John D. Schopp

Sir Ernest Shackleton, 1874-1922

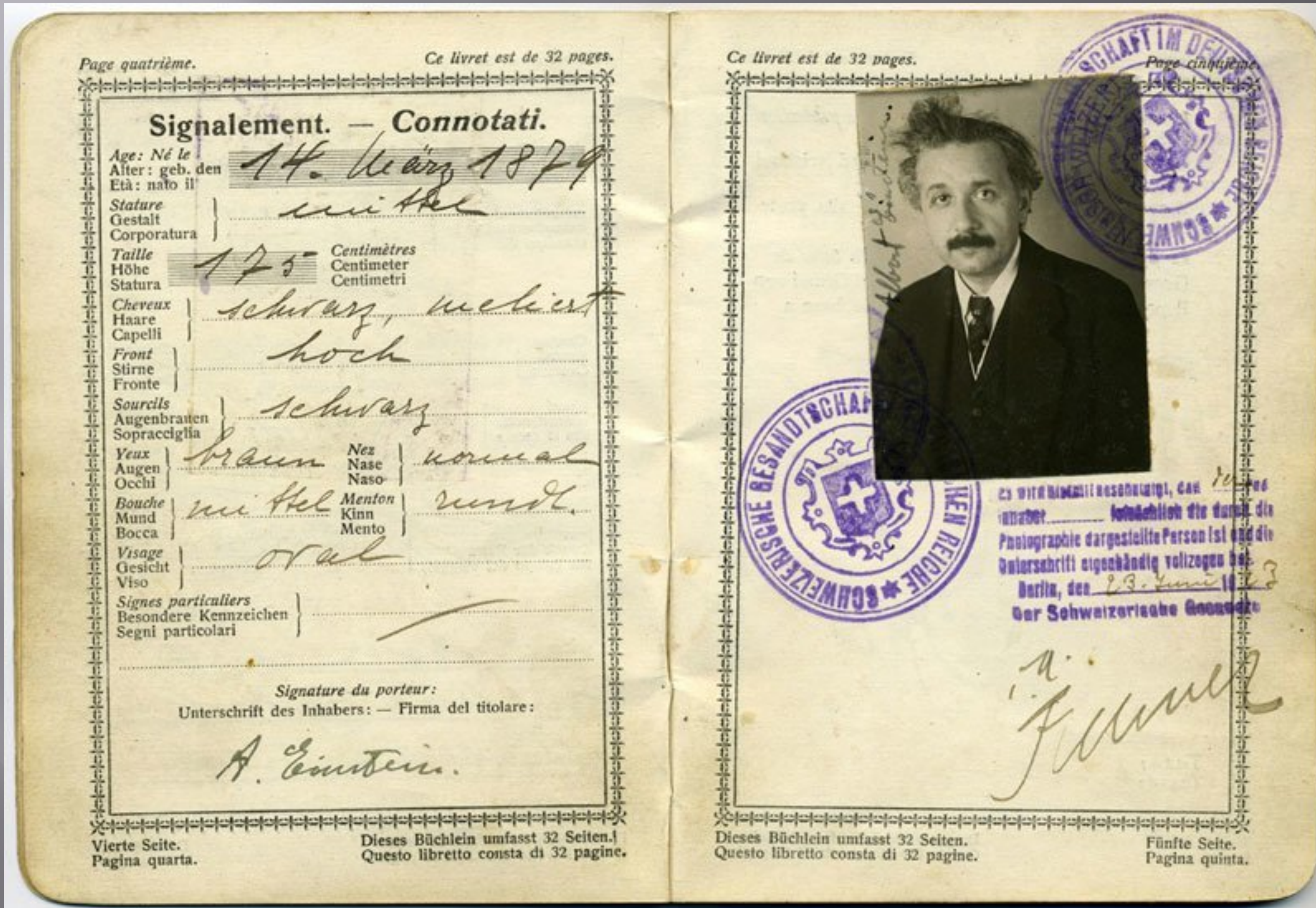
THE LEADER

Known as “the boss,” he never lost a member of any of his south polar expeditions.

He was a hero to Professor Schopp.

February 11, 2016,
Official announcement of the discovery of gravitational waves

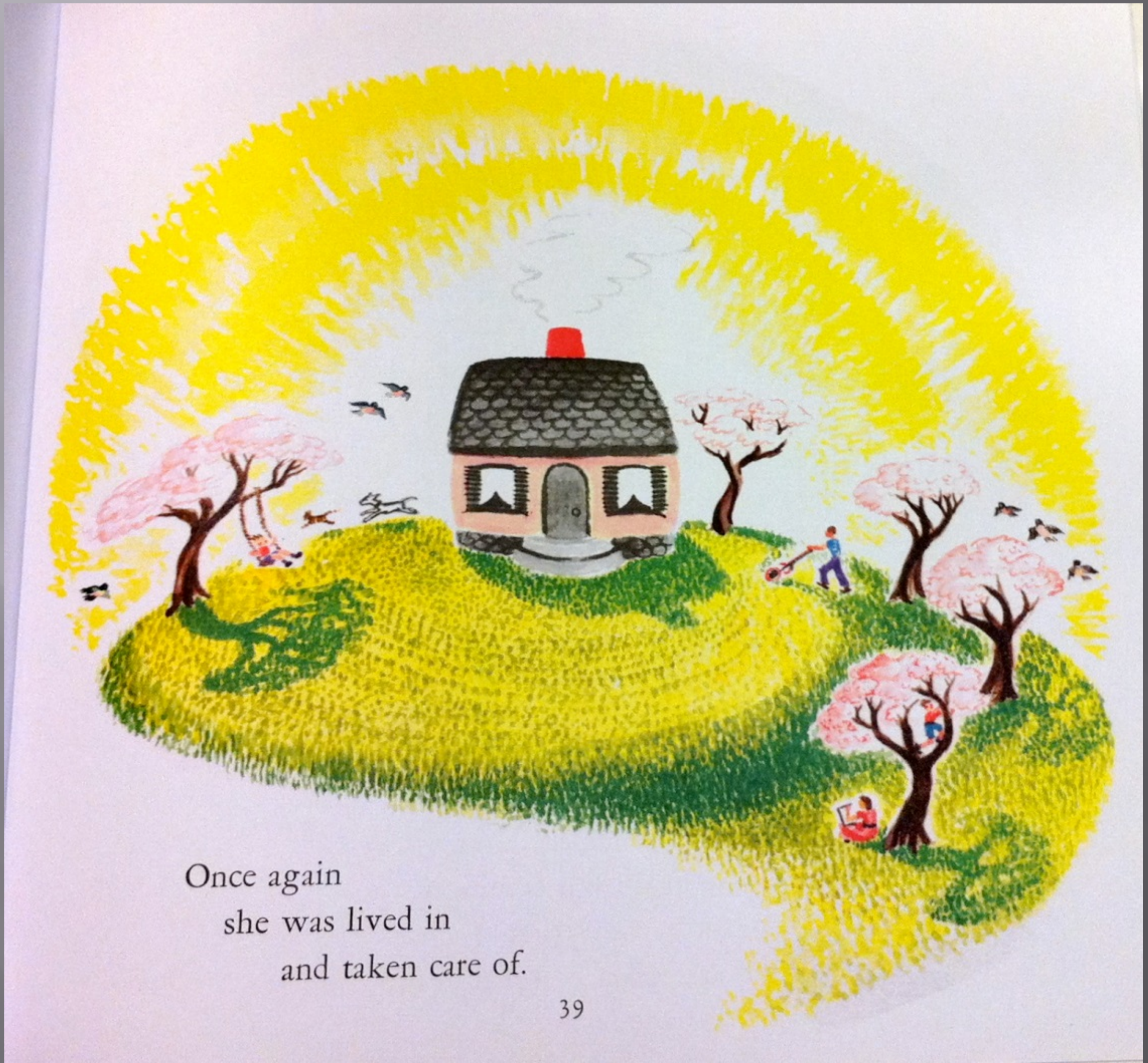
Gravitational waves: a prediction by Einstein, one century ago



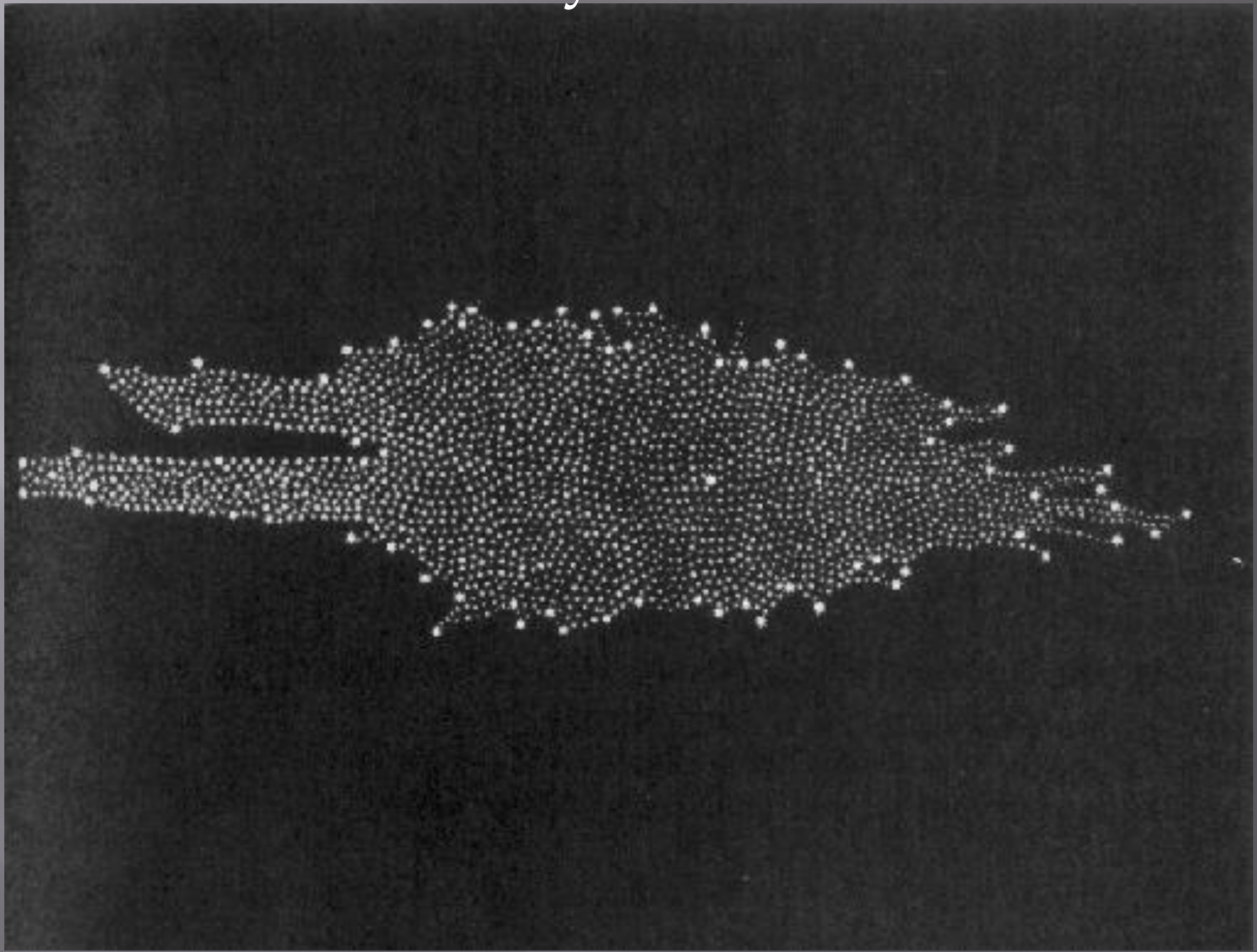
John Brown as "Broadway," on the *Damon Runyon Theater*

As "Broadway" might have put it about the announcement of gravitational waves, "…and there is a story that goes with it."

Our model of the universe, ca. 1910:
comfy, cozy, small, like
Margaret Wise Brown's *Little House*



This model was based on William Herschel's 1781 conception of the universe: solitary, small, sun-centered



Jacobus (1851-1922) and Catharina Kapteyn at the Mount Wilson Observatory

The Kapteyn Universe was an early twentieth century model much like the Herschel universe, but on a better statistical base. Alas, it made no allowance for interstellar absorption.

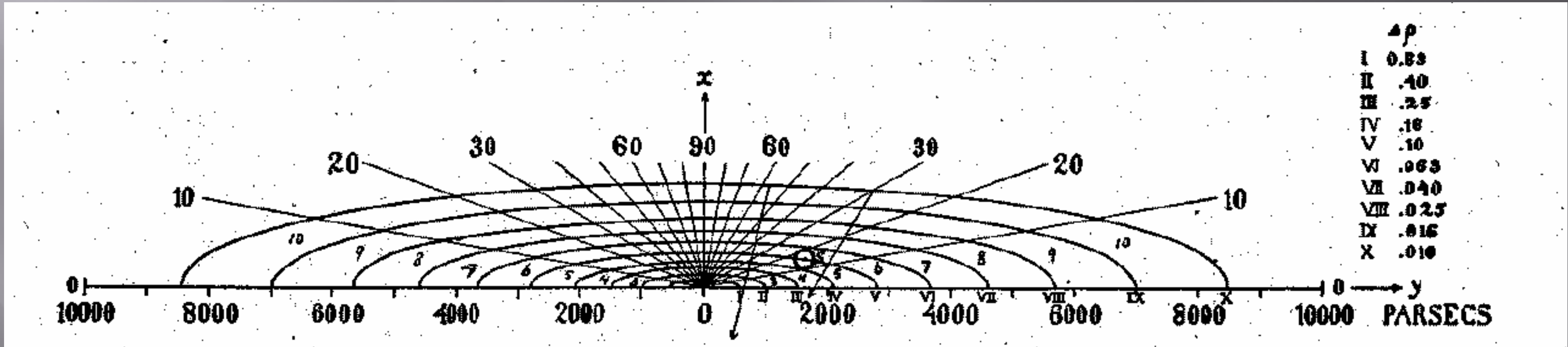
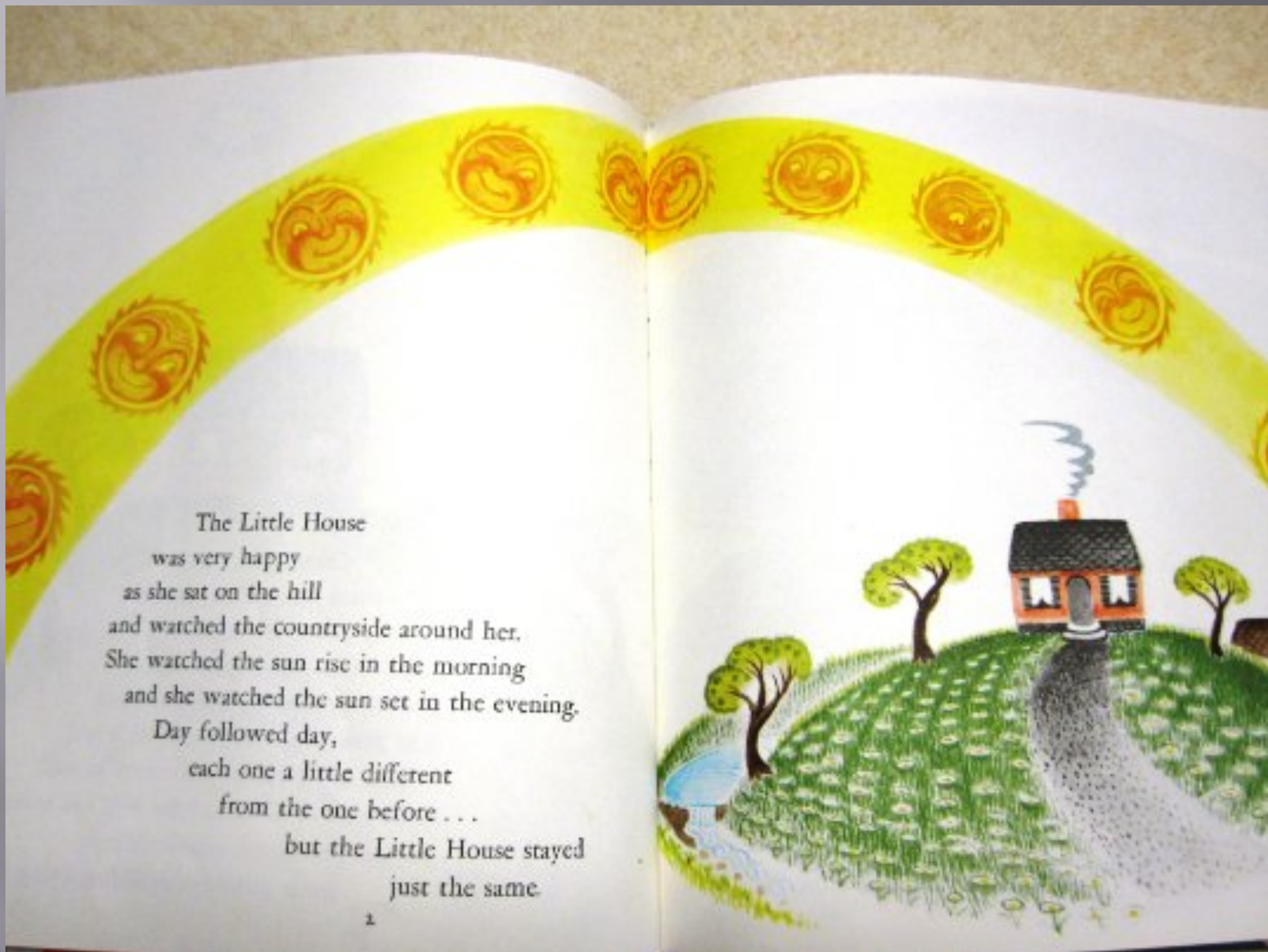


FIG. I



The Little House
was very happy
as she sat on the hill
and watched the countryside around her.
She watched the sun rise in the morning
and she watched the sun set in the evening.
Day followed day,
each one a little different
from the one before . . .
but the Little House stayed
just the same.

Einstein’s theory of general relativity allows him to make exact predictions of the effects of a gravitational field.

Die Feldgleichungen der Gravitation.

Von A. Einstein.

In zwei vor kurzem erschienenen Mitteilungen[1] habe ich gezeigt, wie man zu Feldgleichungen der Gravitation gelangen kann, die dem Postulat allgemeiner Relativität entsprechen, d. h. die in ihrer allgemeinen Fassung beliebigen Substitutionen der Raumzeitvariabeln gegenüber kovariant sind.

Der Entwicklungsgang war dabei folgender. Zunächst fand ich Gleichungen, welche die Newtonsche Theorie als Näherung enthalten und beliebigen Substitutionen von der Determinante 1 gegenüber kovariant waren. Hierauf fand ich, daß diesen Gleichungen allgemein kovariante entsprechen, falls der Skalar des Energietensors der »Materie« verschwindet. Das Koordinatensystem war dann nach der einfachen Regel zu spezialisieren, daß $\sqrt{-g}$ zu 1 gemacht wird, wodurch die Gleichungen der Theorie eine eminente Vereinfachung erfahren. Dabei mußte aber, wie erwähnt, die Hypothese eingeführt werden, daß der Skalar des Energietensors der Materie verschwinde.

Neuerdings finde ich nun, daß man ohne Hypothese über den Energietensor der Materie auskommen kann, wenn man den Energietensor der Materie in etwas anderer Weise in die Feldgleichungen einsetzt, als dies in meinen beiden früheren Mitteilungen geschehen ist. Die Feldgleichungen für das Vakuum, auf welche ich die Erklärung der Perihelbewegung des Merkur gegründet habe, bleiben von dieser Modifikation unberührt. Ich gebe hier nochmals die ganze Betrachtung, damit der Leser nicht genötigt ist, die früheren Mitteilungen unausgesetzt heranzuziehen.

Aus der bekannten Riemannschen Kovariante vierten Ranges leitet man folgende Kovariante zweiten Ranges ab:

$$G_{im} = R_{im} + S_{im} \qquad (1)$$

$$R_{im} = -\sum_{l} \frac{\partial \begin{Bmatrix} im \\ l \end{Bmatrix}}{\partial x_l} + \sum_{l\rho} \begin{Bmatrix} il \\ \rho \end{Bmatrix} \begin{Bmatrix} m\rho \\ l \end{Bmatrix} \qquad (1a)$$

$$S_{im} = \sum_{l} \frac{\partial \begin{Bmatrix} il \\ l \end{Bmatrix}}{\partial x_m} - \sum_{l\rho} \begin{Bmatrix} im \\ \rho \end{Bmatrix} \begin{Bmatrix} \rho l \\ l \end{Bmatrix} \qquad (1b)$$

[1] Sitzungsber. XLIV, S. 778 und XLVI, S. 799. 1915.

Consequences of "Curved Spacetime"

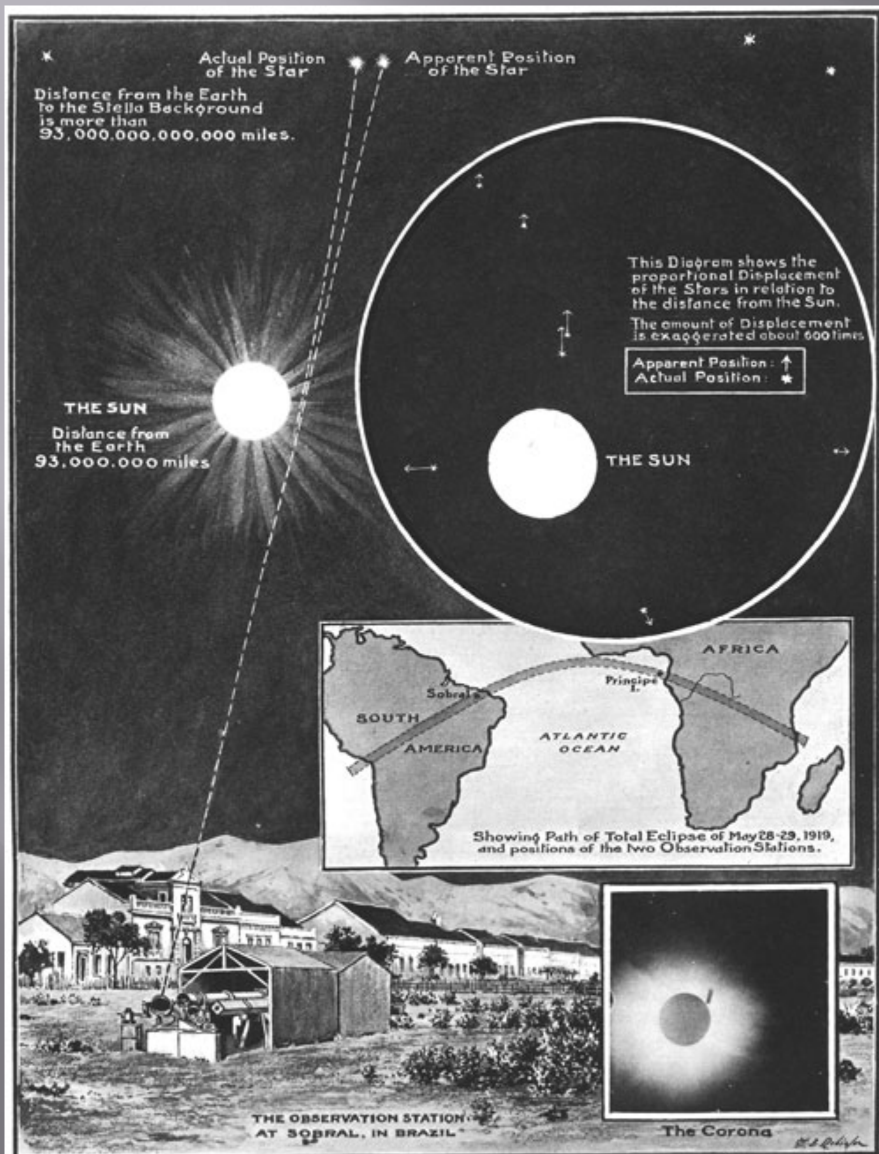
Precession of the perihelion of Mercury
- 0.43 second of arc/century

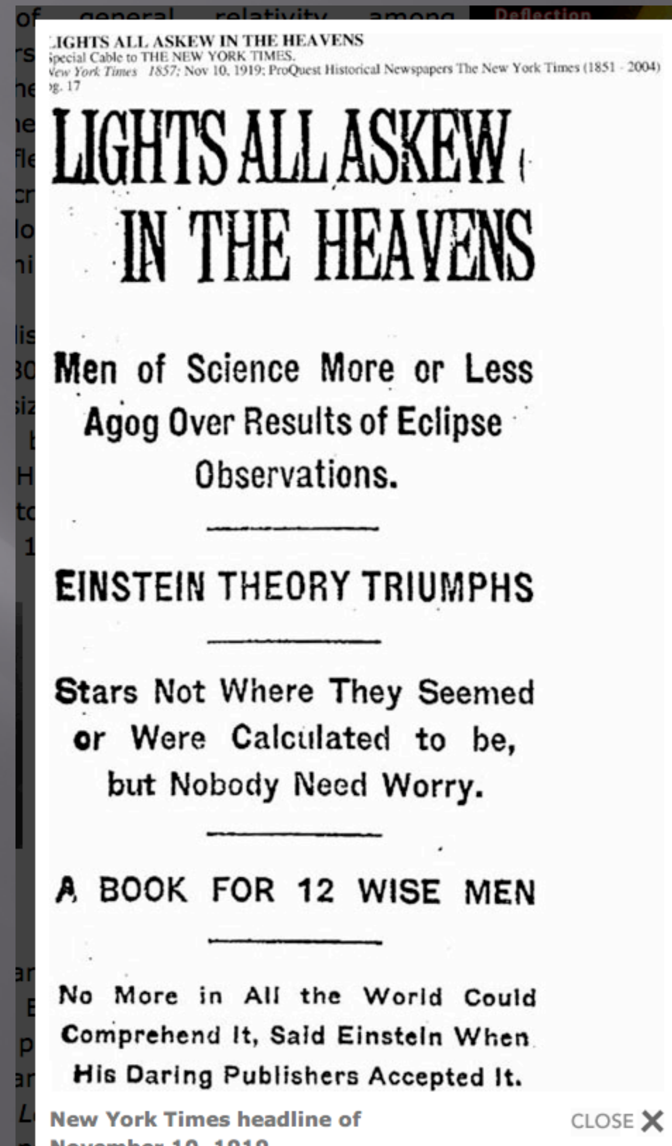
Deflection of light by the sun
- 1.745 seconds of arc at the sun's limb

Gravitational redshift of light
- 0.01 angstroms (sun)

Tiny effects

Sir Arthur Eddington observes an effect in 1919




LIGHTS ALL ASKEW IN THE HEAVENS
Special Cable to THE NEW YORK TIMES.
New York Times 1857; Nov 10, 1919; ProQuest Historical Newspapers The New York Times (1851 - 2004)
pg. 17

LIGHTS ALL ASKEW IN THE HEAVENS

Men of Science More or Less Agog Over Results of Eclipse Observations.

EINSTEIN THEORY TRIUMPHS

Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

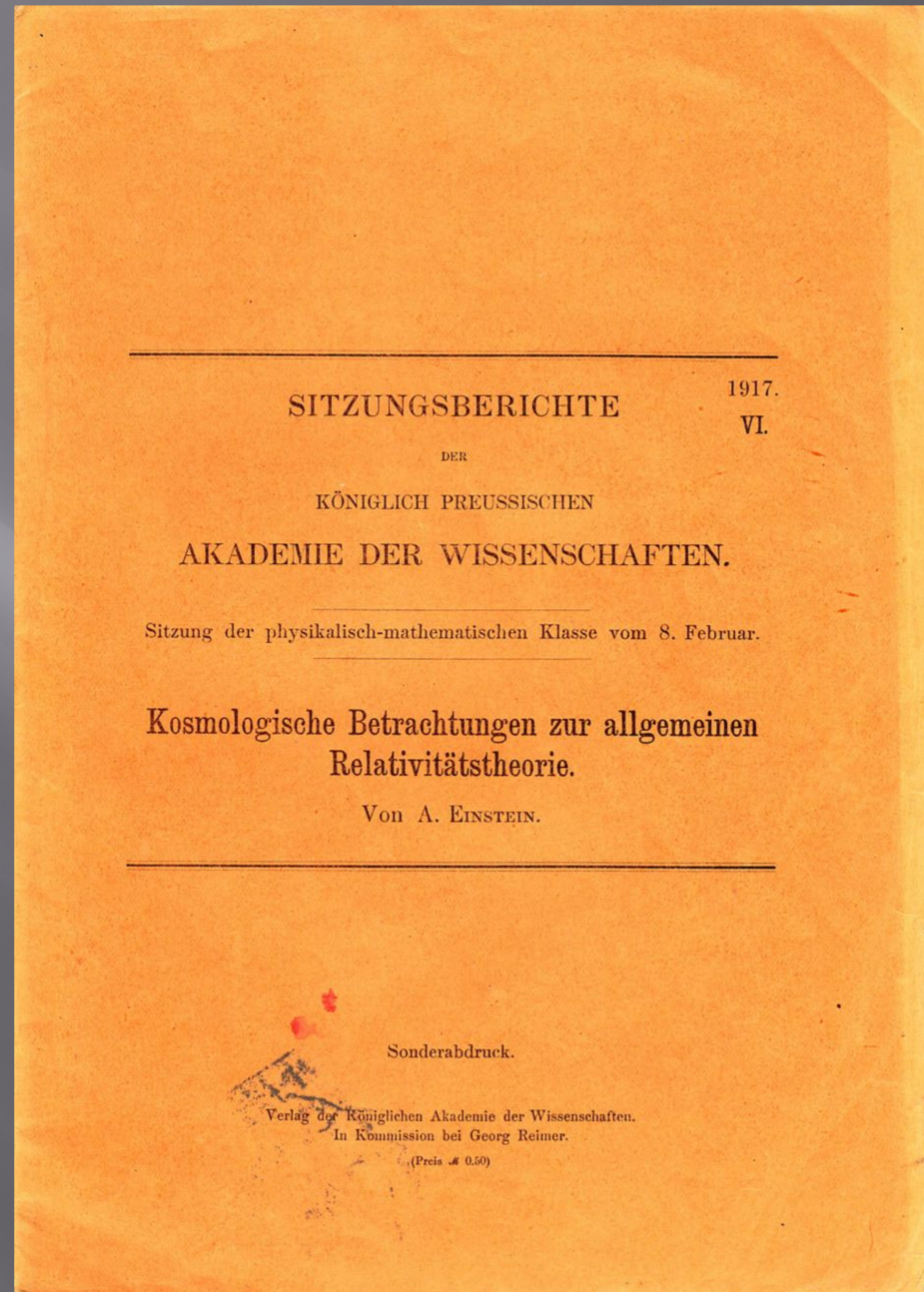
A BOOK FOR 12 WISE MEN

No More in All the World Could Comprehend It, Said Einstein When His Daring Publishers Accepted It.

New York Times headline of November 10, 1919.

CLOSE ✕

Since gravitation is universal, a theory of gravitation should allow for a theory of the organization of the universe. So, in 1917, we have Einstein's "Cosmological Observations…."



SITZUNGSBERICHTE 1917. VI.

DER

KÖNIGLICH PREUSSISCHEN

AKADEMIE DER WISSENSCHAFTEN.

Sitzung der physikalisch-mathematischen Klasse vom 8. Februar.

Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie.

Von A. Einstein.

Sonderabdruck.

Verlag der Königlichen Akademie der Wissenschaften.
In Kommission bei Georg Reimer.
(Preis ℳ 0.50)

Einstein's solution of his gravitation equations results in

"Solution A"

Curvature of space,

"geometry of space-time"

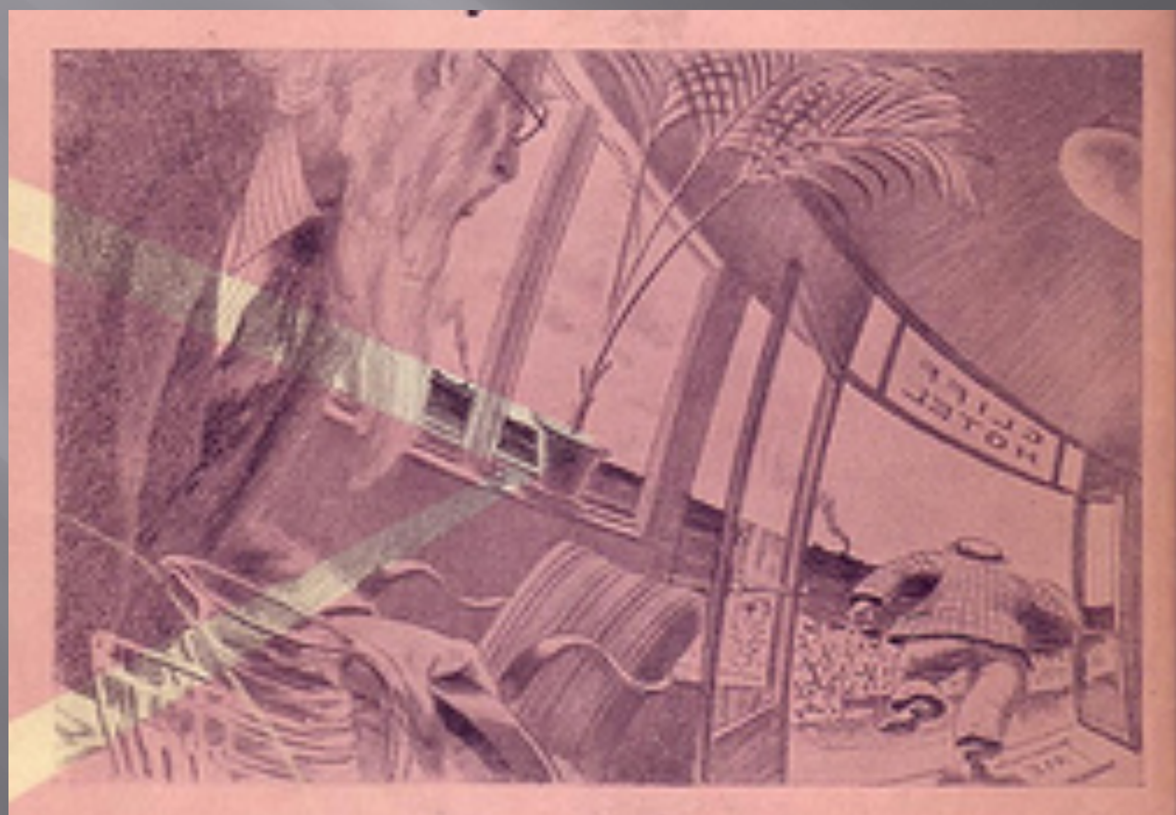
Matter curves space, space tells matter how to behave

Cosmological constant, λ

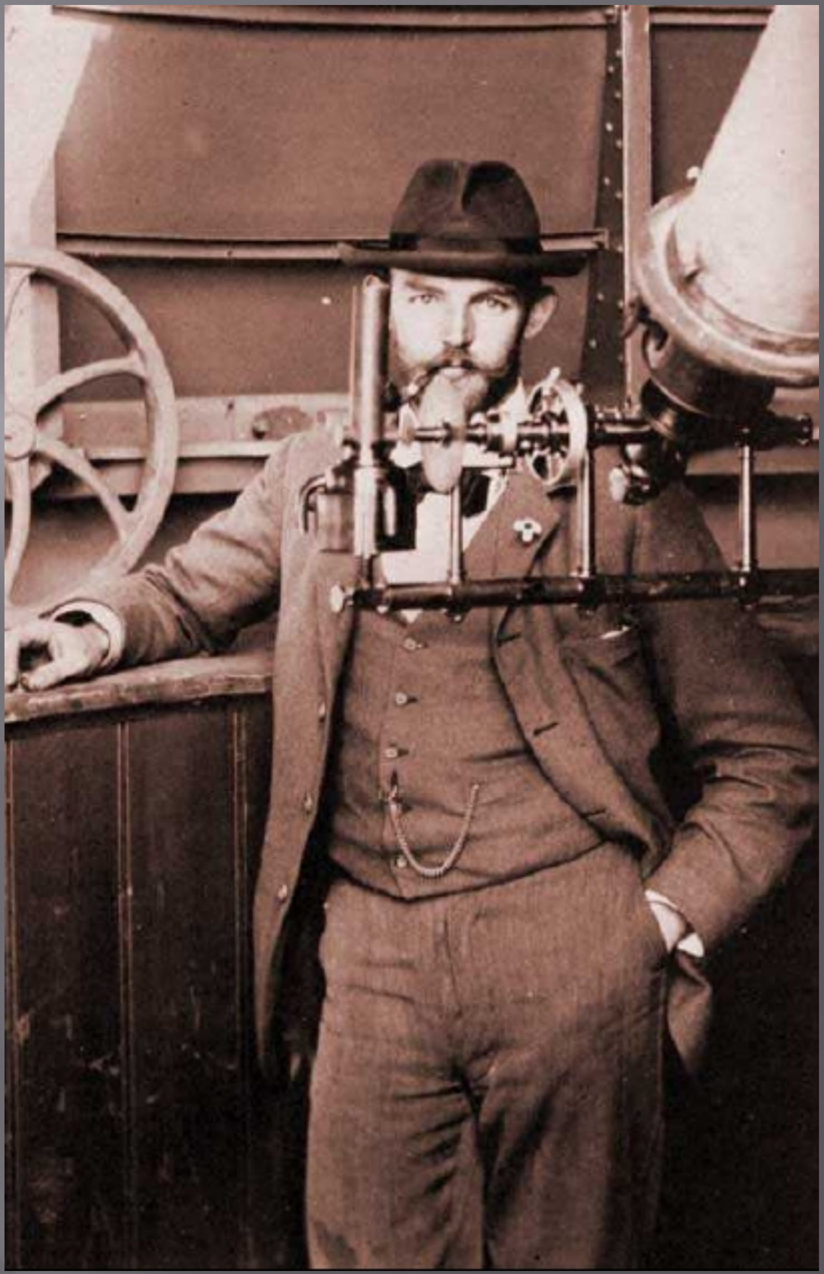
to avoid a dynamic universe that expands or contracts

"revolutionary" but also "static" or "conventional" in the sense of a stationary universe

Einstein’s notion of a curved space-time was revolutionary enough: seen here imaged in a 1939 popularization by George Gamow



Willem de Sitter, 1872-1934, a Dutch colleague of Einstein, made his own solution of Einstein's equations.



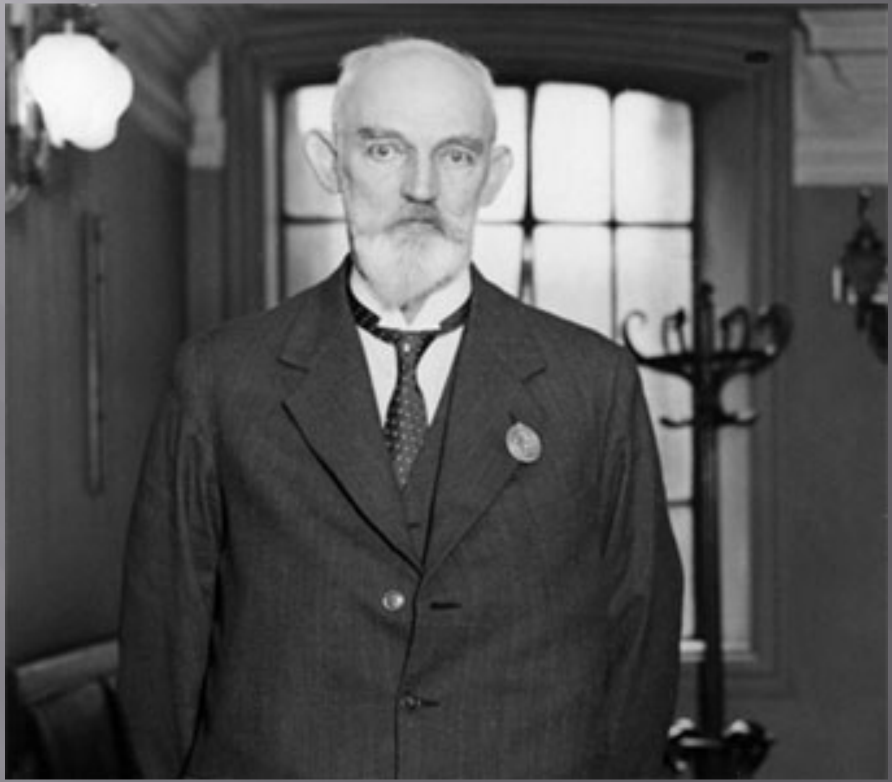
A few months after Einstein, de Sitter announces "Solution B"

Also a static universe

A universe without matter

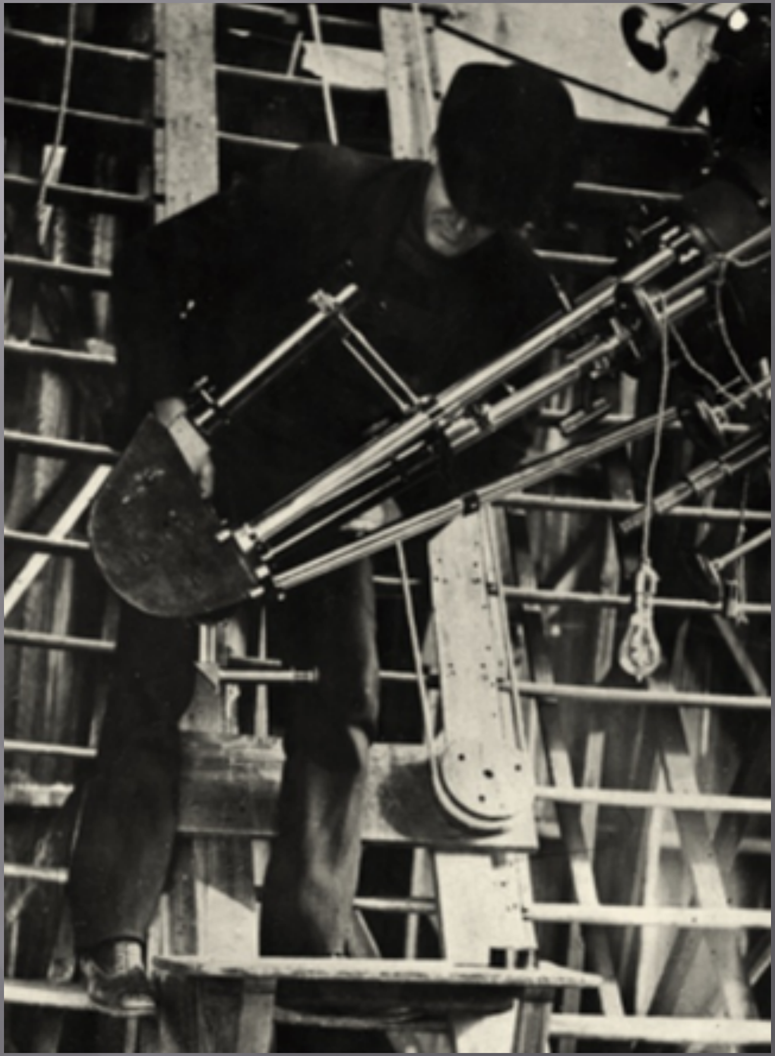
However, if you throw a Mars bar into this empty universe, you would see it seem to recede from you faster and faster.

Observer sees reddening of distant sources of light, viz., the "De Sitter effect"



Vesto Melvin Slipher, 1875-1969

Because if was wartime in 1917, few Europeans knew that in 1914 Slipher had announced that spiral nebulae possessed very high velocities, almost all of them velocities of recession.



The de Sitter effect?

Radial Velocities of Spiral Nebulae

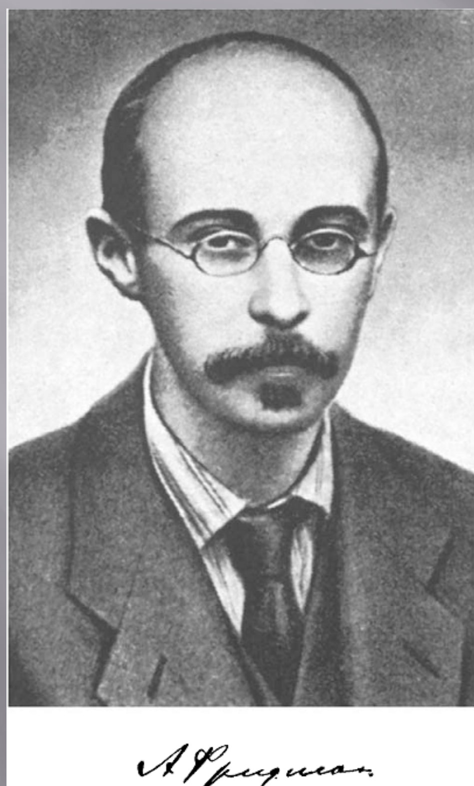
+ indicates receding, − approaching

N. G. C.	R. A. h m	Dec. ° ′	Rad. Vel. km. per sec.
221	0 38	+40 26	− 300
224*	0 38	+40 50	− 300
278†	0 47	+47 7	+ 650
404	1 5	+35 17	− 25
584†	1 27	− 7 17	+1800
598*	1 29	+30 15	− 260
936	2 24	− 1 31	+1300
1023	2 35	+38 43	+ 300
1068*	2 39	− 0 21	+1120
2683	8 48	+33 43	+ 400
2841†	9 16	+51 19	+ 600
3031	9 49	+69 27	− 30
3034	9 49	+70 5	+ 290
3115†	10 1	− 7 20	+ 600
3368	10 42	+12 14	+ 940
3379*	10 43	+13 0	+ 780
3489†	10 56	+14 20	+ 600
3521	11 2	+ 0 24	+ 730
3623	11 15	+13 32	+ 800
3627	11 16	+13 26	+ 650
4111†	12 3	+43 31	+ 800

N. G. C.	R. A. h m	Dec. ° ′	Rad. Vel. km. per sec
4151*	12 6	+39 51	+ 980
4214	12 12	+36 46	+ 300
4258	12 15	+47 45	+ 500
4382†	12 21	+18 38	+ 500
4449	12 24	+44 32	+ 200
4472	12 25	+ 8 27	+ 850
4486†	12 27	+12 50	+ 800
4526	12 30	+ 8 9	+ 580
4565†	12 32	+26 26	+1100
4594*	12 36	−11 11	+1100
4649	12 40	+12 0	+1090
4736	12 47	+41 33	+ 290
4826	12 53	+22 7	+ 150
5005	13 7	+37 29	+ 900
5055	13 12	+42 37	+ 450
5194	13 26	+47 36	+ 270
5195†	13 27	+47 41	+ 240
5236†	13 32	−29 27	+ 500
5866	15 4	+56 4	+ 650
7331	22 33	+33 23	+ 500

…the reason for interest in Solution B

Aleksandr Friedmann, 1888-1925



Friedmann, in 1922, produces his own solution

A universe with matter

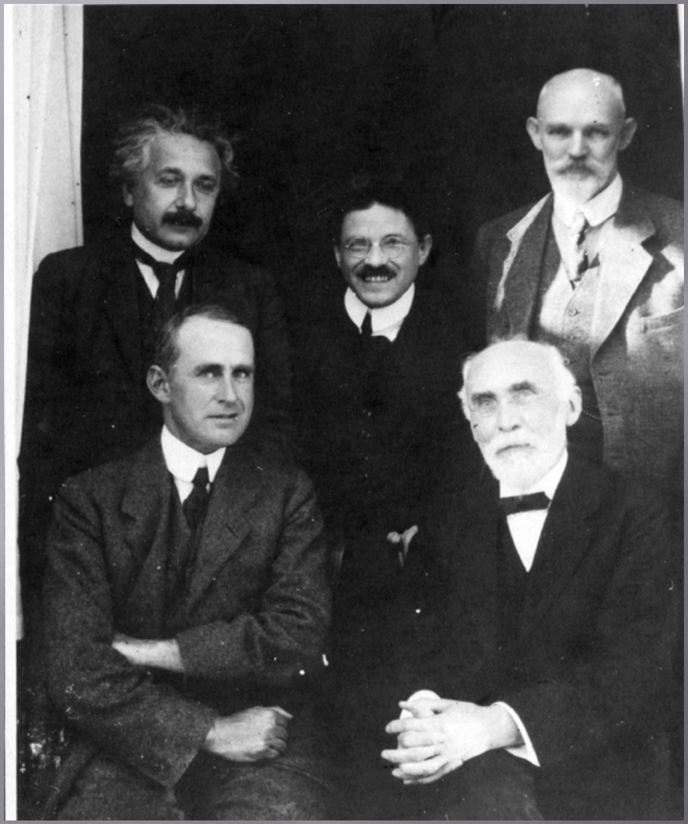
- Examination of non-stationary models of the universe
- Models that expand, contract, or oscillate

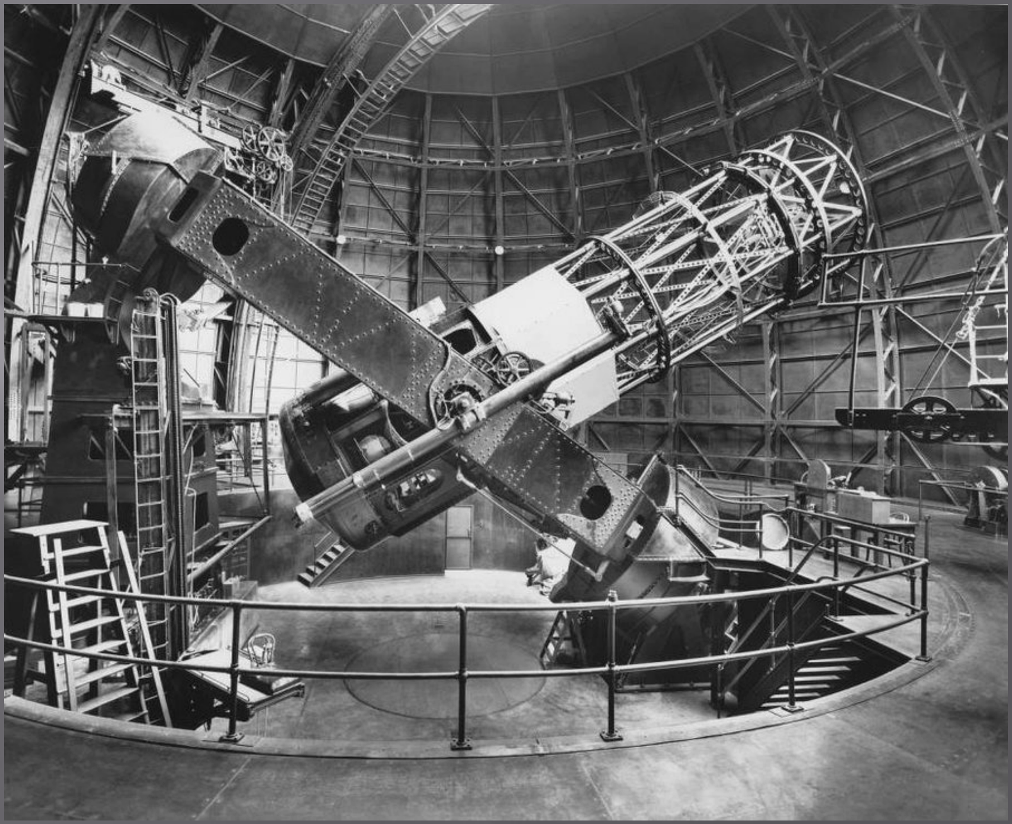
….just a mathematical exercise?

"On the Curvature of Space," *Zeitschrift für Physik (1922)*

Had Friedmann lived…, he well might have won fame as the first expounder of an expanding universe.

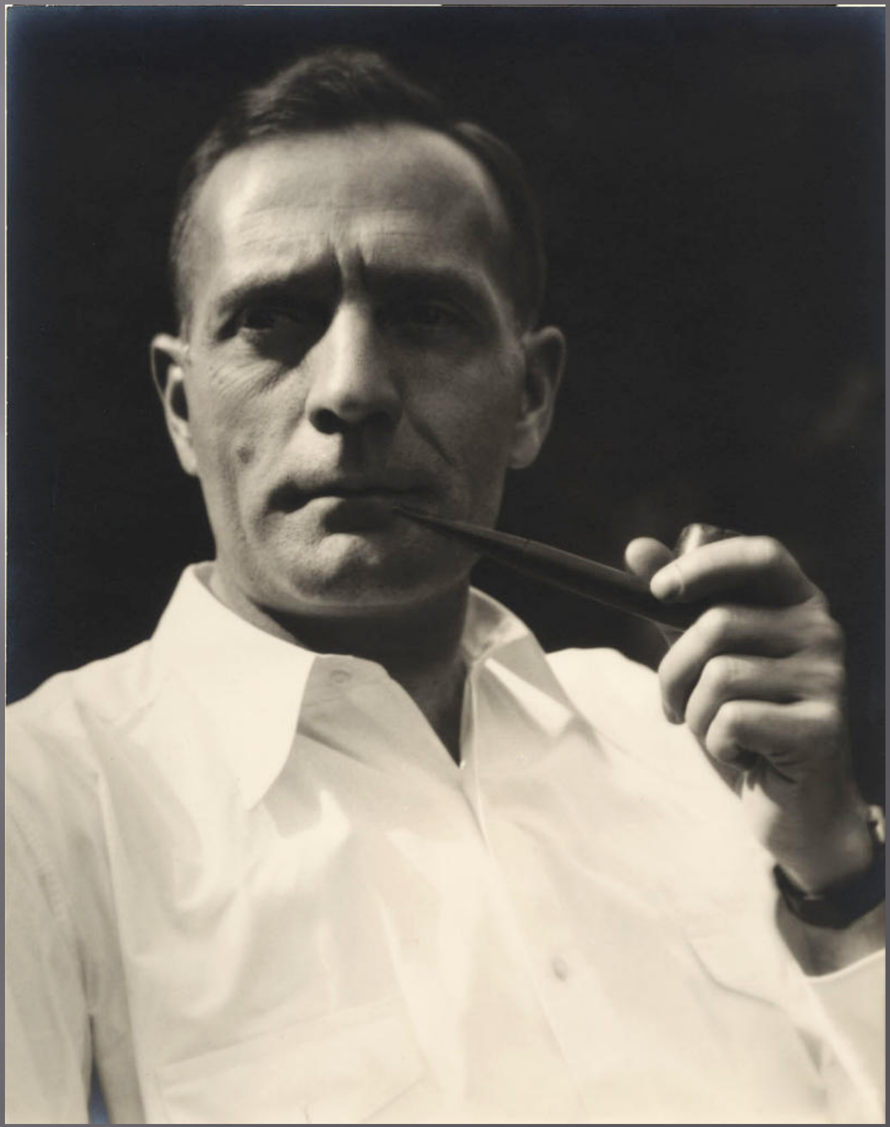
European theories | American observations





The Europeans had the theoretical experience and interest; the Americans had big telescopes and good observing conditions.

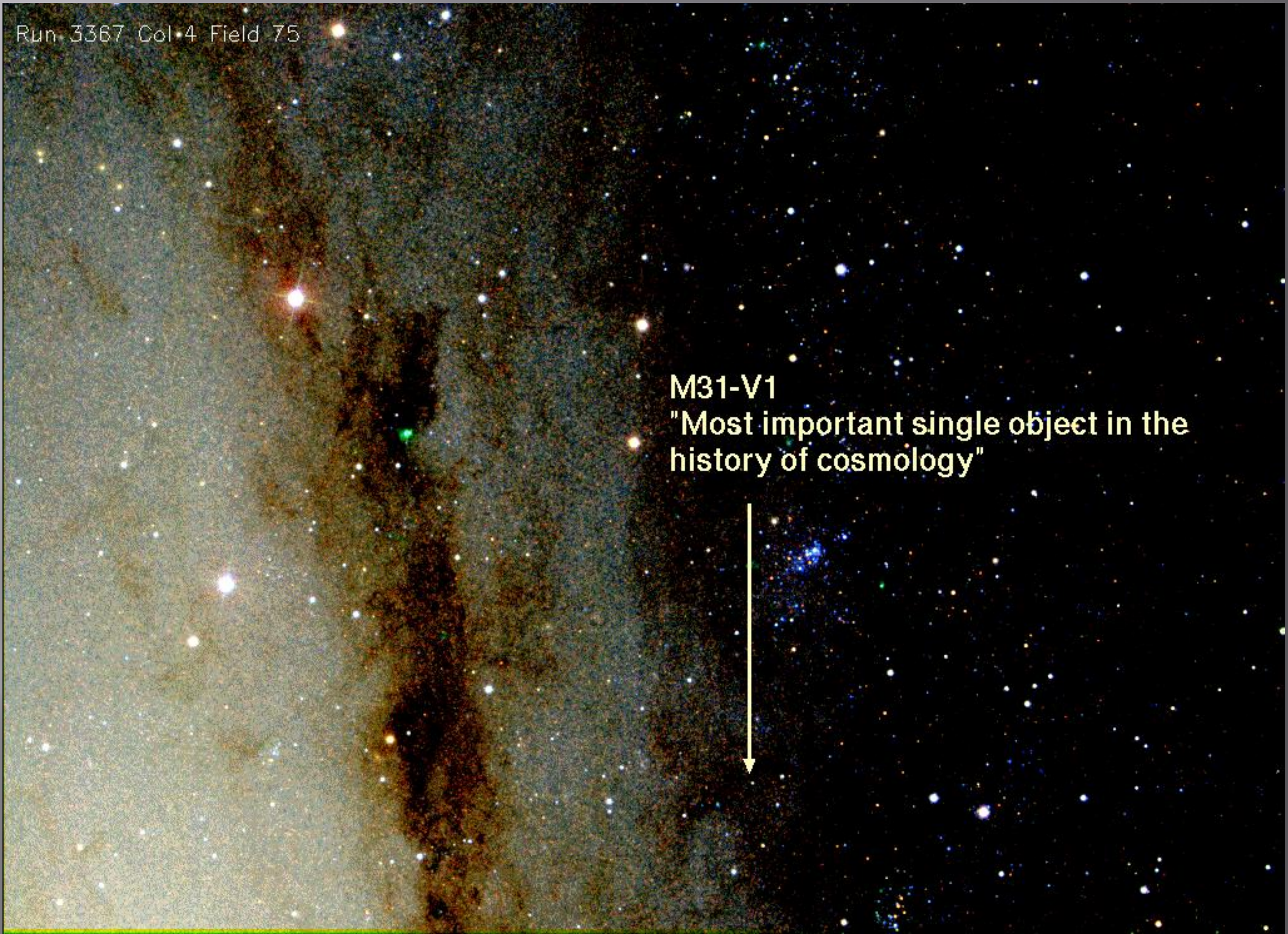
Edwin Hubble,
1889-1953



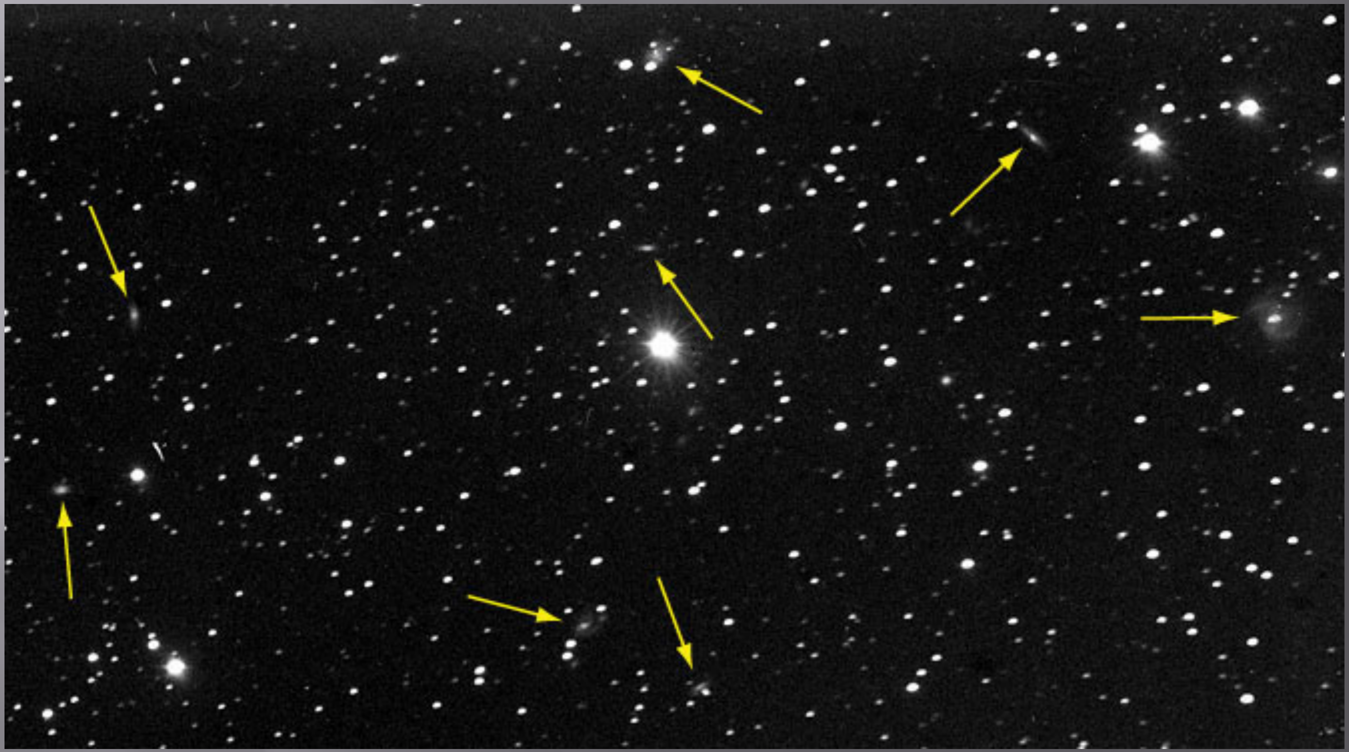
Hubble, using the great telescopes at Mt. Wilson beginning in 1919,

discovered a Cepheid variable star in the great spiral nebula in Andromeda, and this allowed him to calculate its distance, demonstrating that the spiral nebulae were separate galaxies

continued Slipher's work on the radial velocities of spiral nebulae, and, using his determinations of their distances, was able to plot a relationship between distances and velocities.

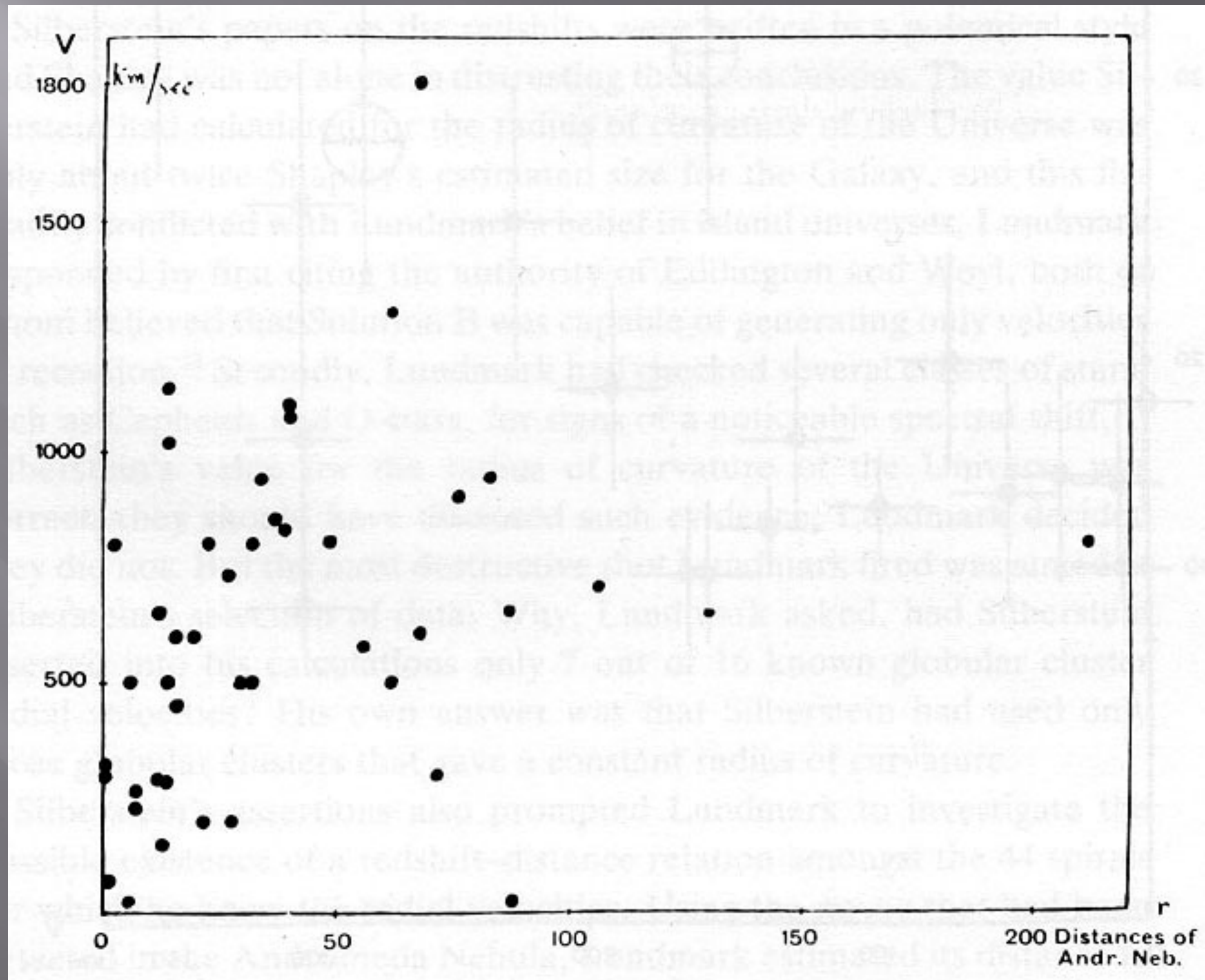

Run 3367 Col 4 Field 75
M31-V1
"Most important single object in the history of cosmology"

Studying galaxies as a way to decide between models of the universe



1924

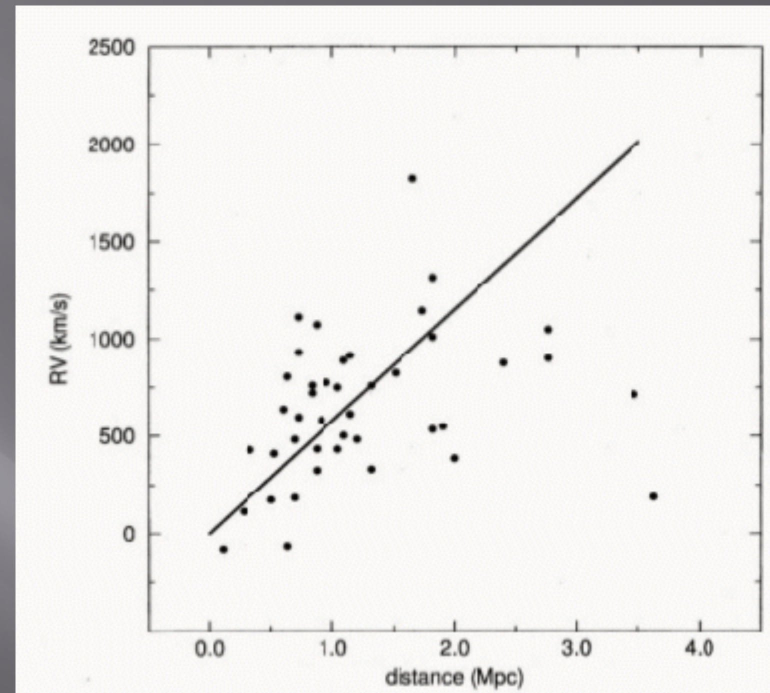
There were earlier, but premature, attempts to relate distances of spirals to their velocities, but these failed due to inaccurate distances.



Georges Lemaître,
1894-1966

Lemaître, a Belgian priest with considerable training in mathematics and physics, developed his own solutions of Einstein's equations. They were similar to Friedmann's (he did not know Friedmann's work). In 1927 he published his theory of an expanding universe, and he even drew a graph relating the velocities of spiral nebulae to their distances.

Georges Lemaître and the graph he did *not* publish



1927: re-discovery of the Friedmann universe,
an expanding universe

Annales de la Societé scientifique de Bruxelles

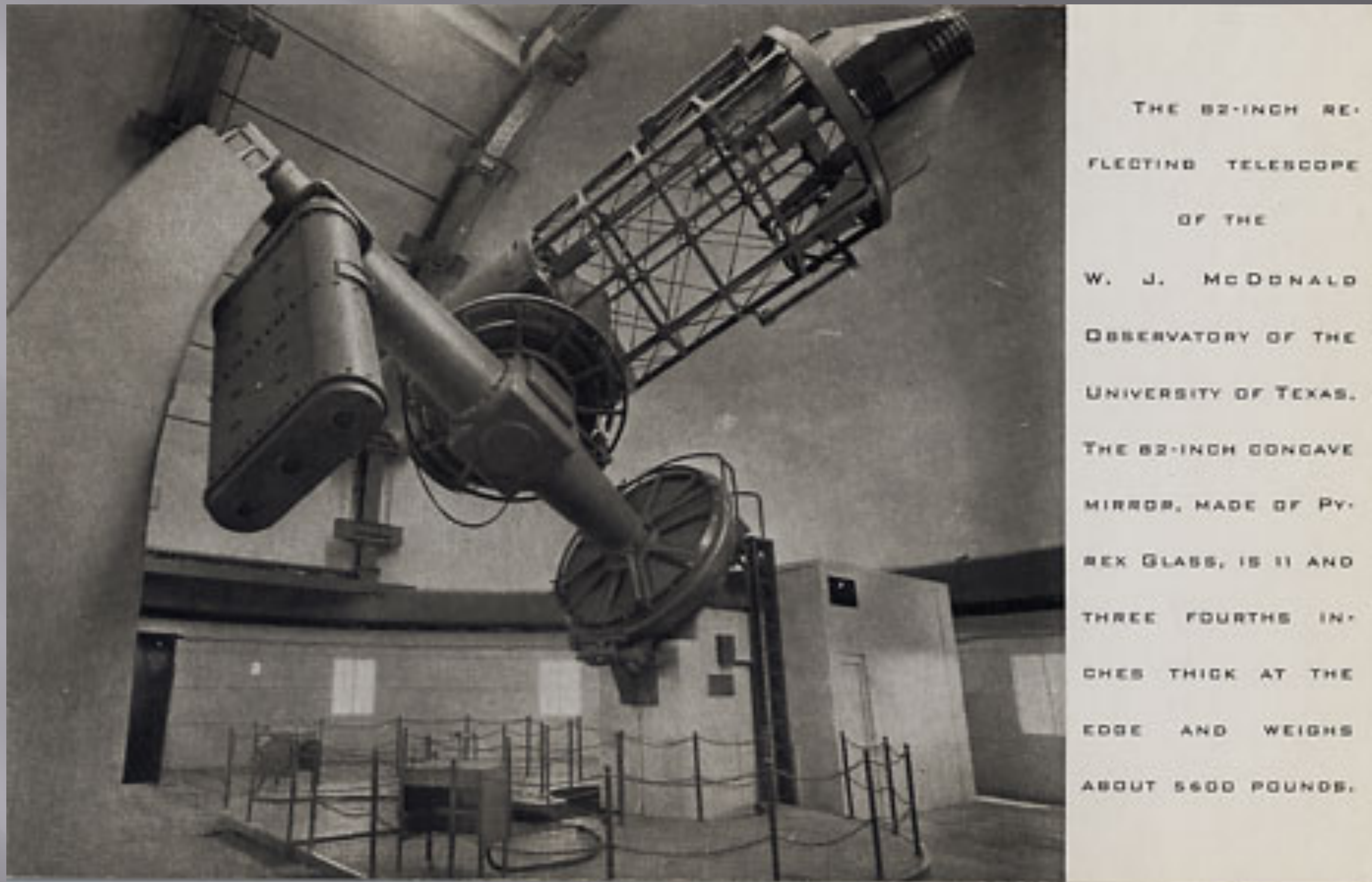
“Your calculations are correct, but your grasp of physics is abominable.”

Einstein to Lemaître in 1927. Einstein did not know of the work of Slipher or Hubble.

Edwin Hubble and Milton Humason

Humason obtained the redshifts, Hubble obtained the distances

Hubble and Humason are smiling because they had access to the biggest telescope in the world, and the somewhat smaller telescopes at less favored observatories were in use for other projects. Here is the 72” telescope in Victoria, British Columbia, dedicated to stellar spectroscopy.



Another potential competitor, dedicated however to stellar spectroscopy

Hubble and Humason, 1929

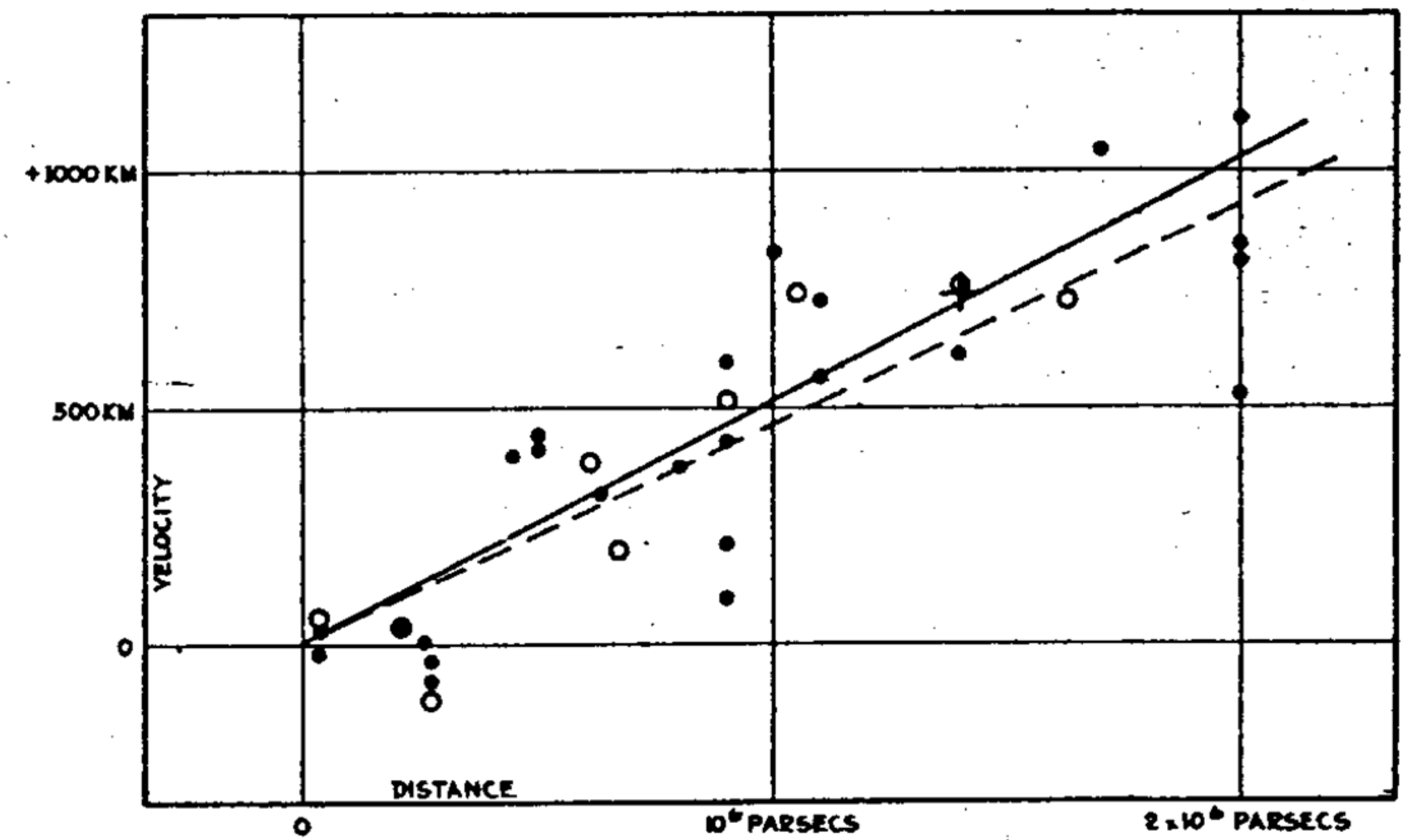
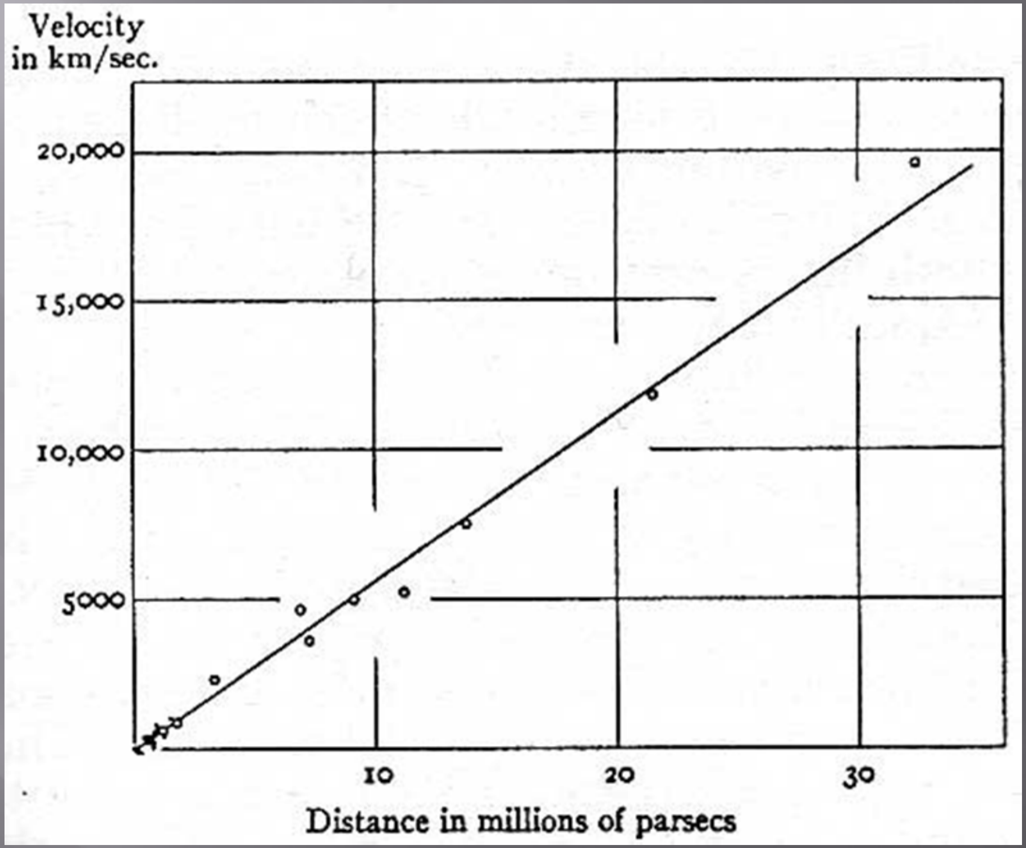


FIGURE 1

The first "Hubble Diagram" – or the second Lemaître diagram?

1931



The 1929 data are at the far lower left of the plot.

But not everybody went along on the ride of relativistic cosmology.

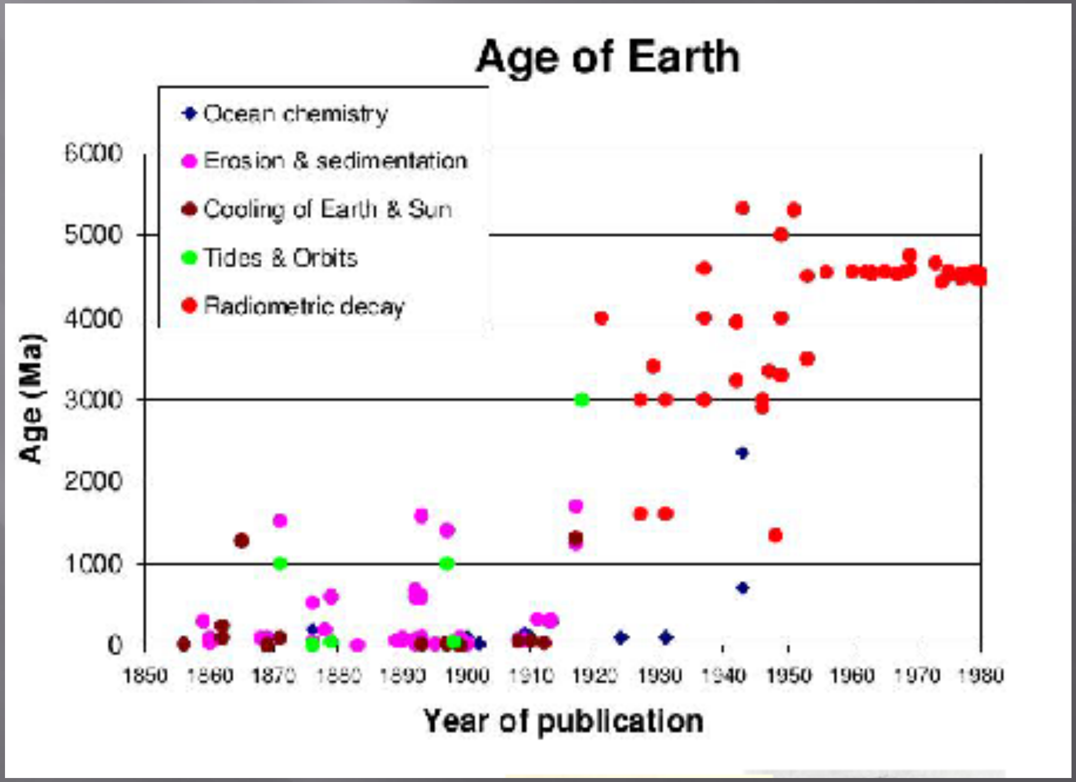
Do the redshifts reflect the de Sitter effect?

Should we speak of redshifts or actual velocities?

Is this real? Hubble always had his doubts on the matter.

Age of the universe: ~2 billion years
Age of the earth: ~3-4 billion years

The "Hubble diagram" implied an age of the universe that was younger than the earth's age!



Fritz Zwicky, 1898-1974

He suggested that the velocities of recession were not real, but that light changed frequency as it passed over long distances

The "tired light" hypothesis did not gain many followers, as it proposed a new law of physics.

However, there were doubts…the age of the universe, the strange geometries,… beginning a long night of cosmology.

Astronomers had been forced in the past to learn spectroscopy, photography, and now, to understand Einstein, they were to master tensor calculus?

And all to what effect, since there was only one telescope in the world dedicated to relativistic cosmology….

In 1930, at a London meeting, theoretical cosmologists ponder whether a static universe is possible.

Eddington: "I suppose the trouble is that people look for static solutions."

de Sitter: "It would be desirable to know what happens when we insert matter into the empty world represented by solution B."

Lemaître to Eddington: "I just read….your suggestion. I made these investigations two years ago."

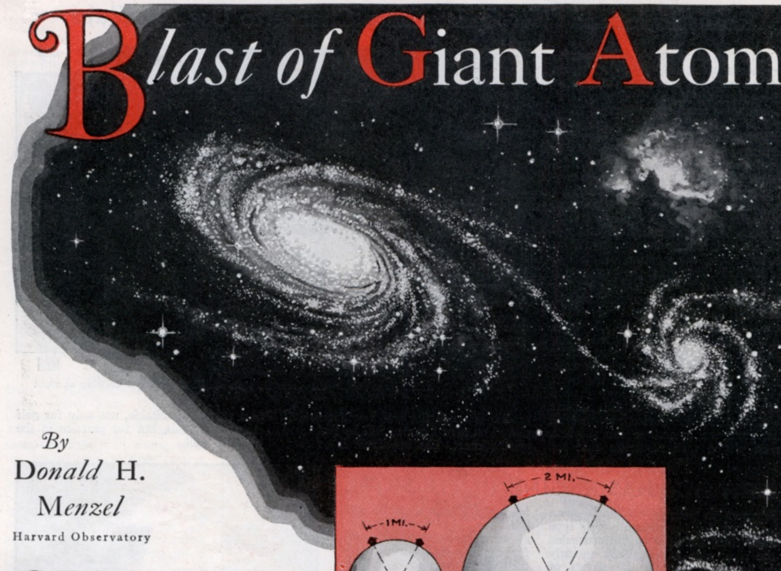
1931: the expanding universe

Eddington publicizes Lemaître's work, and the expanding universe becomes a "standard" model the universe in the form of a unique atom whose atomic weight is the total mass of the universe. This highly unstable atom ~~xx~~ would divide in smaller and smaller atoms by a kind of super-radioctive process. Some rest of this process would, according to Sir Jeans idea, foster the heat of the stars until our low atomic number atoms may allow live to be possible.

Clearly the initial quantum could not conceile in itself the whole course of evolution; but, according to the indetermination principle, that is not necessary. Our world is now a world where something happens; the whole story of the world does not need to be written down in the first quantum as a song on the ~~x~~ disc of a phonograp. The whole matter of the world must be present at the beginning, but the story it has to tell may be written step by step.

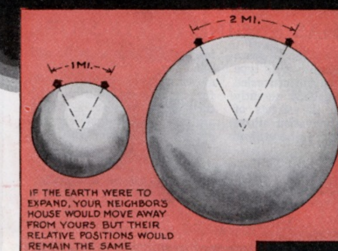
I think that every one who believes in a supreme being supporting avery being and every acting, believes also that God is essentially hidden and may be glad to see how present physics provides a veil hiding the creation.

Blast of Giant Atom



By
Donald H.
Menzel

Harvard Observatory



IF THE EARTH WERE TO EXPAND, YOUR NEIGHBOR'S HOUSE WOULD MOVE AWAY FROM YOURS BUT THEIR RELATIVE POSITIONS WOULD REMAIN THE SAME

OUT of a single, bursting atom came all the suns and planets of our universe!

That is the sensational theory advanced by the famous Abbe G. Lemaître, Belgian mathematician. It has aroused the interest of astronomers throughout the world because, startling as the hypothesis is, it explains many observed and puzzling facts.

According to Lemaître's theory, all the matter in the universe was once packed within a single, gigantic atom, which, until ten thousand millions years ago, lay dormant. Then, like a sky-rocket touched off on the Fourth of July after having remained quietly for months on a store shelf, the atom burst, its far-flung fragments forming the stars of which our universe is built.

The manner in which certain kinds of atoms explode can be seen easily in a simple experiment. If you take a radium watch into a dark room and look at the dial through a magnifying glass, you see what appears to be a brilliant display of miscroscopic fireworks. While you are looking at the showering sparks, remember that each flash comes from an exploding atom. In each spark, you see a small-scale reproduction of the new theory of the birth of our universe.

On the average, every radium atom lies dormant for about 1,730 years, after which time it explodes and shoots out particles in much the same way as the parent atom gave birth to the stars.

The new theory provides an explanation for one of the most extraordinary scientific facts ever discovered. Our telescopes show us that there are, out in space, millions of disk-shaped star-clusters known as extra-galactic nebulae. It is generally believed that our Milky Way is such an object and that our sun is but one of billions of stars that go to form it. One of the larger members of the class, the spiral nebula in Canes Venatici, is so far away that light from it takes almost a million years to reach us. Furthermore, observations indicate that every second it moves still farther away from our solar system by some 170 miles.

For every large, bright nebula there are thousands of small, faint, and presumably much more distant ones. Surveys out to one hundred million light years are in progress. The extraordinary feature referred to above is not, however, the magnitude of the figures, but the discovery that the more distant the nebula the more rapid is its motion *in a direction away from us!* The present record-holder is a tiny nebula whose cosmic speedometer registers in excess of twelve thousand miles a second!

Why, astronomers have asked, are the

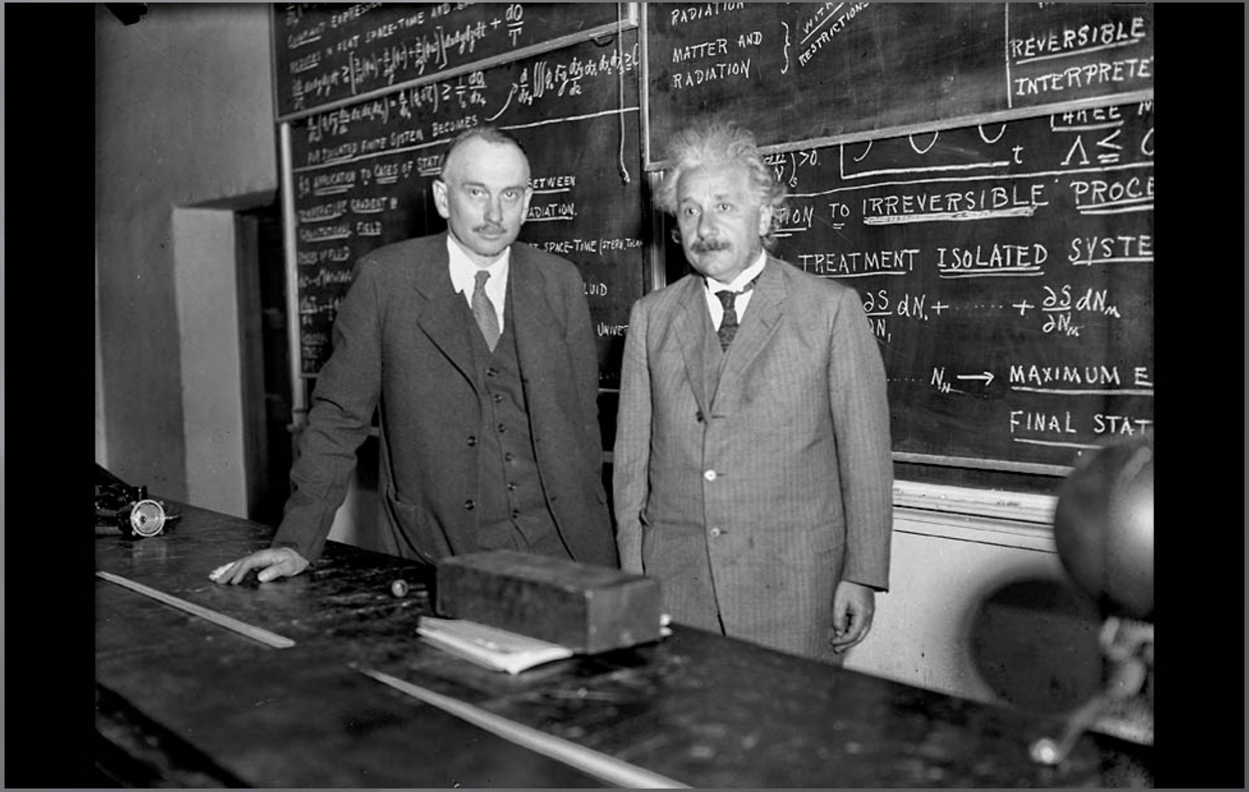
YOU CAN SEE AN ATOM BOMBARDMENT IF YOU LOOK AT THE NUMERALS ON A RADIUM DIAL WATCH UNDER A MAGNIFYING GLASS IN THE DARK

1931 An international gathering at Cal Tech

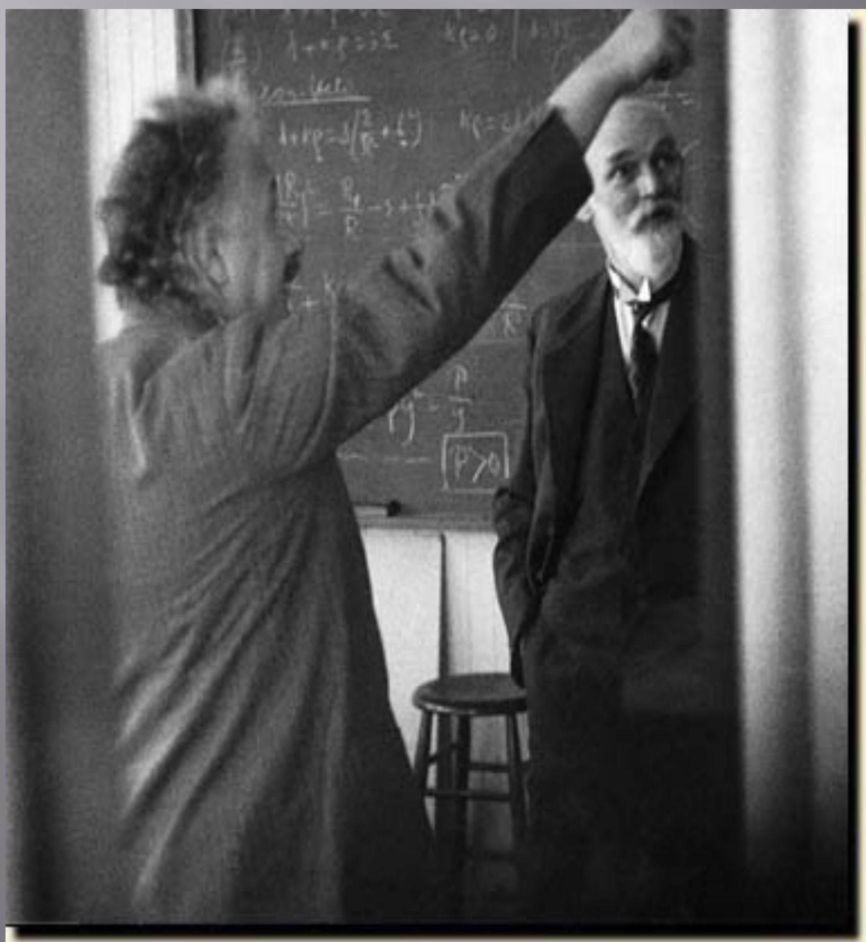
Einstein and Hubble meet, and Einstein learns of the observational evidence.

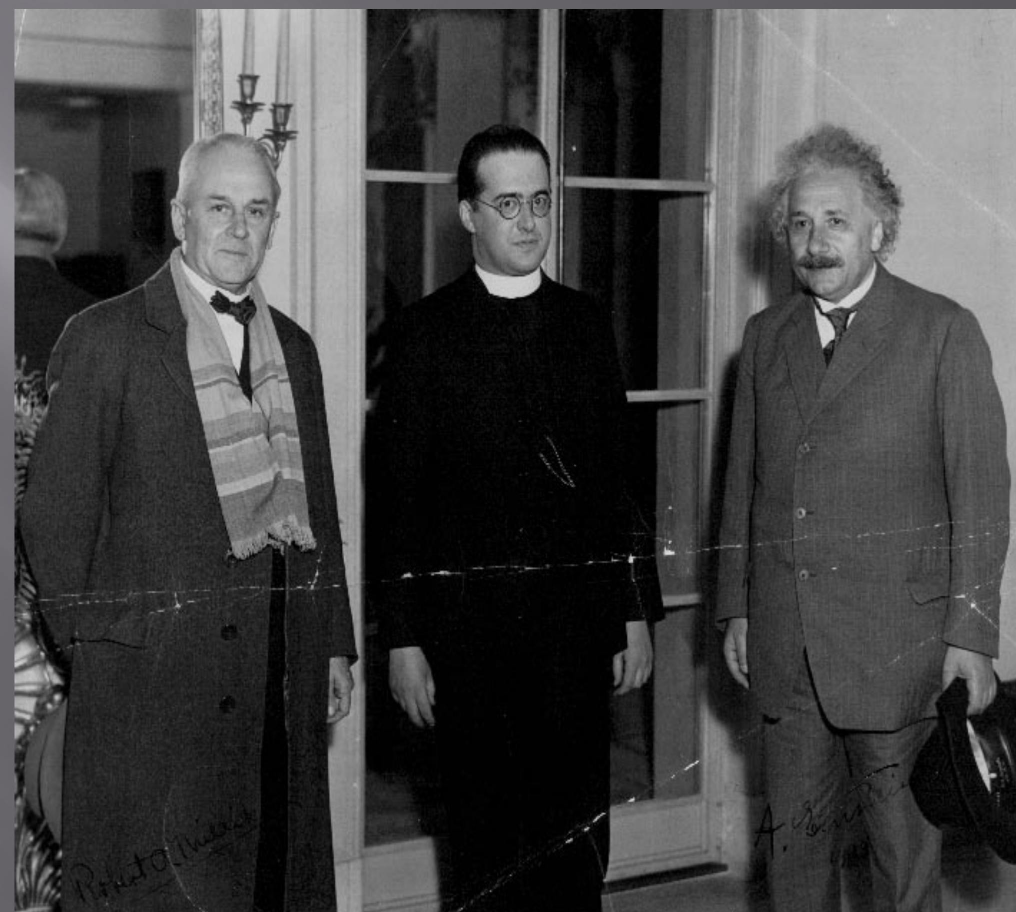
Richard C. Tolman and Einstein

Because Tolman spoke German well and knew the theory of general relativity well, he helped to convince Einstein.



De Sitter and Lemaître also came to Cal Tech, and they developed an expanding universe model.






M.L. Humason
Edwin Hubble
A. Einstein
W.W. Campbell
W.S. Adams

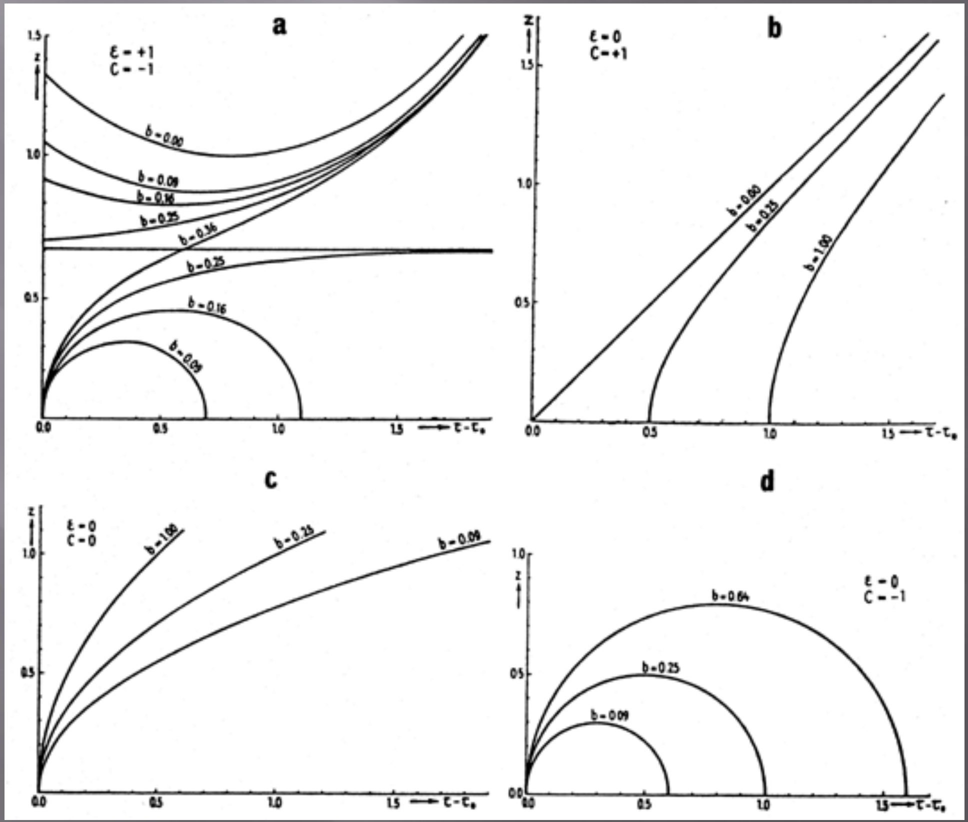
Nevertheless, the “long night” of relativistic cosmology was beginning. Why?

Otto Heckmann

Arthur Milne

1932: alternative solutions of the equations appear…

Otto Heckmann published no fewer than twelve solutions. How were astronomers to choose between expanding, oscillating, and different philosophies of relativity?



Hubble's doubts (?)   Does redshift mean velocity?

Lack of instrumentation

Nobody else had big telescopes.

Minute effects as measured by the three tests

Others: why bother?

Not our circus, not our monkeys….

1938 American Astronomical Society meeting in Ann Arbor. Heber Curtis at far left. An early champion of the notion that spirals were galaxies.

However, Curtis had attempted to measure, without success, displacement of starlight at a solar eclipse.

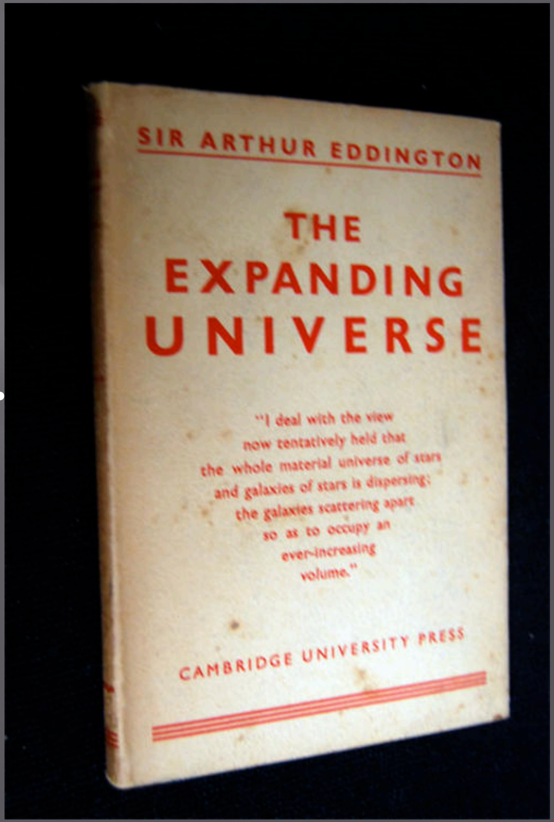
Curtis 1938, “Lessons on Cosmogony”

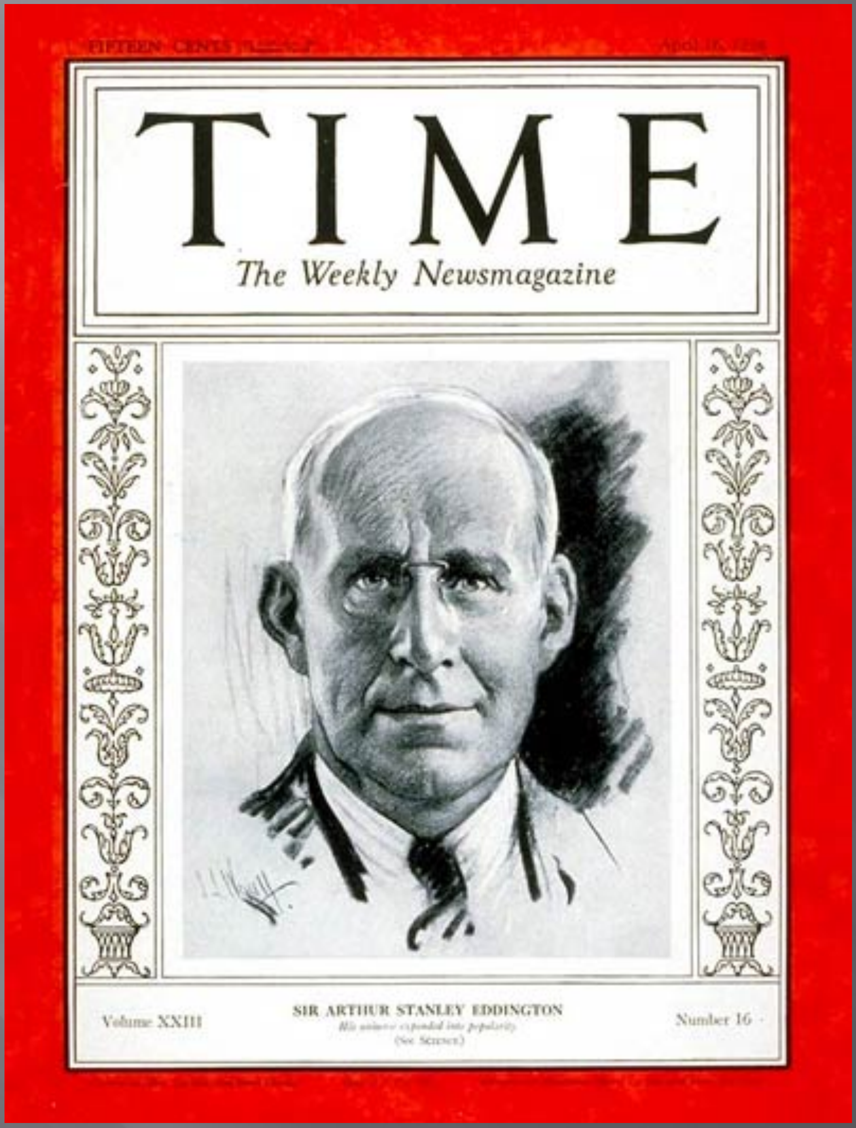
a. Alternate calculations of the precession of the perihelion of Mercury.
b. Solar eclipse measurements have been “divinely inspired.”
c. Too much static in the derived values of relativistic redshift in the solar spectrum.

Too many solutions.
Unnecessary geometry.
Eddington “credulous.”
Age of the earth.

Eddington, who had measured the deflection of starlight at the 1919 eclipse, wrote a famous book, still in print, about relativity and the expanding universe.

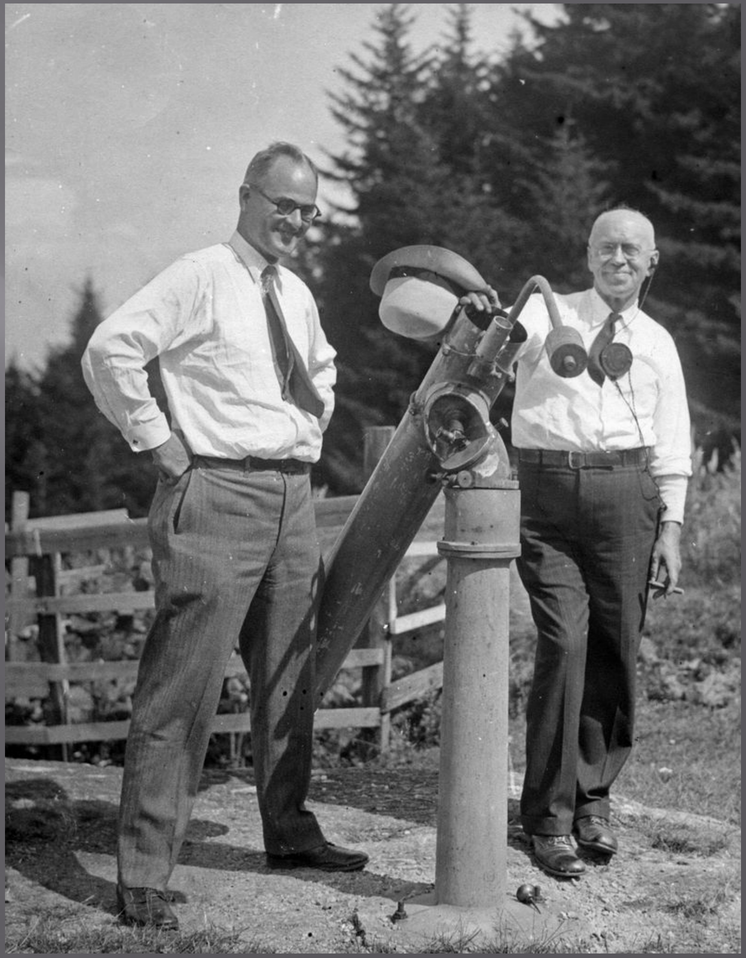
But it was hard to read and contained some very strange philosophical notions, unique to Eddington.



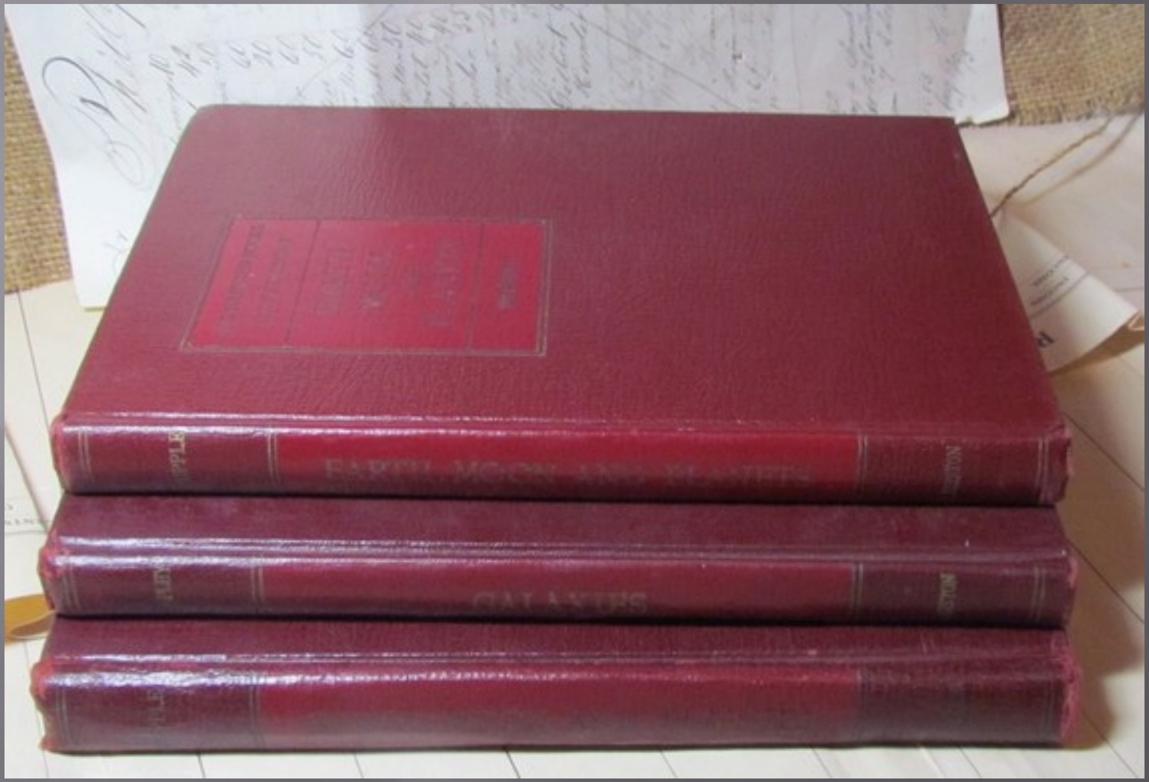

FIFTEEN CENTS
TIME
The Weekly Newsmagazine
Volume XXIII
SIR ARTHUR STANLEY EDDINGTON
His universe expanded into popularity
(See Science)
Number 16

Dinsmore Alter of the Griffith Observatory, here with Alfred Hitchcock, left the whole matter out of his own textbook.

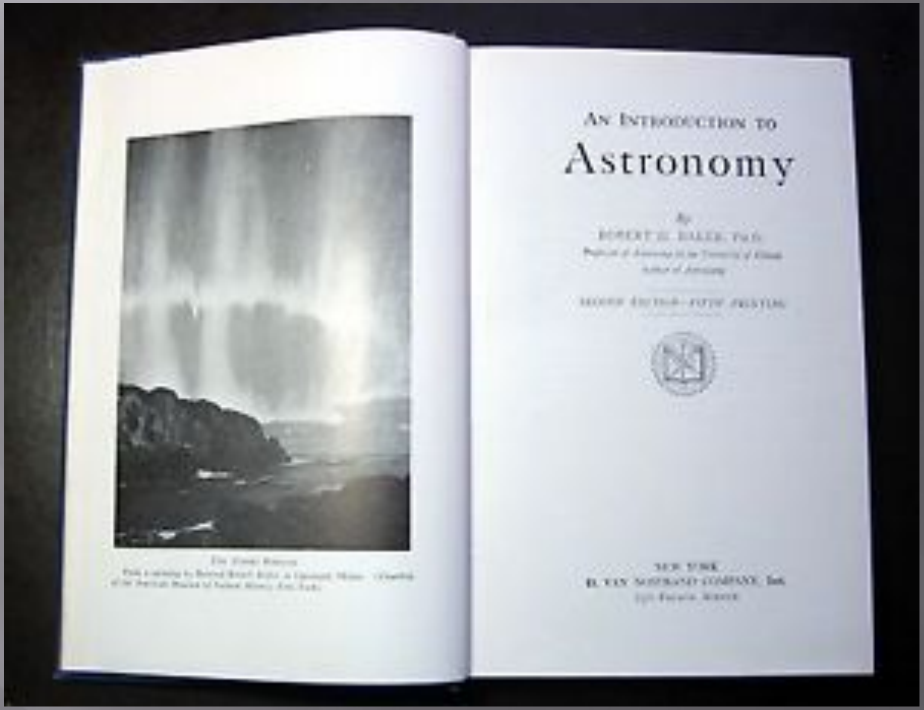
Albert Ingalls of the *Scientific American*, editor of the telescope making column and book reviewer, left cosmology out of his recommendations.



The Harvard Books on Astronomy, a very popular series for the educated public, was supposed to have a volume on relativity and cosmology, -- but it was soon cancelled.

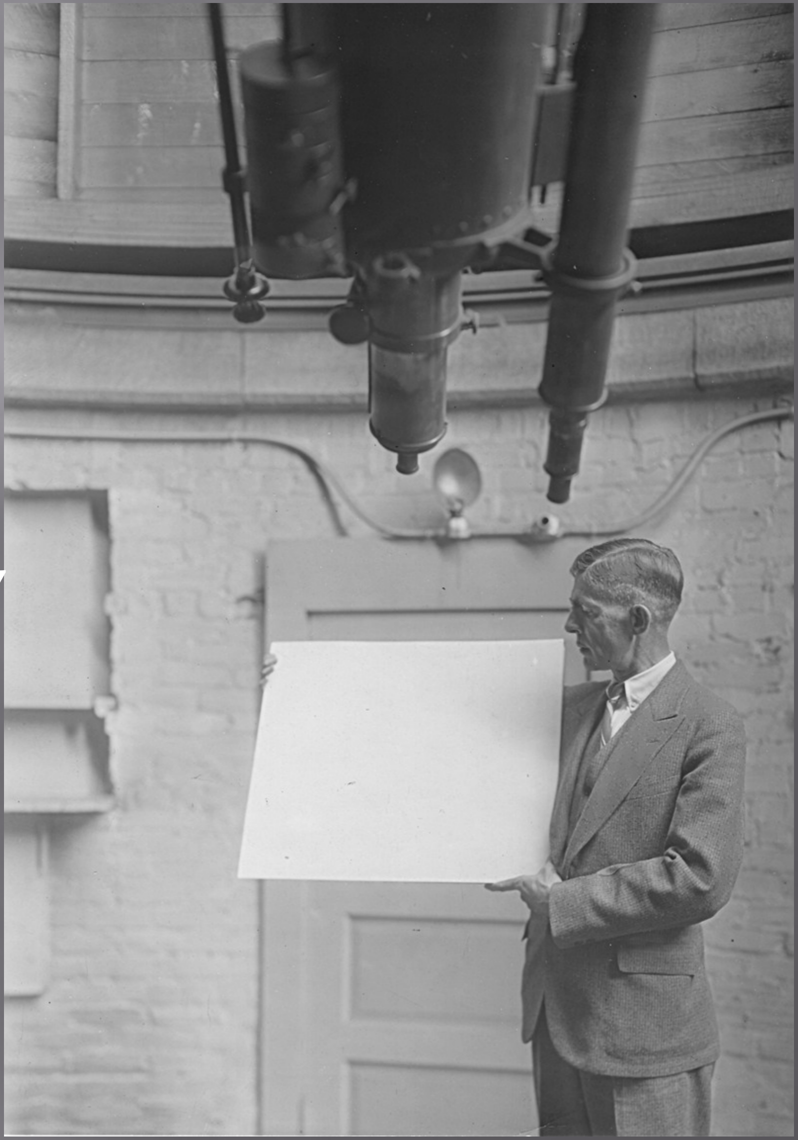


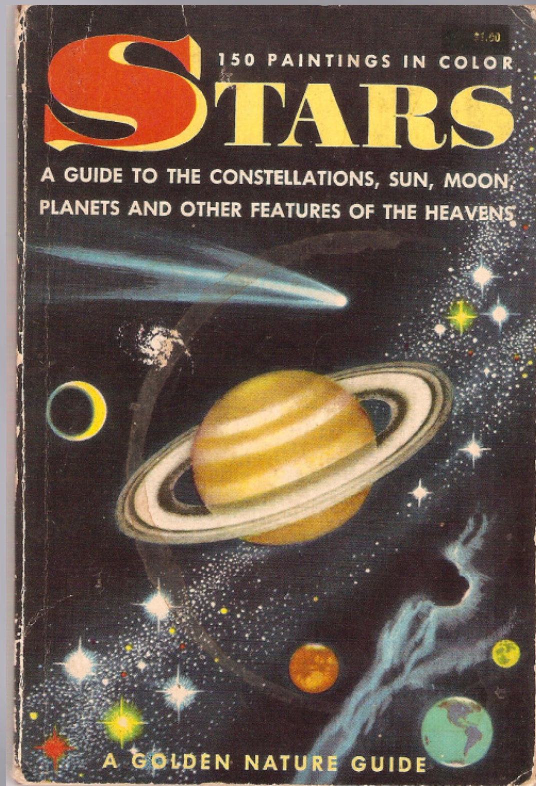
The best-selling astronomy textbook, 1930-1965



Robert H. Baker

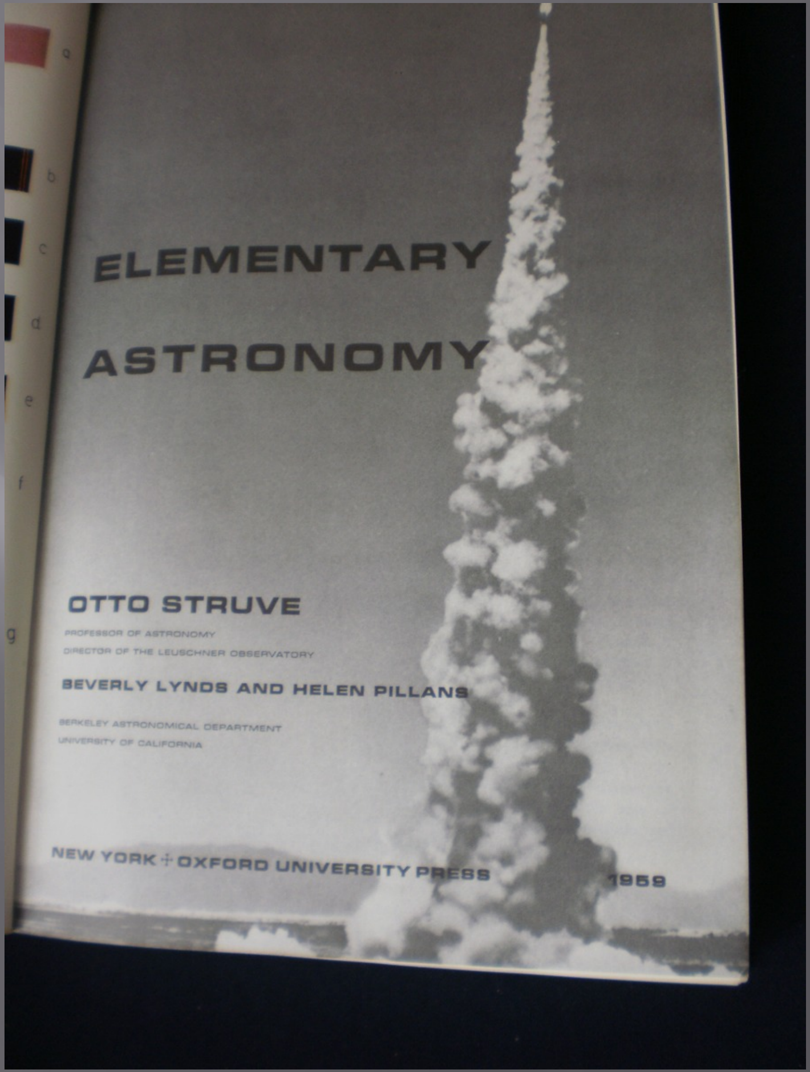
Baker wrote the best selling textbooks over the era from 1937 to 1964: only a page on the subject.





Zilch in the best-selling popular book

In a standard text of 1960, only a page or so on the "expansion," but nothing on the cosmology.

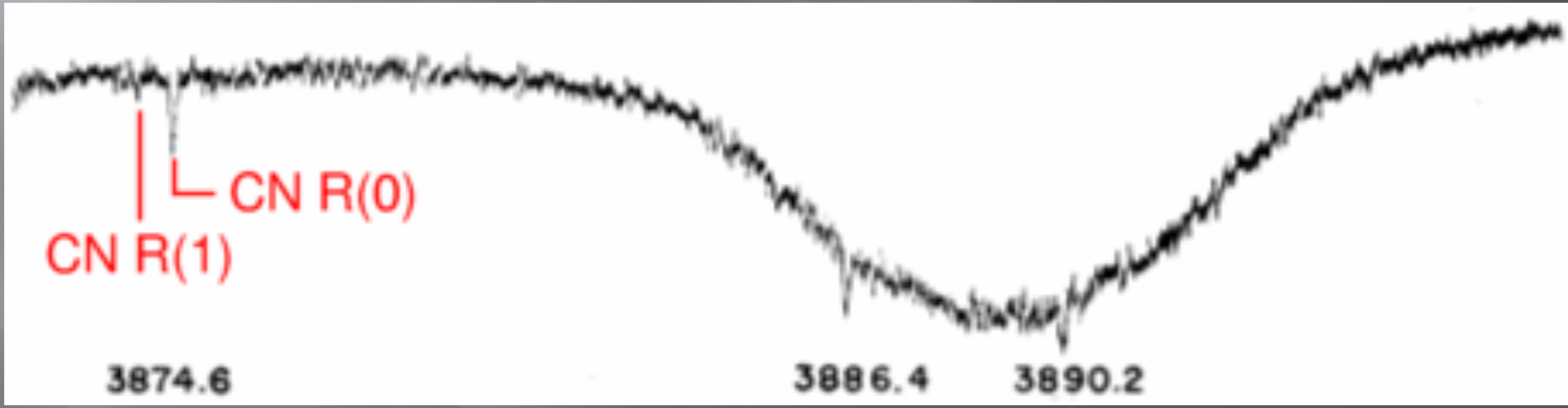


..only one glimmer in the night

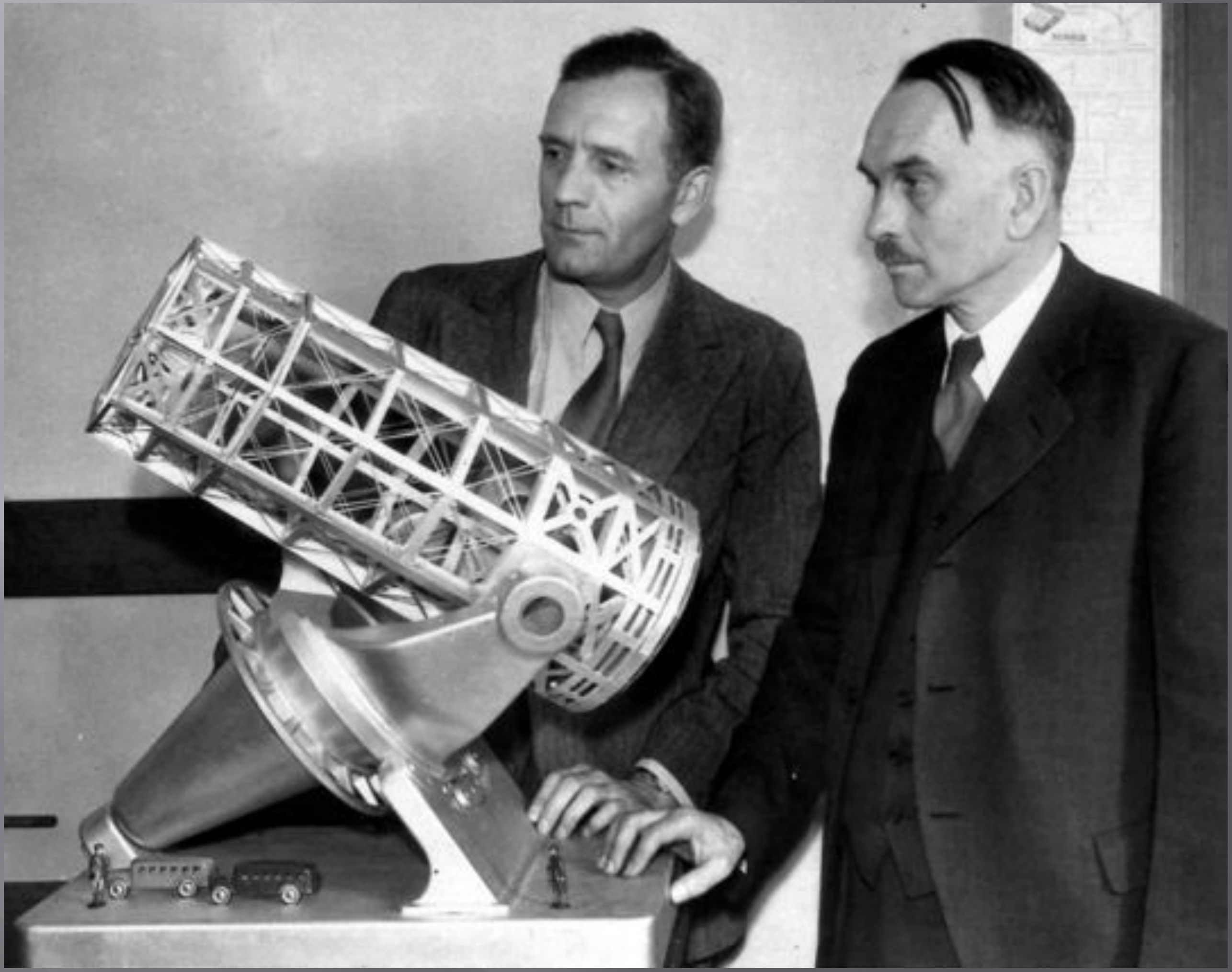
On the right: Andrew McKellar of the Dominion Astrophysical Observatory in Victoria, B.C., with the 72" mirror. McKellar was interested in stellar spectra and in interstellar clouds.

Zeta Ophiuchi: in 1938 McKellar examined the spectrum of this star and the absorption lines in the spectrum from the cloud of gas and dust lying between us and the star.

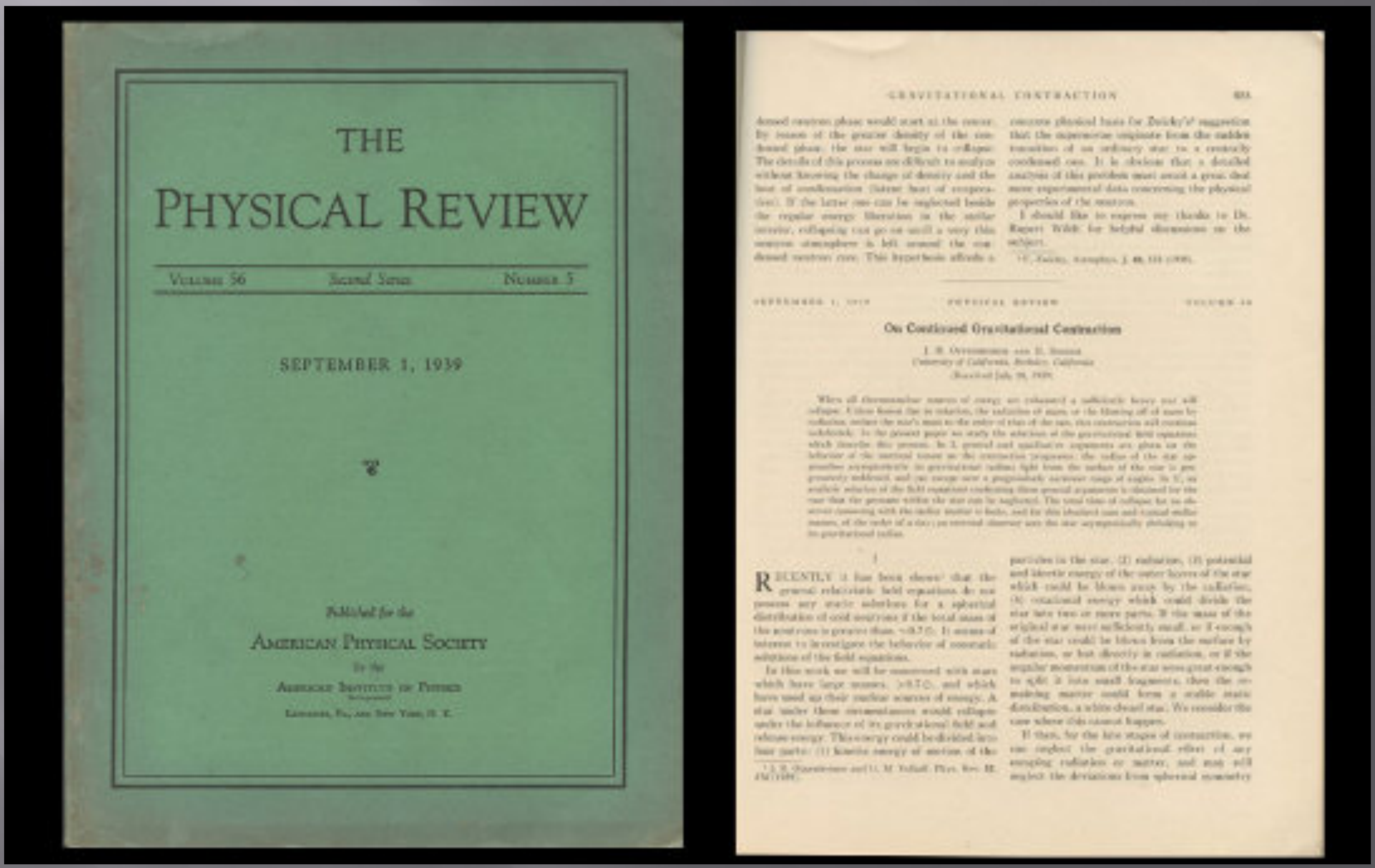
McKellar noticed the presence of Cyanogen in the interstellar cloud; but he also noticed the less intense line of Cyanogen in a state of excitement, due to a temperature of a few degrees above absolute zero. He could not explain the temperature. We now know that it represents the remnant of the Big Bang.



Here, in the late 1930s, are Hubble and Tolman in front of a model of the 200″ telescope, whose construction was suffering delay after delay.

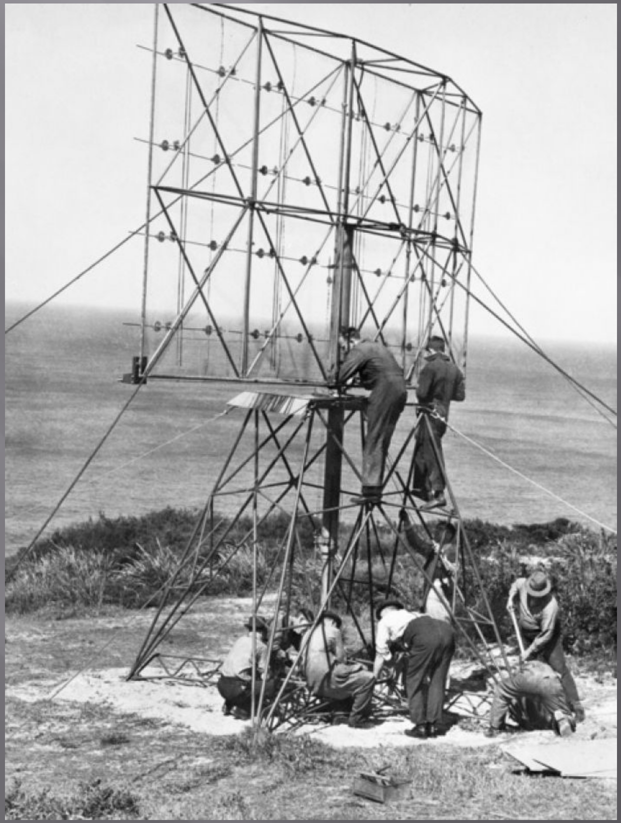


An article about what we now know as Black Holes, classic relativistic phenomena. The author might have been expected to continue: but note the date: the outbreak of war.



The article's author, J. Robert Oppenheimer, became sidelined with war work and ended up leading the scientific team that built the first atom bomb.

Another glimmer: the development of radar in World War II led to the growth of radio astronomy. In the next slide, a gathering of Australian radio astronomers, all former radar specialists. Note the sole woman.



Also as a wartime development, two new cosmological theories.

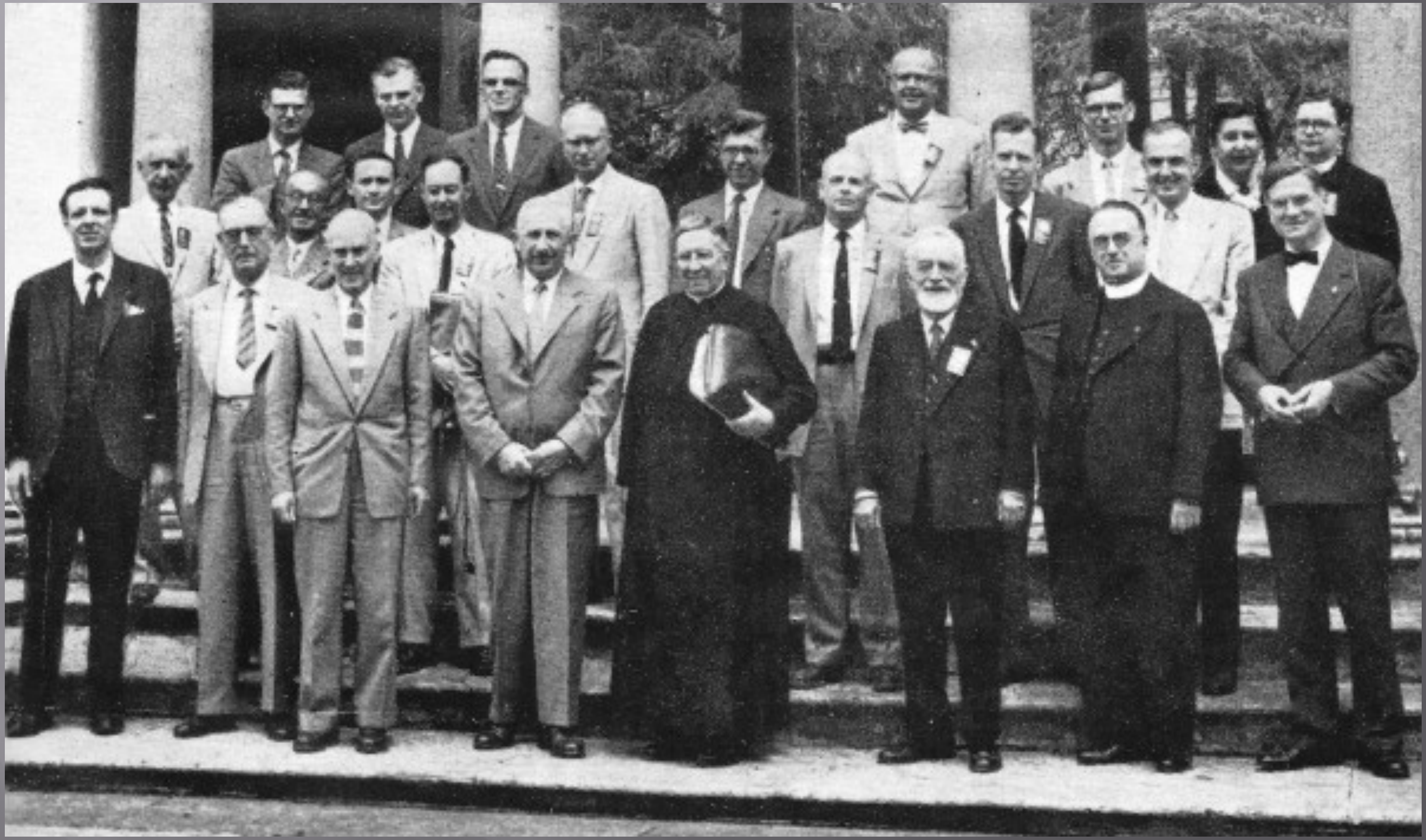
1. A “hot” Big Bang, to explain the observed abundance of elements. In this theory, there would be a remnant radiation from the original heat, perhaps a few degrees above absolute zero… but how to measure it?
2. The notion of a steady state universe, whose expansion involves the continuous creation of new matter.

Robert Hermann, George Gamow, Ralph Alpher
1946
a hot big bang, a remnant radiation, a few degrees K

Thomas Gold, Hermann Bondi, Fred Hoyle: the steady state, continuous creation theory

The night begins to end….

In 1950, Baade, with the Mount Wilson instruments, recalibrates the distance scale, and ends up making the universe older than the earth. Whew!



Walter Baade

Charles and Harold Lower of 1032 Pennsylvania St., San Diego

These amateurs helped to perfect the survey instruments on which Baade depended.


Isn't this a better photo of Lower? At bottom

The San Dieg

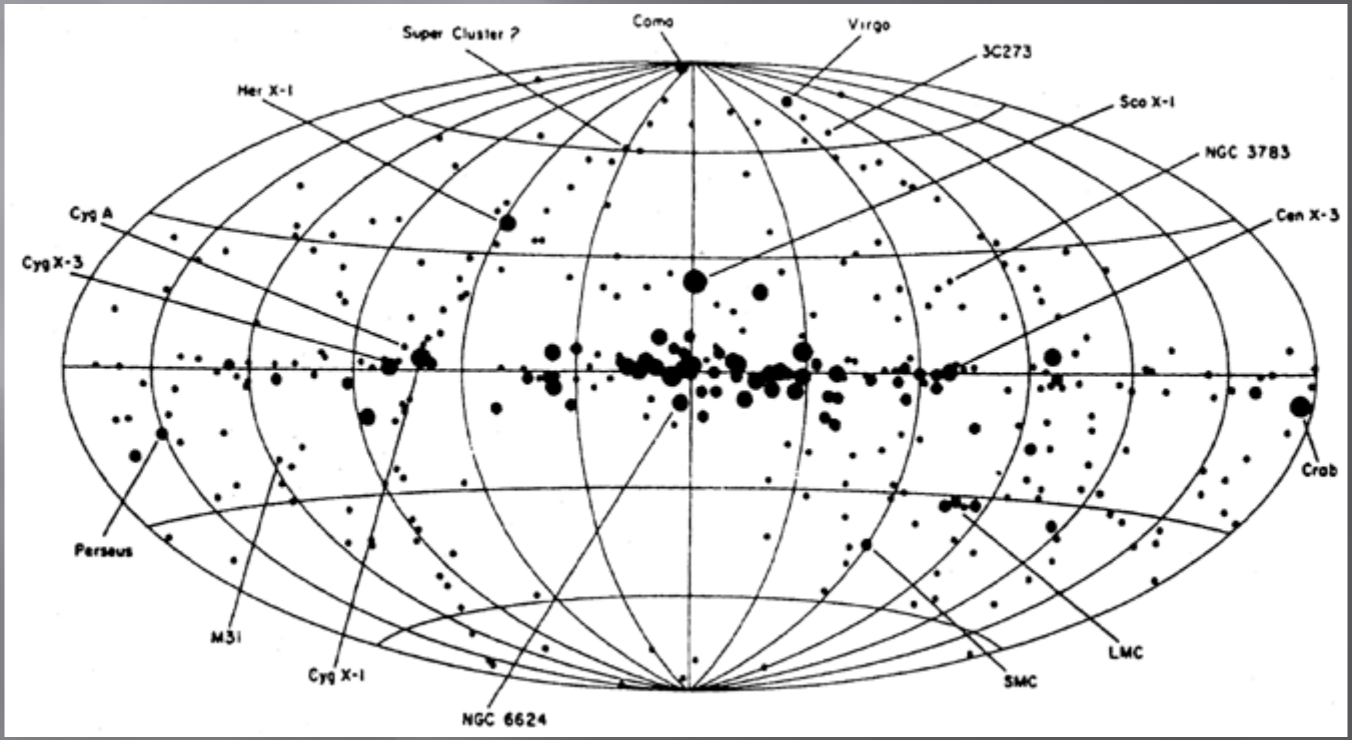
SAN DIEGO, MONDAY, MAY 28, 1934

Star-Gazing Brings Back Fleeting Health

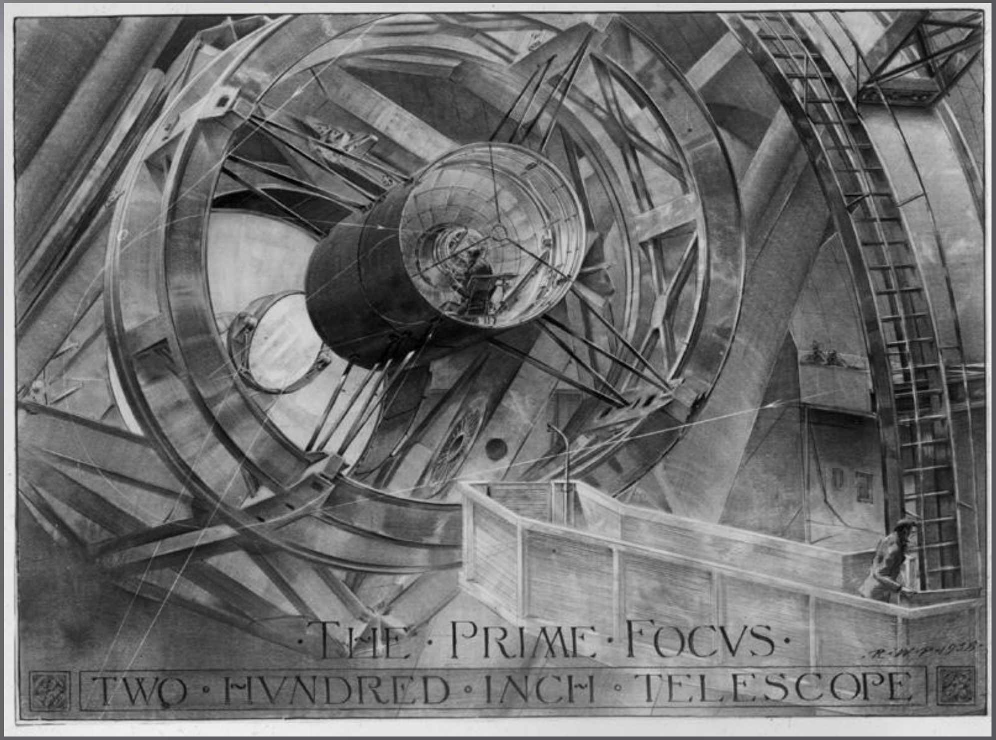
I wrote this newspaper for it, but newspapers never answer letters

Star-gazing in the family backyard has brought health, scientific recognition, and father-son camaraderie to Charles A. Lower, left, and Harold Lower, right (and insert). Insert at the left is a picture of the moon, showing the type of detailed work possible with the long Cassegrainian, and shorter Newtonian, 12-in. reflecting telescopes built by the Lowers.

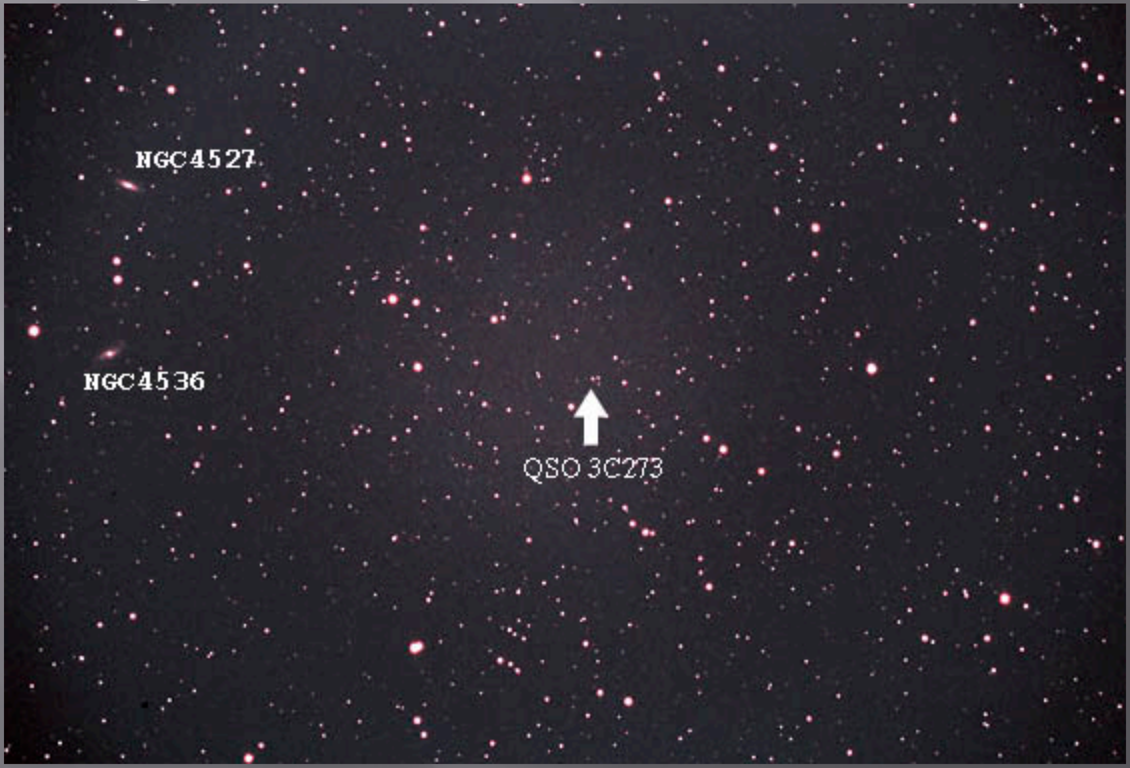
In the late 1950s and early 1960s, surveys with radio telescopes located peculiar objects of very small size emitting enormous amounts of radiation: termed quasi-stellar objects, or quasars.

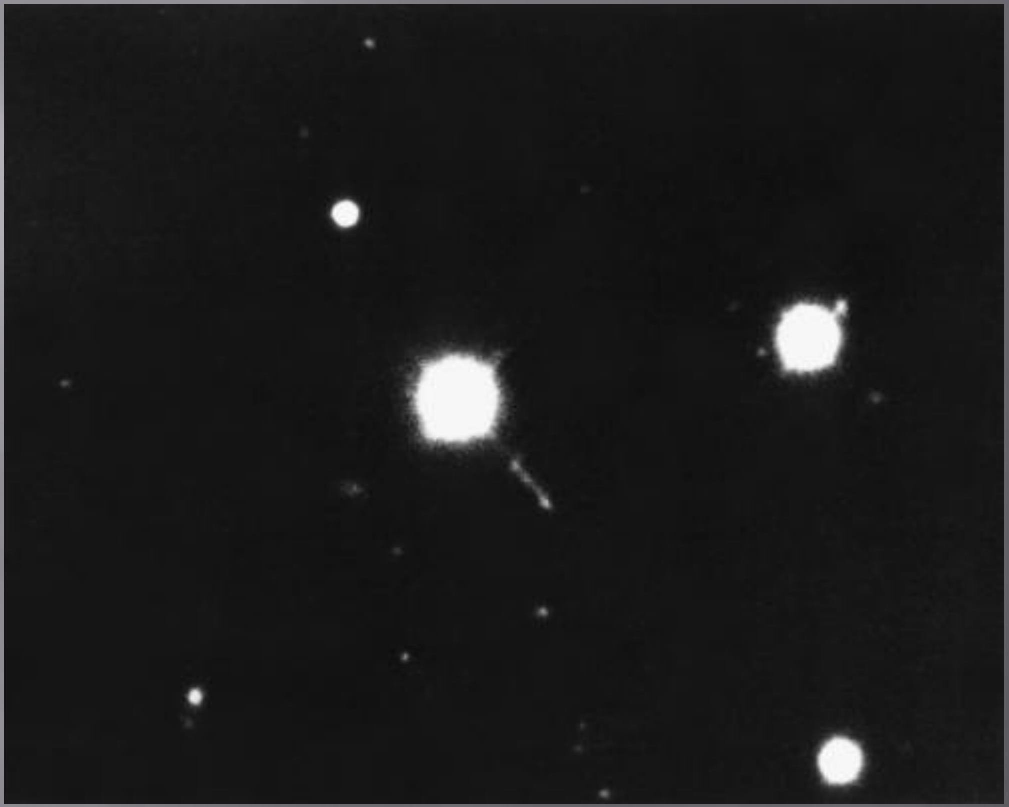


1963: rebirth



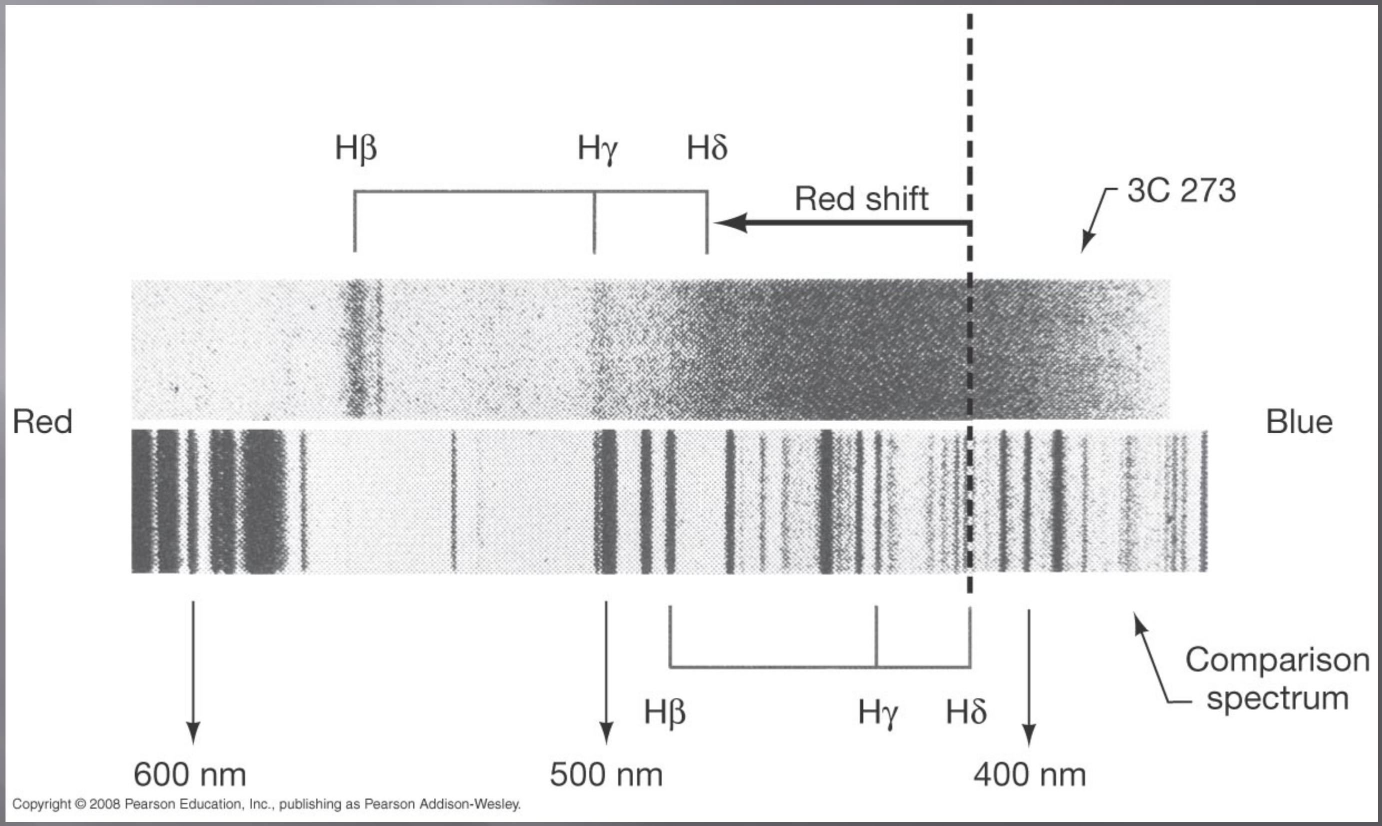
The Parkes radio telescope in Australia provided general locations for a few of these QSOs, and the 200″ Palomar telescope provided photographs and spectrograms.



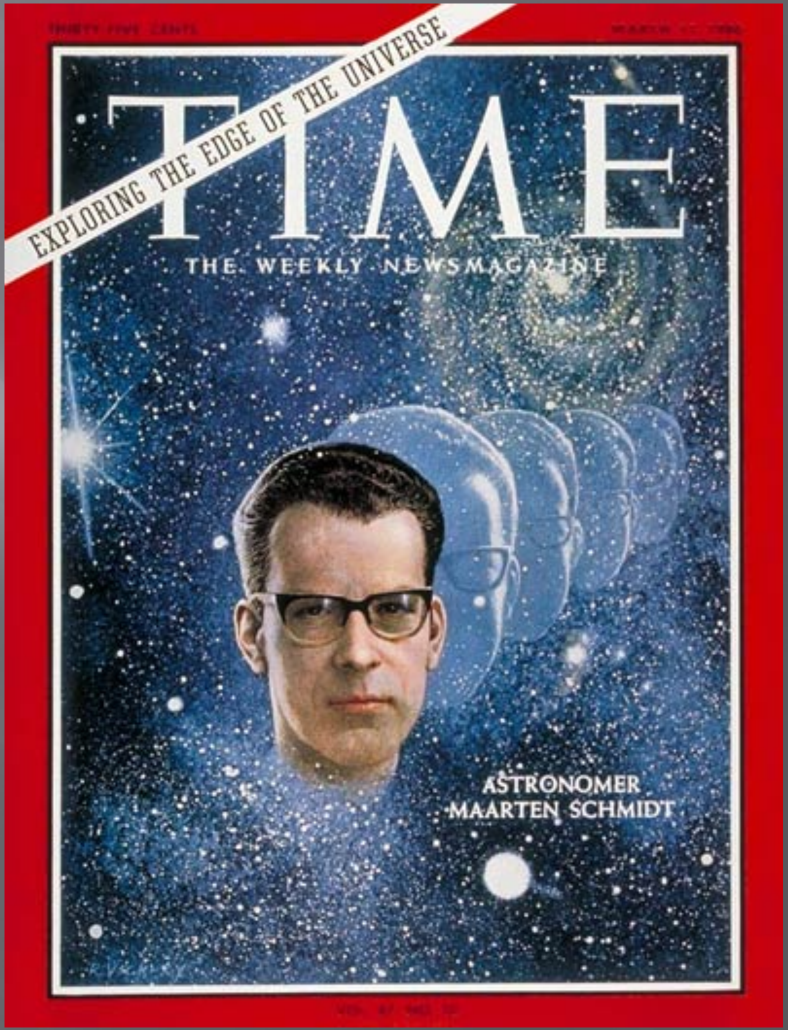


Bright
A jet
Small
Distant……?

A small object, with an enormous redshift, implying a very great distance and a very great age….a cosmologically significant object, relatively bright for its size…need relativity to explain all this.



..enormous energies,
great distances,
early universe
return of relativity



1963: the rebirth of relativistic cosmology at the First Texas Symposium on relativistic astrophysics: note our old friend Oppenheimer on the right.

At the symposium banquet in the Statler-Hilton Hotel, those at the head table included (left to right): Cyril Hazard, University of Sydney, Australia; Rudolph Minkowski, University of California; Thomas Matthews, California Institute of Technology; W. W. Morgan, Yerkes Observatory; P. G. Bergmann, Yeshiva University; Fred Hoyle, Cambridge University, England; Mrs. E. L. Schucking, University of Texas; and J. Robert Oppenheimer, Institute for Advanced Studies, Princeton. Unless otherwise indicated, delegate pictures with this article are by Al Mitchell, director of information, Graduate Research Center of the Southwest.

1963 quasars
1965 discovery of the cosmic microwave background radiation, as predicted by Alpher, Gamow, and Herman in 1948
1967 discovery of pulsars

All this required relativistic cosmology, which began its Renaissance.

Quasars took on a life of their own….

From the "little house" of 1910 to gravitational lensing and our expanding universe….

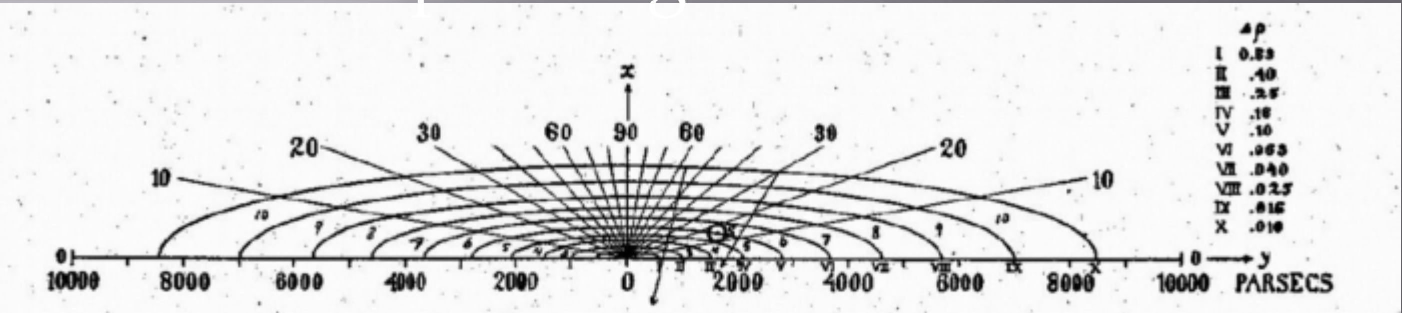
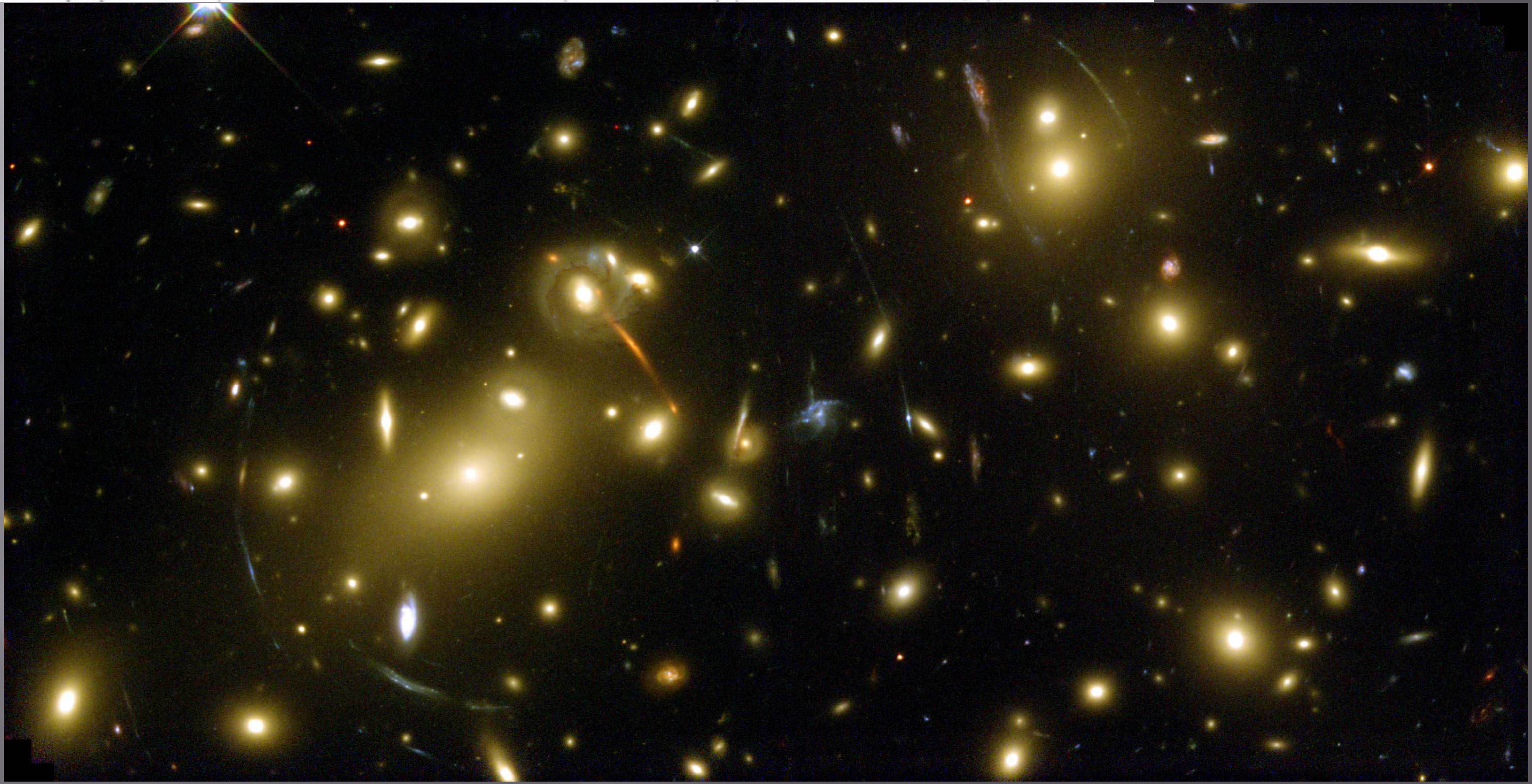


FIG. 1



We began with Professor Schopp. We end with one of his beloved composers, Schubert. Schubert's last piano sonata begins with a wonderful melody followed by a mysterious trill. It is like our wonderful universe, with gravitation waves as our mysterious trill…