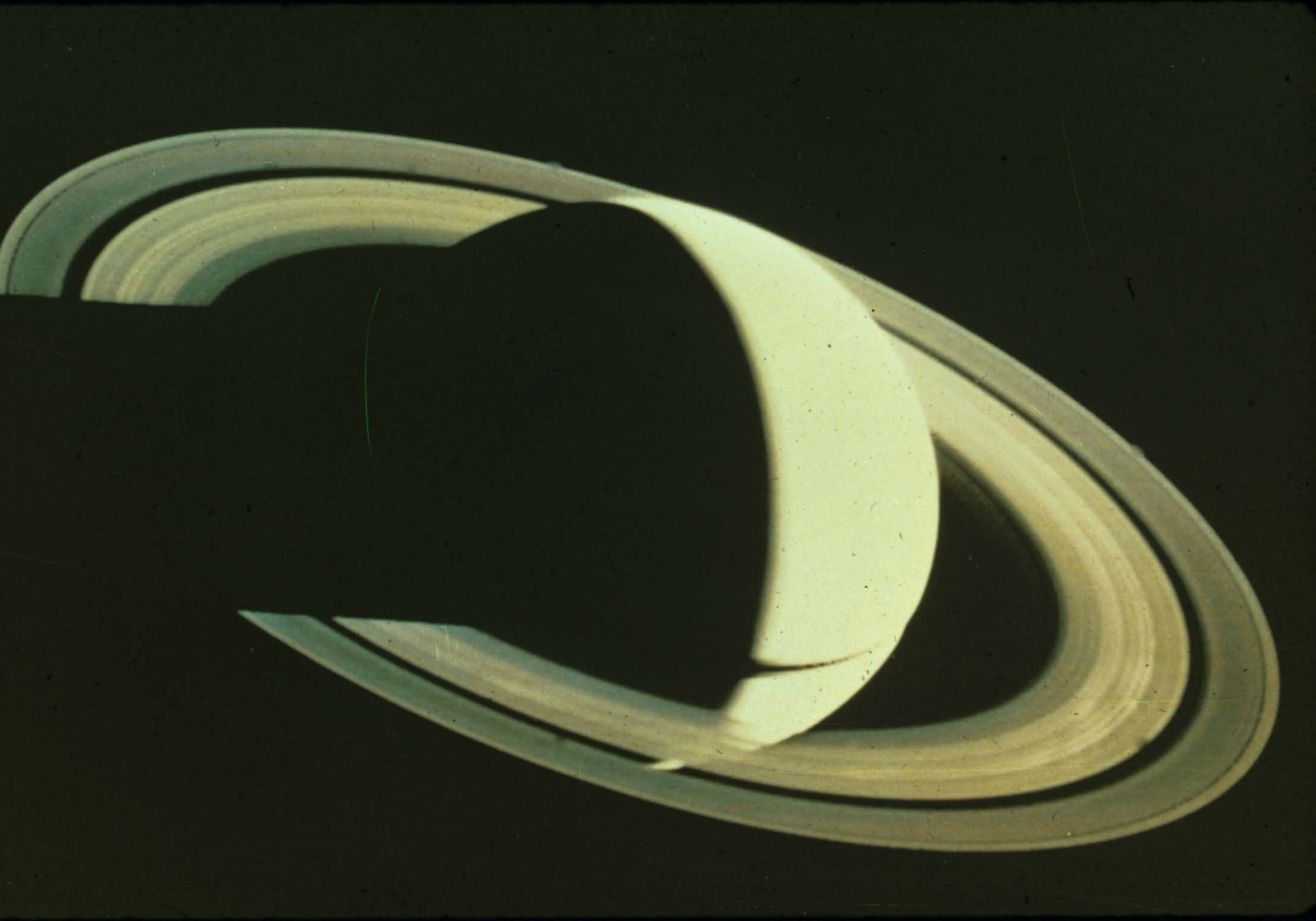



$R_{ik} = 0$







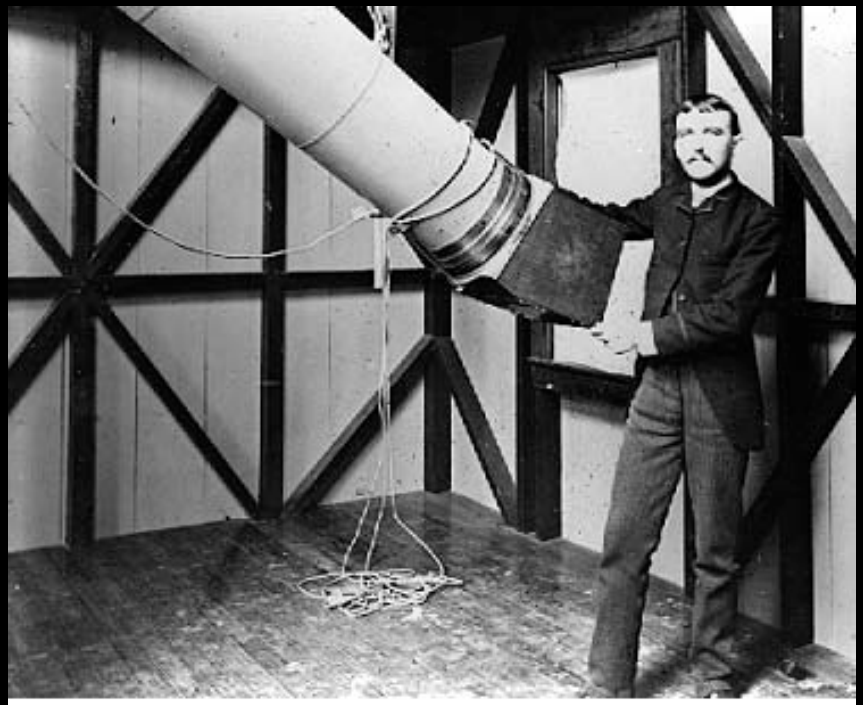


First Photograph

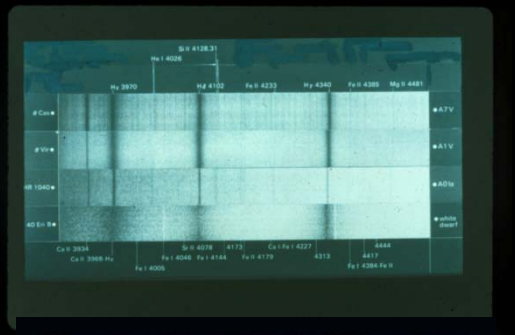
Nicephore Niepce, 1795

Window at Le Gras, 1826!

First Astronomical Spectrum



Henry Draper (1837-1882) SI neg. 48,235

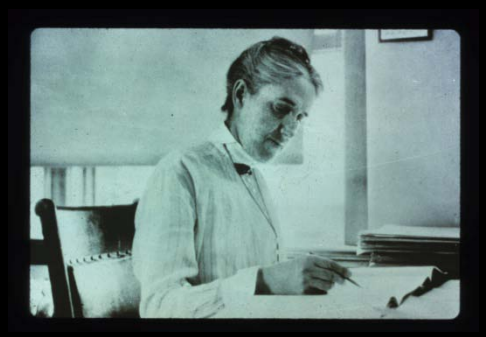


Spectrum

Comet

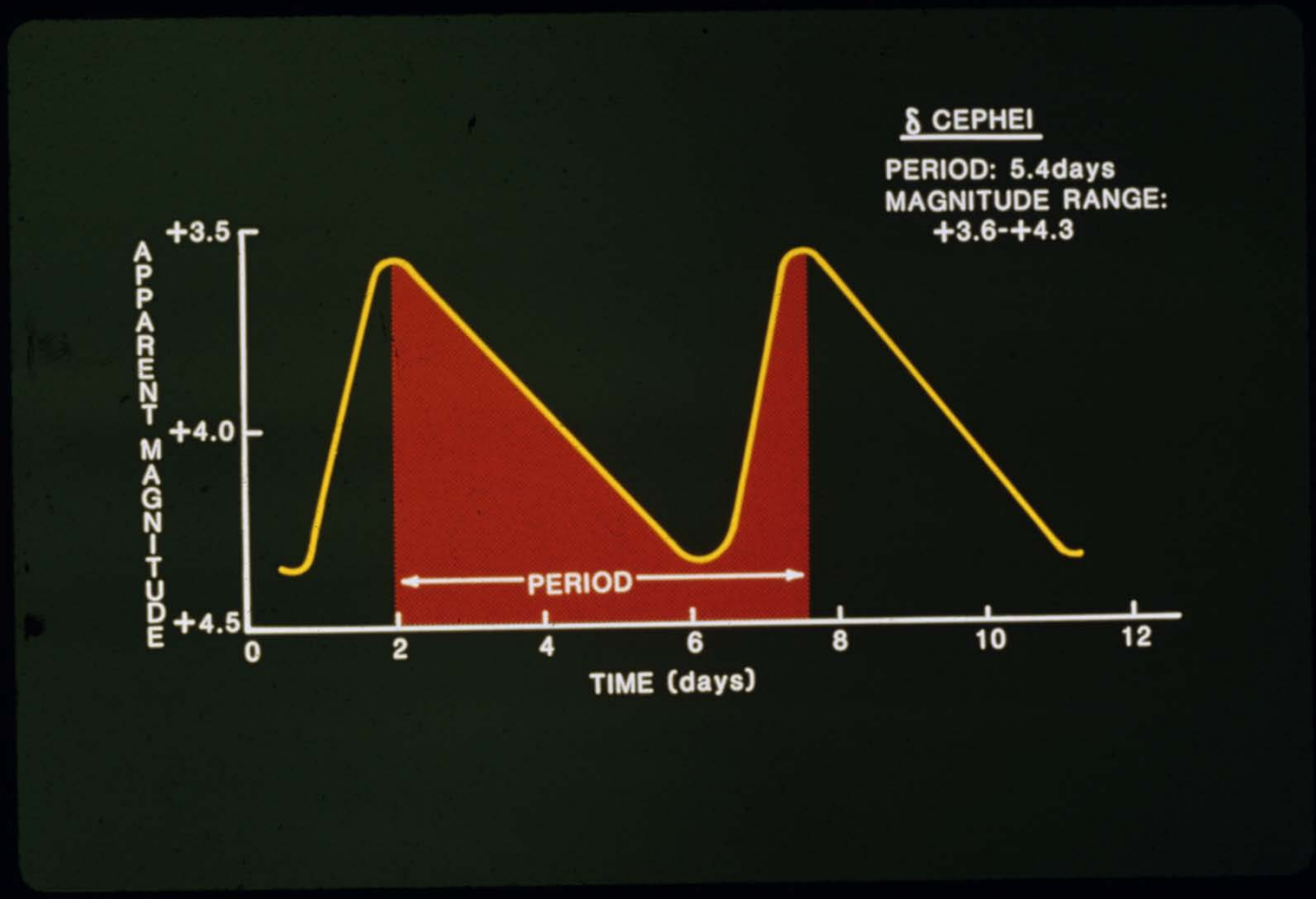
Orion Nebula

Harvard College Observatory



- Edward Pickering- instrument builder, allowed many 1000's of spectra to be taken.
- Annie Jump Cannon- analyzed ~230,000 spectra, came up with stellar classification system.
- Henrietta Leavitt- discovered Cepheid variables had a Period-Luminosity Relationship, used to measure distance to stars.

Cepheid Period-Luminosity Relationship



The Man Who Measured the Milky Way

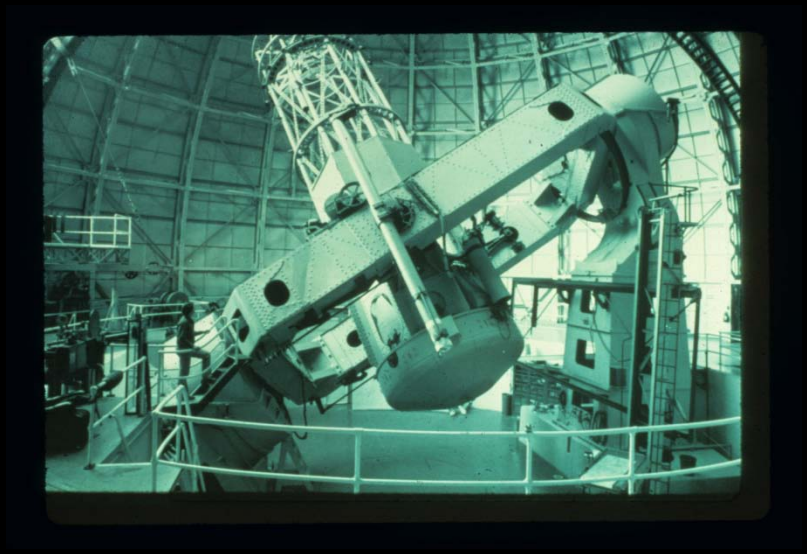
- Harlow Shapley

Great Debate with Curtis
1920

Globular Cluster

100,000 ly across!

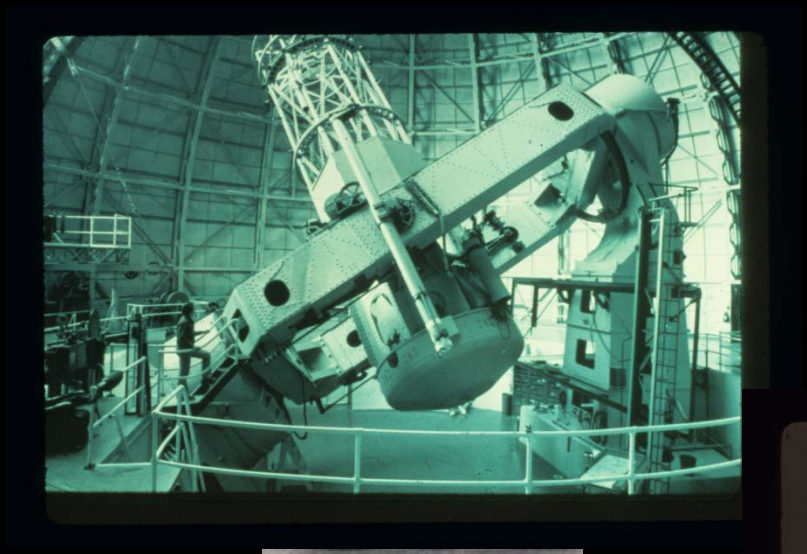
Mt. Wilson 100 inch Telescope gets Built



Largest Telescope in the World from 1917 to 1948

Telescope on road to site:

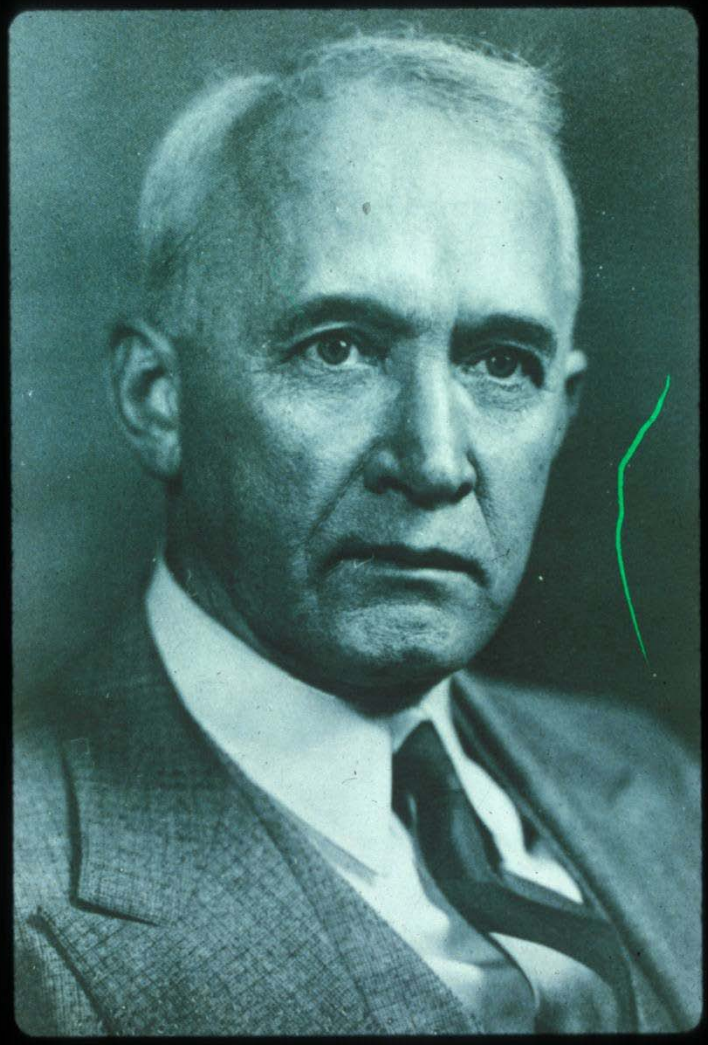
Mt. Wilson 100 inch Telescope gets Built



Milton Humason

Together these two
Measure the Universe

Edwin Hubble

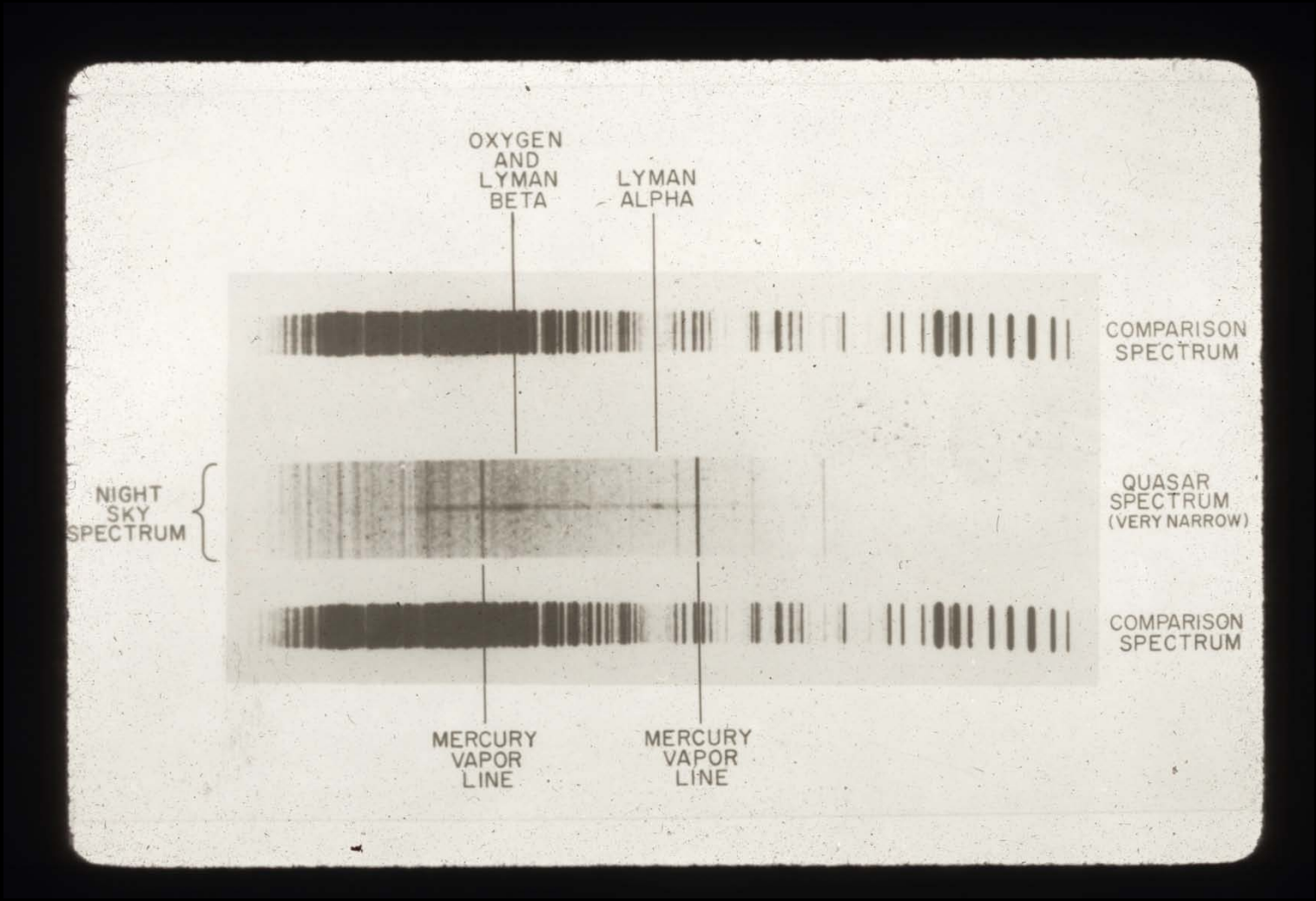


Vesto Slipher, Lowell Observatory

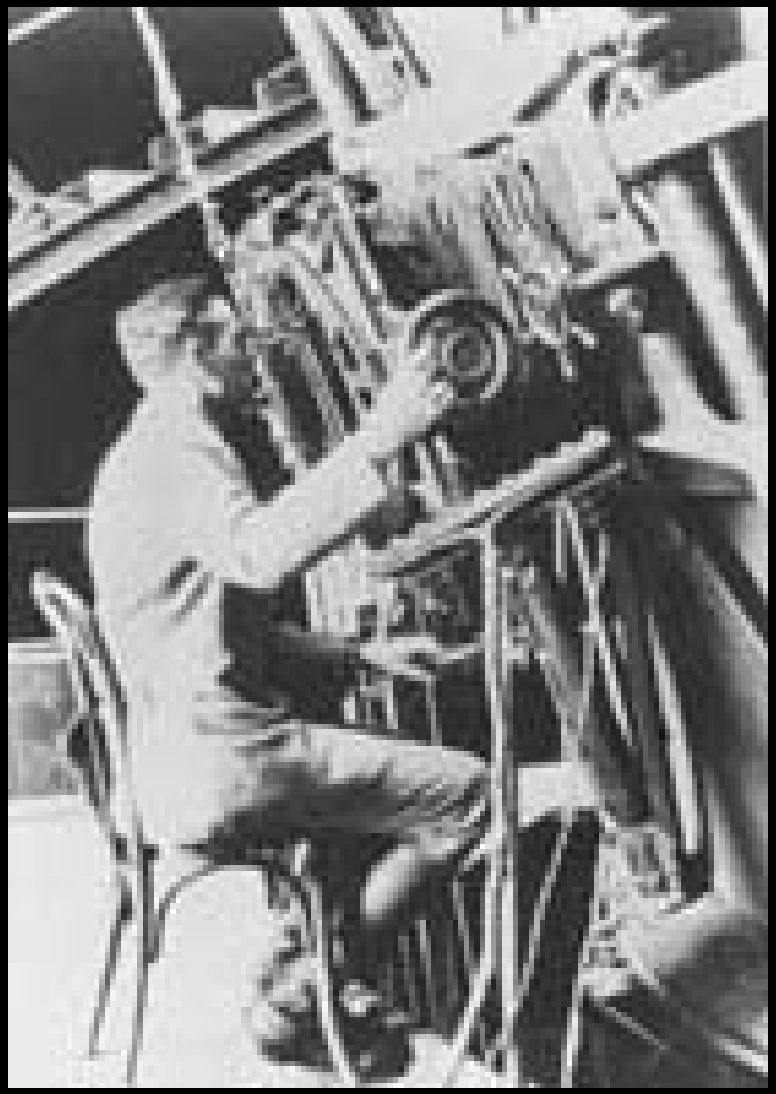
Measured velocities of nearby galaxies

Seyfert Galaxy (active nuclei)

Determine galaxy velocity by looking at how much its spectrum is shifted because of Doppler effect:



Hubble at Mt. Wilson Telescope



appearance the spectrum is very much like spectra of the Milky Way clouds in Sagittarius and Cygnus, and is also similar to spectra of binary stars of the W Ursae Majoris type, where the widening and depth of the lines are affected by the rapid rotation of the stars involved.

The wide shallow absorption lines observed in the spectrum of N. G. C. 7619 have been noticed in the spectra of other extra-galactic nebulae, and may be due to a dispersion in velocity and a blending of the spectral types of the many stars which presumably exist in the central parts of these nebulae. The lack of depth in the absorption lines seems to be more pronounced among the smaller and fainter nebulae, and in N. G. C. 7619 the absorption is very weak.

It is hoped that velocities of more of these interesting objects will soon be available.

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, the other criteria merely check the order of the distances. This method is restricted to the few nebulae which are well resolved by existing instruments. A study of these nebulae, together with those in which any stars at all can be recognized, indicates the probability of an approximately uniform upper limit to the absolute luminosity of stars, in the late-type spirals and irregular nebulae at least, of the order of M (photographic) $= -6.3$.[1] The apparent luminosities of the brightest stars in such nebulae are thus criteria which, although rough and to be applied with caution,

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

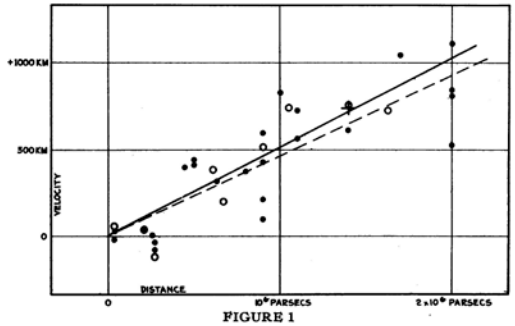
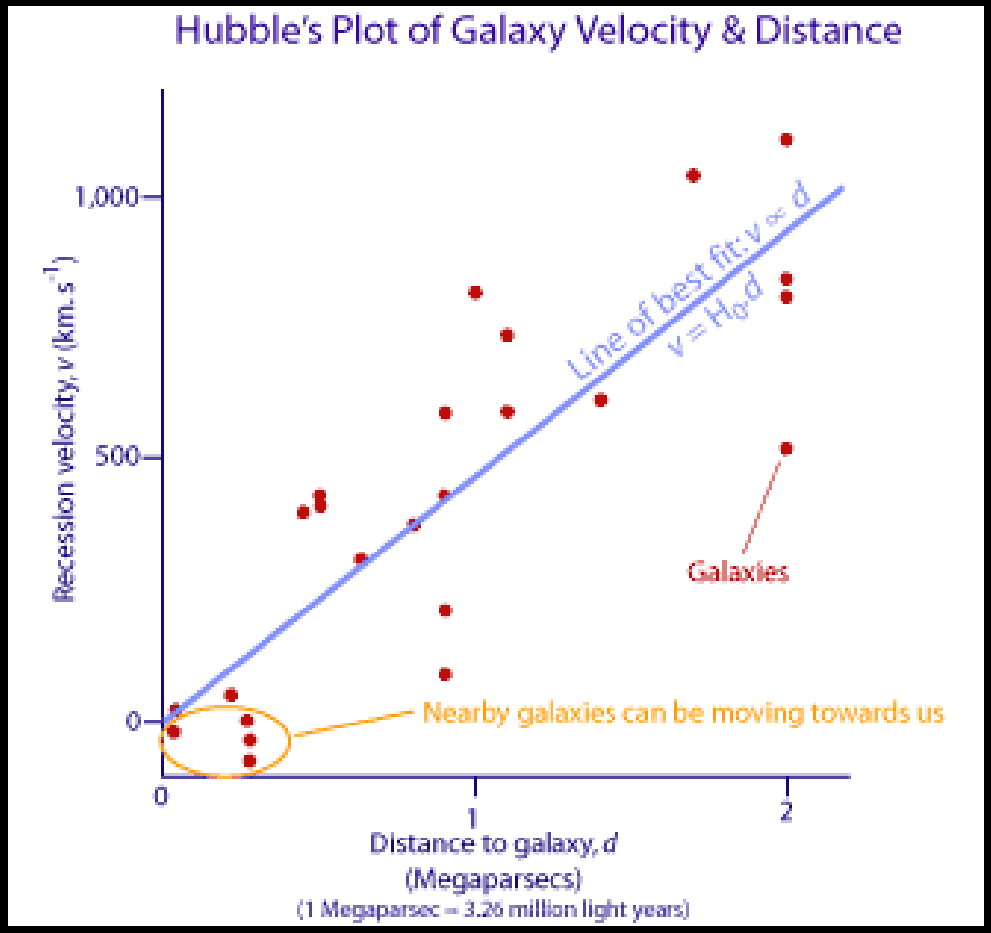


FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

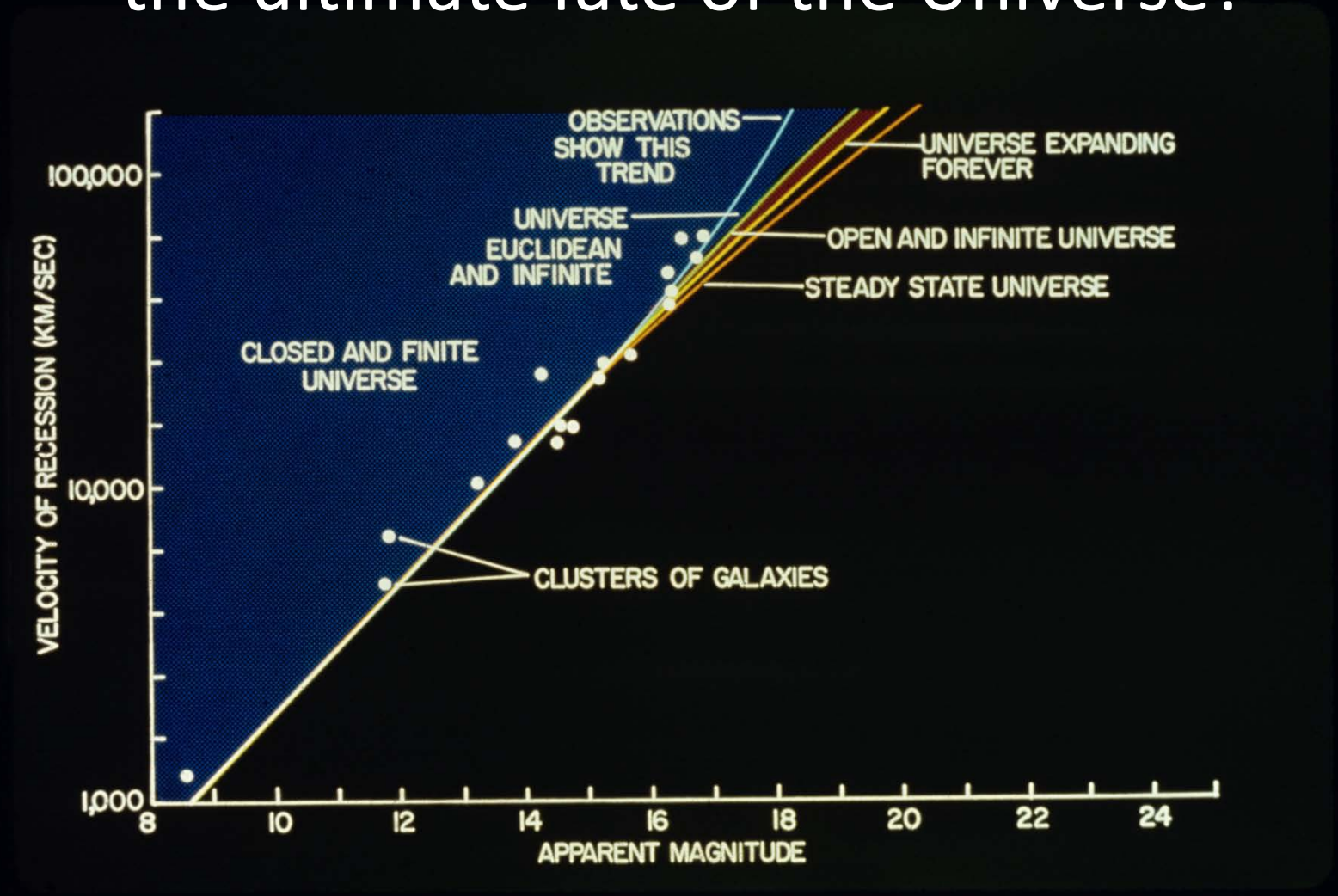
Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution 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

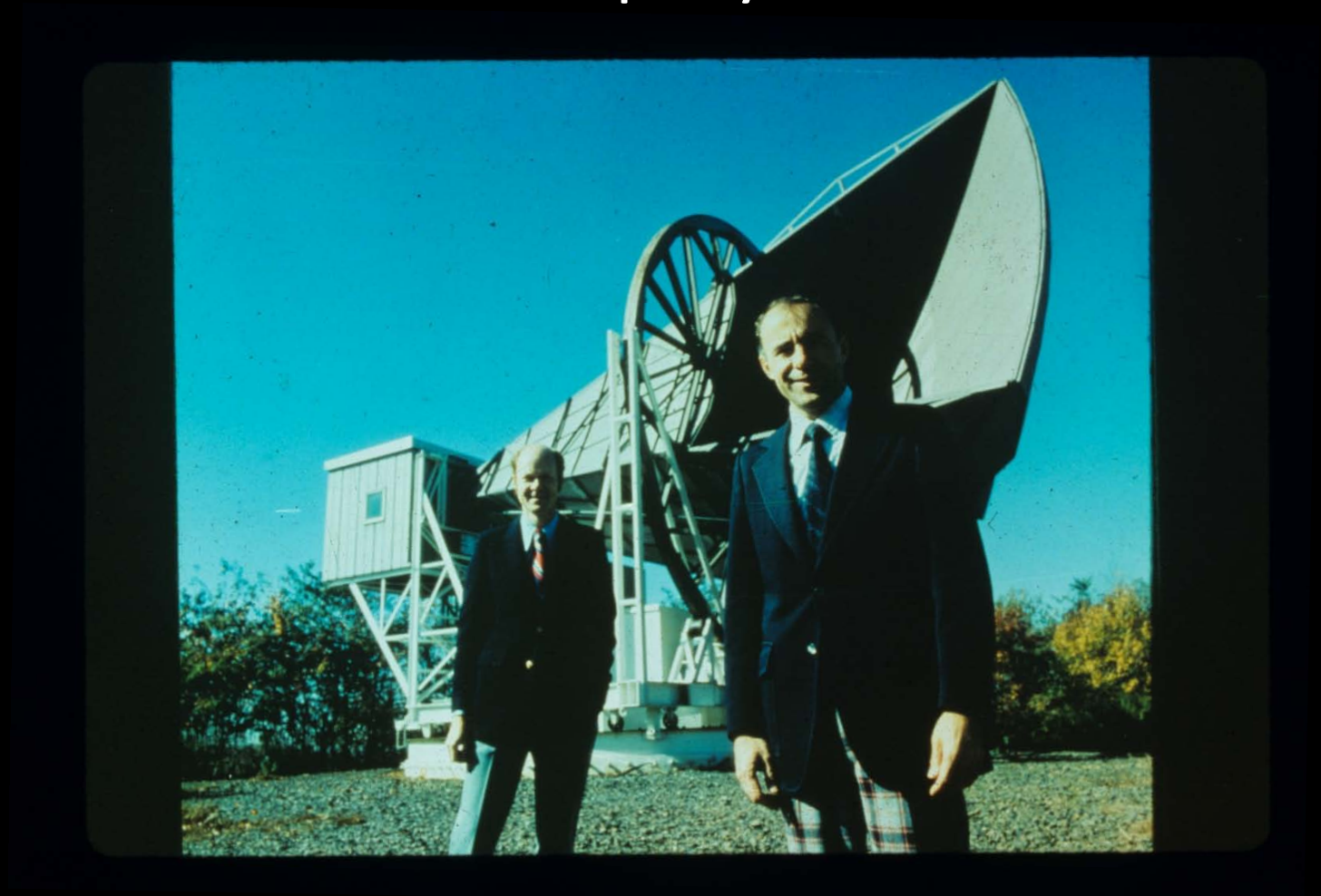


Plot of Hubble & Humason's Original 1929 Data: This was the first observational proof of the Big Bang Theory!

What can the Hubble Law plot tell us about the ultimate fate of the Universe?



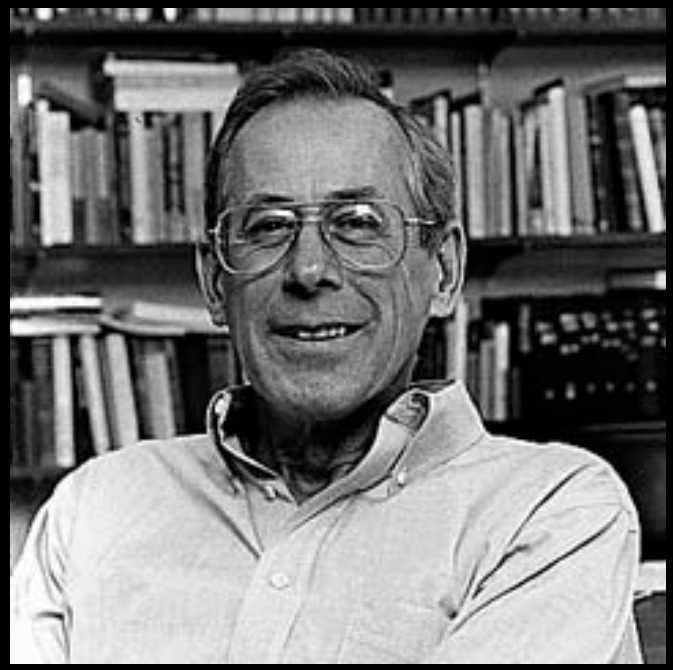
What you didn’t know about your phone company….



Arno Penzias and Bob Wilson @ Bell Labs, Holmdel NJ

Meanwhile down the road at Princeton….

Robert Dicke



James Peebles

WMAP Space Observatory Map of Early Universe