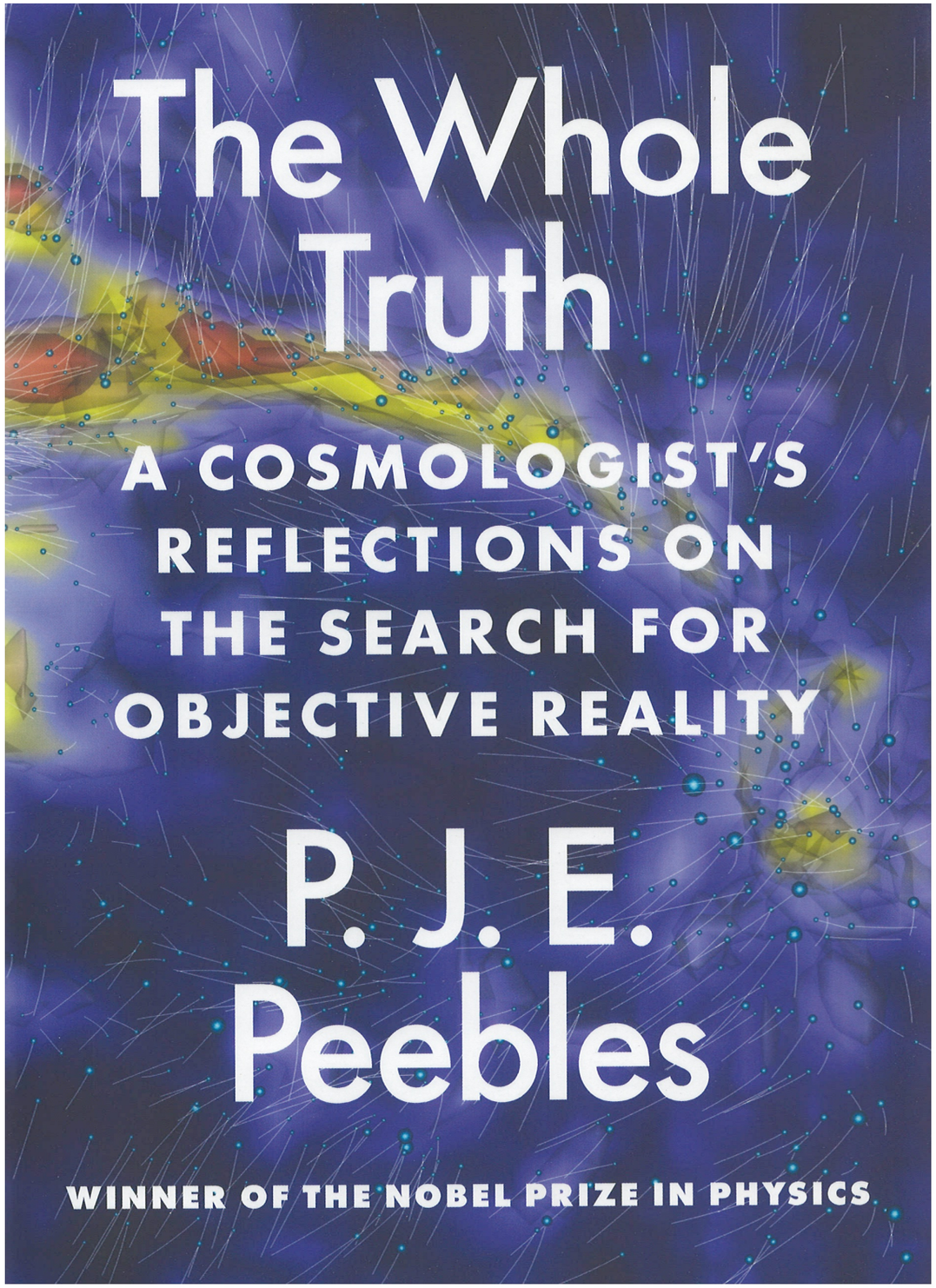
The Sociology and Practice of Natural Science

PJE Peebles
November
2022

Natural scientists observe the world around us and try to make sense of that they find.

Sociologists of science observe natural scientists at work and try to make sense of that they observe.

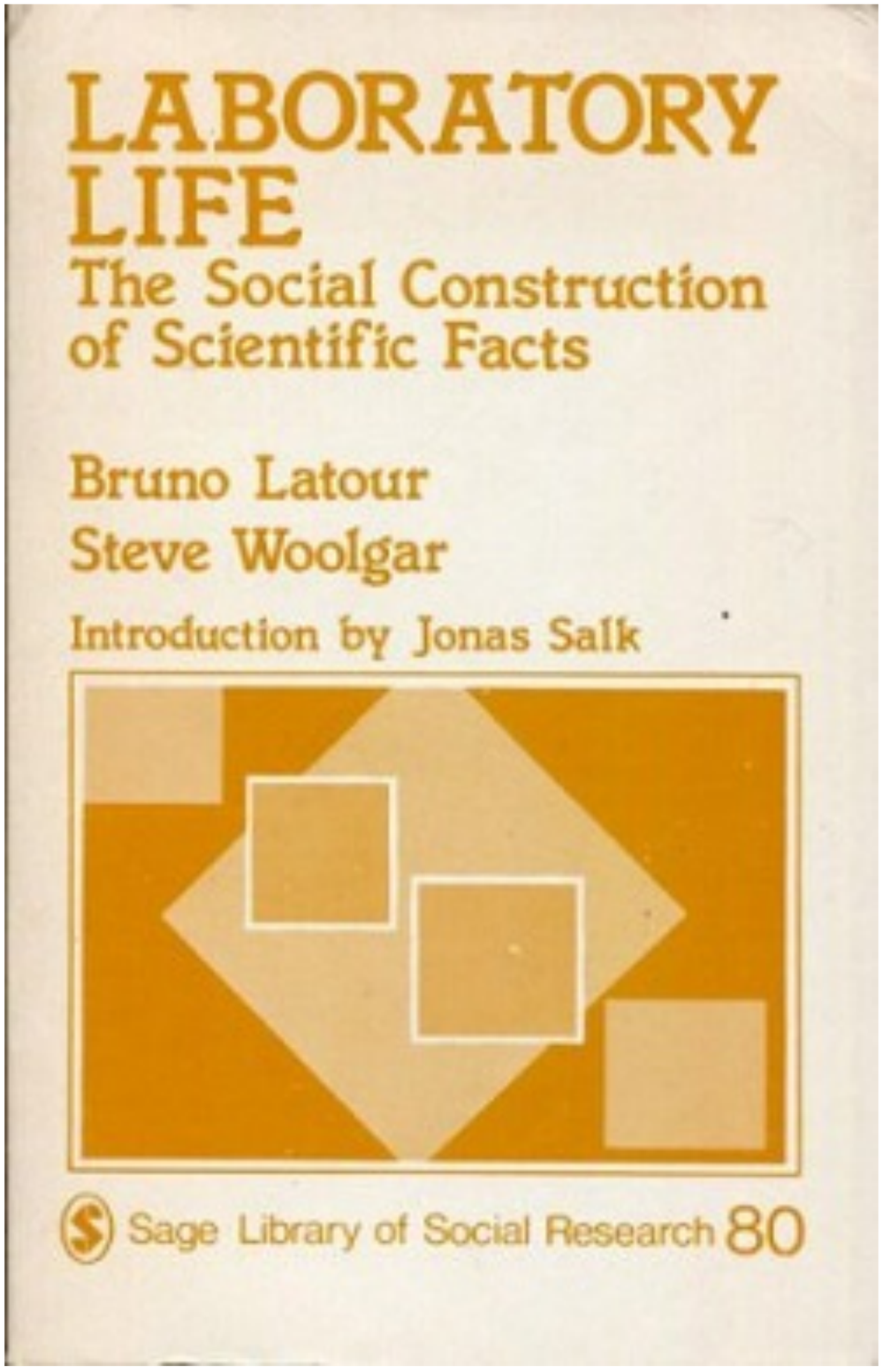
The two cultures do not always get along well. I offer examples taken from this book, and cases where we agree.



Constructions in Natural Science
Bruno Latour and Steve Wolgar, 1986

Bruno Latour

"We are not arguing that somatostatin [a peptide hormone that regulates the endocrine system] does not exist, nor that it does not work, but that it cannot jump out of the very network of social practice which makes possible its existence."



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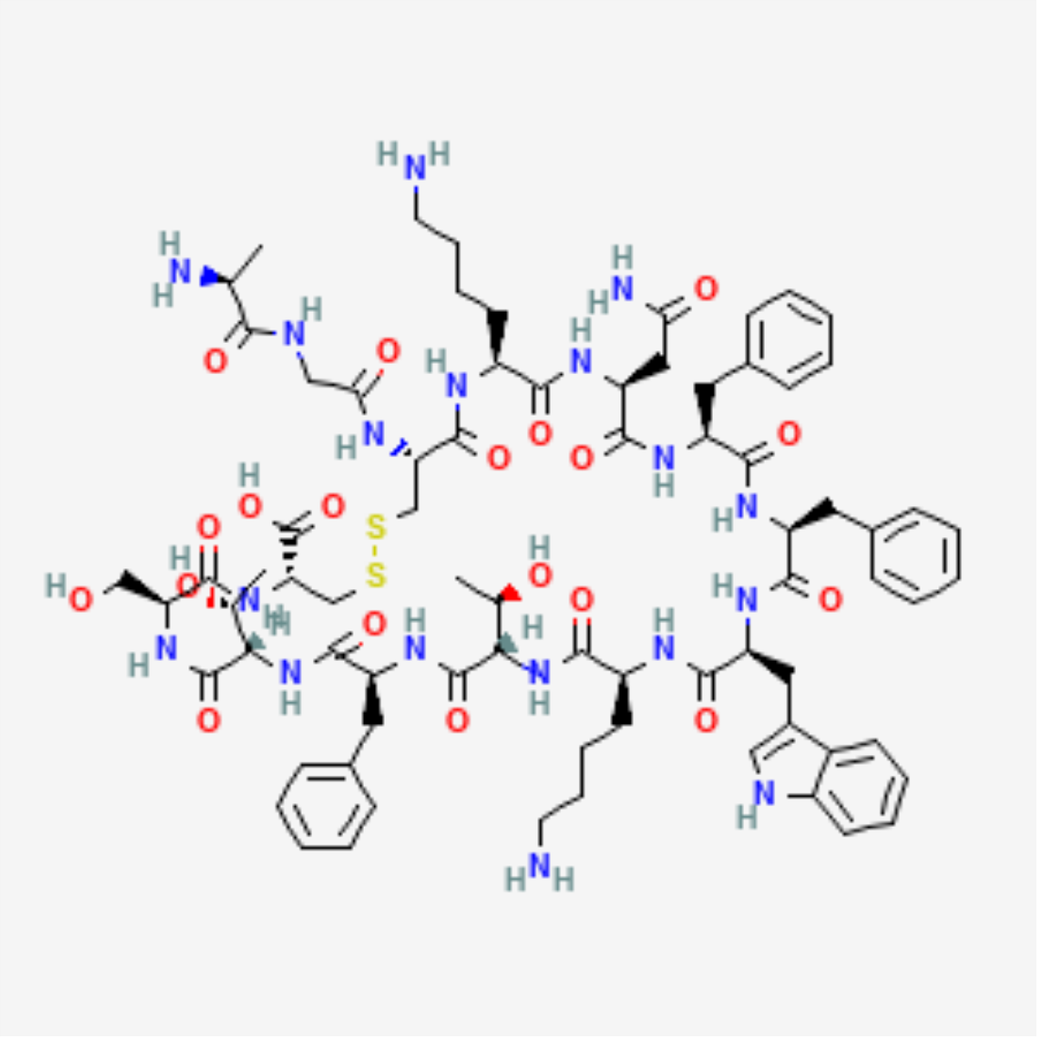
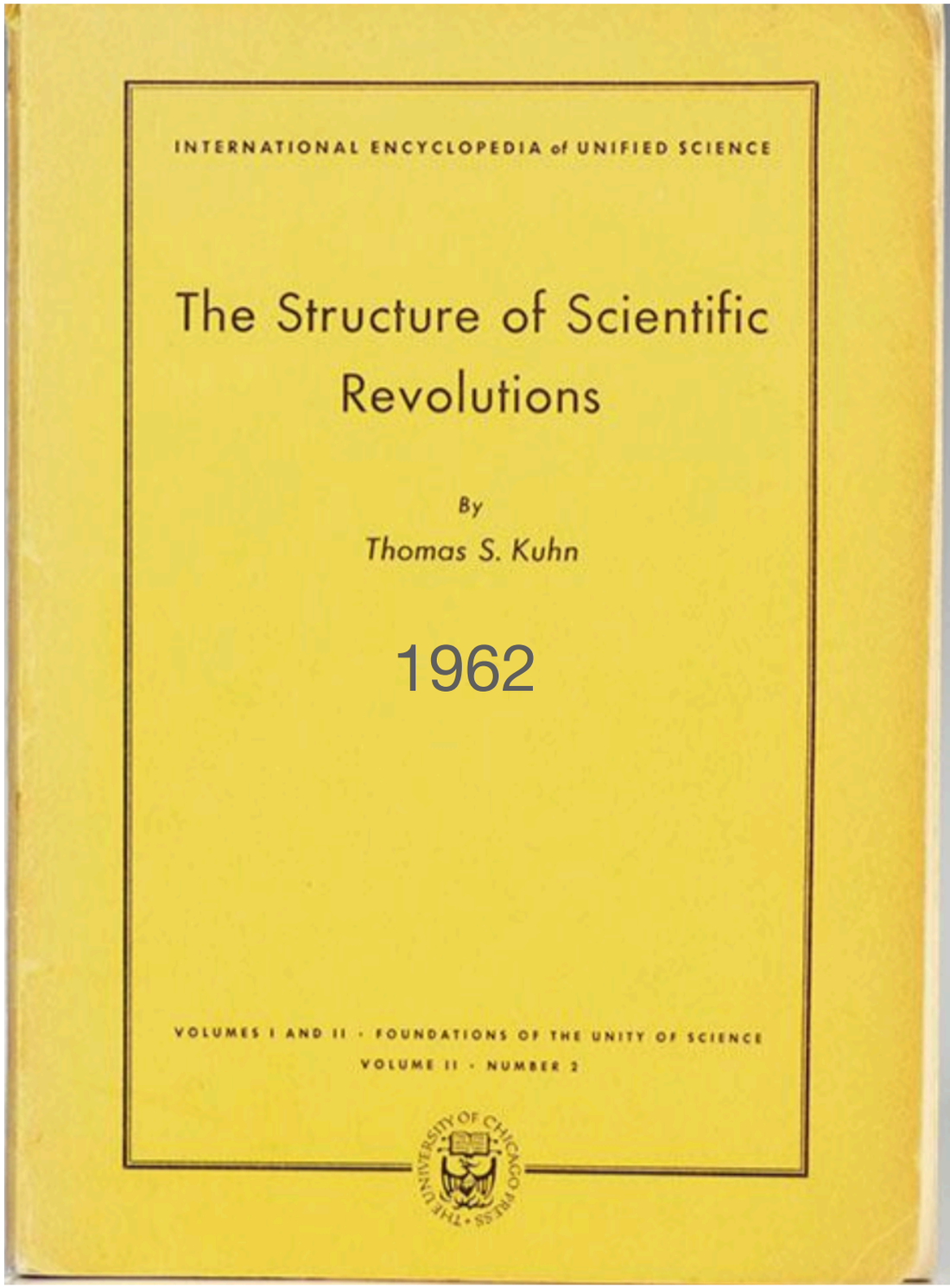


"We are not arguing that somatostatin [a peptide hormone that regulates the endocrine system] does not exist, nor that it does not work, but that it cannot jump out of the very network of social practice which makes possible its existence."

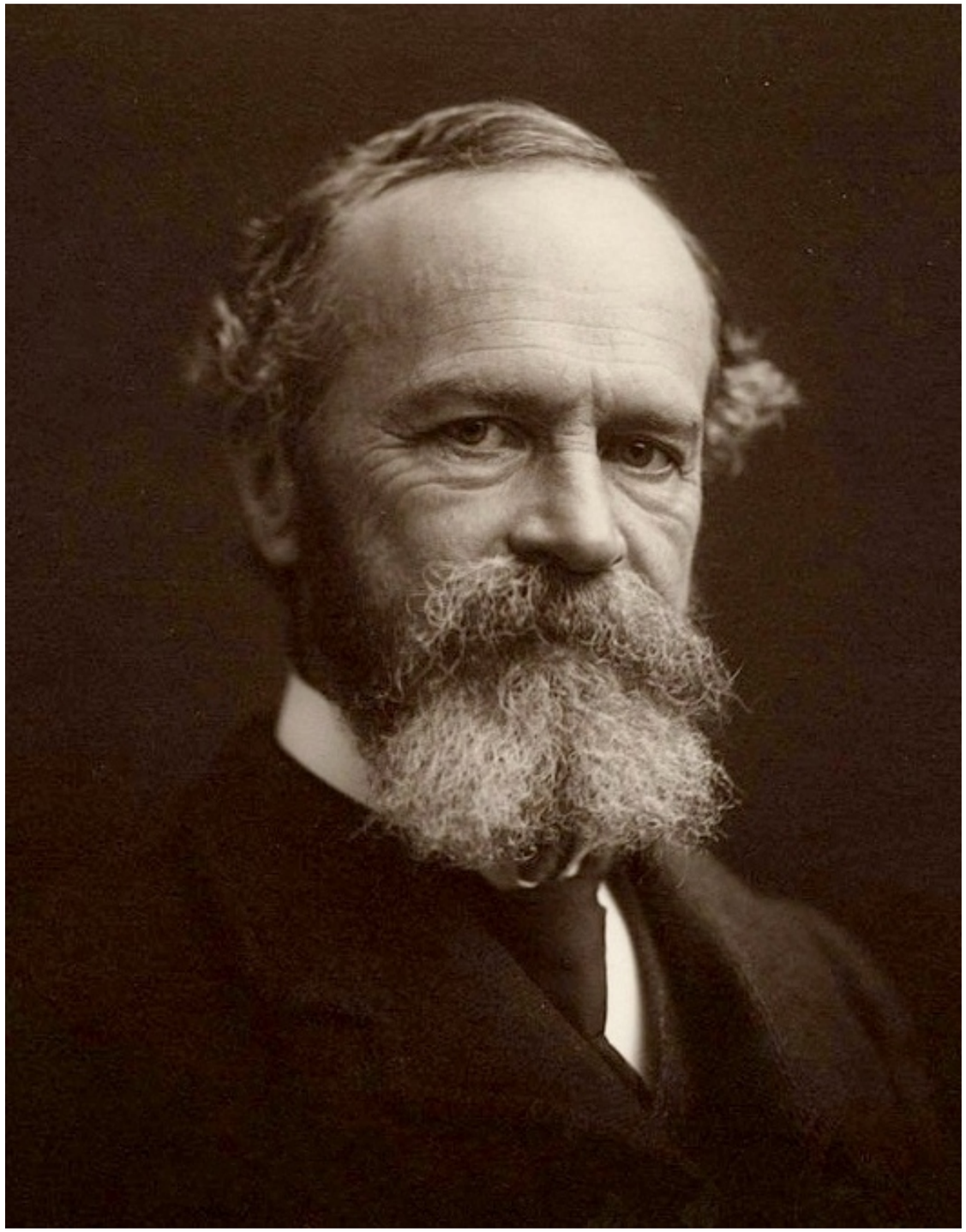
Constructions in Natural Science
Thomas Kuhn, PhD Physics under van Vleck Harvard

‘There is, I think, no theory-independent way to reconstruct phrases like ‘really there’; the notion of a match between the ontology of a theory and its “real” counterpart in nature now seems to me illusive in principle.



Constructions in Natural Science
William James, 1907

It is . . . as if reality were made of ether, atoms or electrons, but we mustn't think so literally. The term 'energy'' doesn't even pretend to stand for anything 'objective.' It is only a way of measuring the surface of phenomena so as to string their changes on a simple formula . . .



Constructions in Natural Science
Charles Sanders Peirce, 1878

One man may investigate the velocity of light by studying the transits of Venus and the aberration of the stars; another by the oppositions of Mars and the eclipses of Jupiter's satellites; a third by the method of Fizeau; a fourth that of Foucault; a fifth by the motions of the curves of Lissajoux; a sixth, a seventh, an eighth, and a ninth, may follow the different methods of comparing the measures of statical and dynamical electricity. They may at first obtain different results, but, as each perfects his method and his processes, the results will move steadily together toward a destined centre. So with all scientific research.

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Constructions in Natural Science
James Clerk Maxwell, the mid-1800s

Maxwell's equations describe the behavior of electricity and magnetism. They are applied in many different ways.

Maxwell wrote (maybe approximately)

"The opinion seems to have got abroad, that in a few years all great physical constants will have been approximately estimated, and that the only occupation which will be left to [people] of science will be to carry on these measurements to another place of decimals. … But we have no right to think thus of the unsearchable riches of creation, or of the untried fertility of those fresh minds into which these riches will continue to be poured."

Constructions in Natural Science
James Clerk Maxwell, the mid-1800s

Maxwell's equations are productively applied to an enormous variety of situations, from the design of power plants, to the trickle of energy that allows electromagnetism to operation your cell phone. These successful applications are in effect enormous numbers of tests that the classical theory passes.

But Maxwell's equations fail when applied to the behaviour of atoms. The equations are wrong, if you want to get technical about it. So are all the rest of our physical theories.

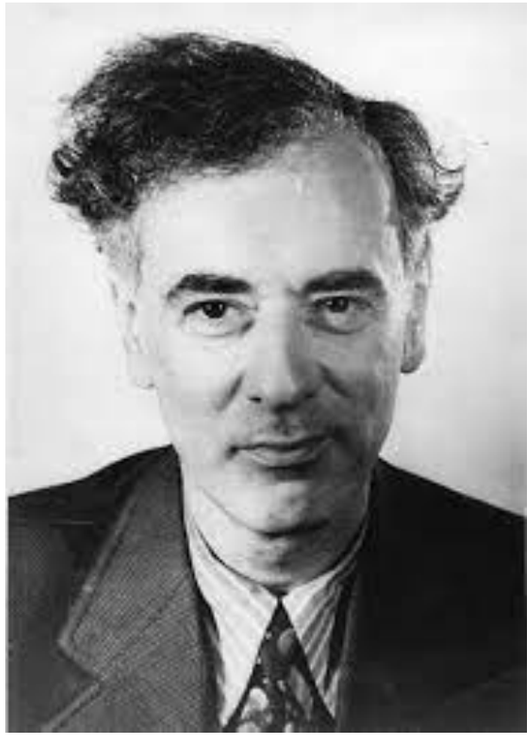
But Maxwell's equations are what certainly looks like good approximations to an objective reality. So it is for all our established physics. It is the best we can ever do.

Constructions in Natural Science

“somatostatin cannot jump out of the very network of social practice which makes possible its existence.”

Latour was embedded in a laboratory investigating a new and complex phenomenon. Would Latour’s observation of the use of Maxwell’s equations in the design of an electromagnetic power plant and its energy transition lines have given Latour confidence in the reality of electric and magnetic fields, independent of social practice?

Constructions in Natural Science
Consider Landau and Lifshitz 1948; English translation 1951



THE
CLASSICAL THEORY
OF FIELDS

by

L. LANDAU AND E. LIFSHITZ
Institute for Physical Problems
Academy of Sciences of the U.S.S.R.

Translated from the Russian
by
MORTON HAMERMESH
Argonne National Laboratory

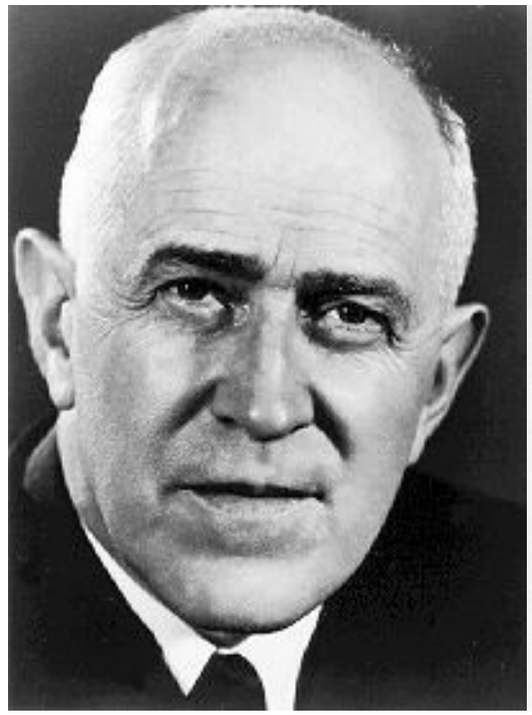
ADDISON-WESLEY PUBLISHING COMPANY, INC.
READING, MASSACHUSETTS, U.S.A.

The first two thirds of this book are on the behaviour of the classical electromagnetic field, solid stuff. The last third is on Einstein's theory of gravity, general relativity. In 1950 GR was a social construction that the elite made a canonical part of physics even through the three tests were marginal at best.

As sociologists say, physicists certainly deal with social constructions.

Now GR passes demanding tests that make it a scientific construction. But that's now, not then.

Constructions in Natural Science




William F. Ogburn and Dorothy Thomas
Political Science Quarterly, Vol. 37, No. 1 (March 1922)

ARE INVENTIONS INEVITABLE? A NOTE ON SOCIAL EVOLUTION

IT is an interesting phenomenon that many inventions have been made two or more times by different inventors, each working without knowledge of the other's research. There are a number of cases of such duplicate inventions or discoveries that are of common knowledge. It is well known, for instance, that both Newton and Leibnitz invented calculus.

79. Law of expansion of gases. By Charles (1783) and Gay-Lussac (1802).

80. Continuity of gaseous and liquid states of matter. By Ramsay (1880) and Jamin (1883).

81. Kinetic theory of gases. By Clausius (1850) and Rankine (1850).

82. Law of conservation of energy. By Mayer (1843), Joule (1847), Helmholz (1847), Colding (1847) and Thomson (1847).

83. Mechanical equivalent of heat. By Mayer (1842), Carnot (1830), Seguin (1839) and Joule (1840).

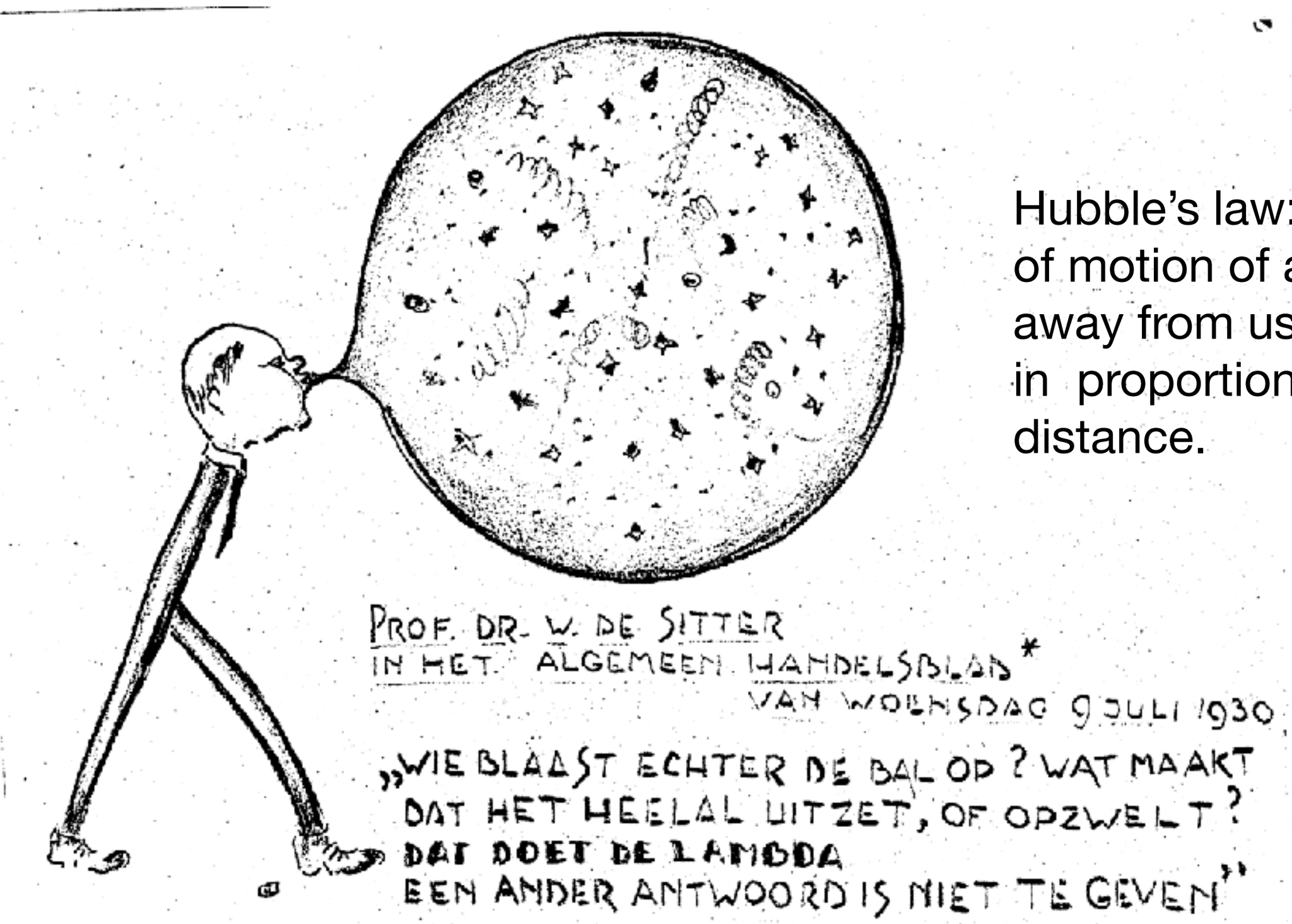
SINGLETONS AND MULTIPLES IN SCIENTIFIC DISCOVERY: A CHAPTER IN THE SOCIOLOGY OF SCIENCE *

ROBERT K. MERTON †

Professor of Sociology, Columbia University

"Appropriately enough, this [independent discovery] is an hypothesis confirmed by its own history. (Almost, as we shall see, it is a Shakespearian play within a play.) For this idea of the sociological significance of multiple independent discoveries and inventions has been periodically rediscovered [by sociologists] over a span of centuries."

The expanding universe.



Hubble's law: the rate of motion of a galaxy away from us increases in proportion to its distance.

"Who however blows up the ball? What makes the Universe expand or swell up? That is done by the Lambda.

These four followed a reasonably close to linear path to the redshift-distance relation.

Percival Lowell

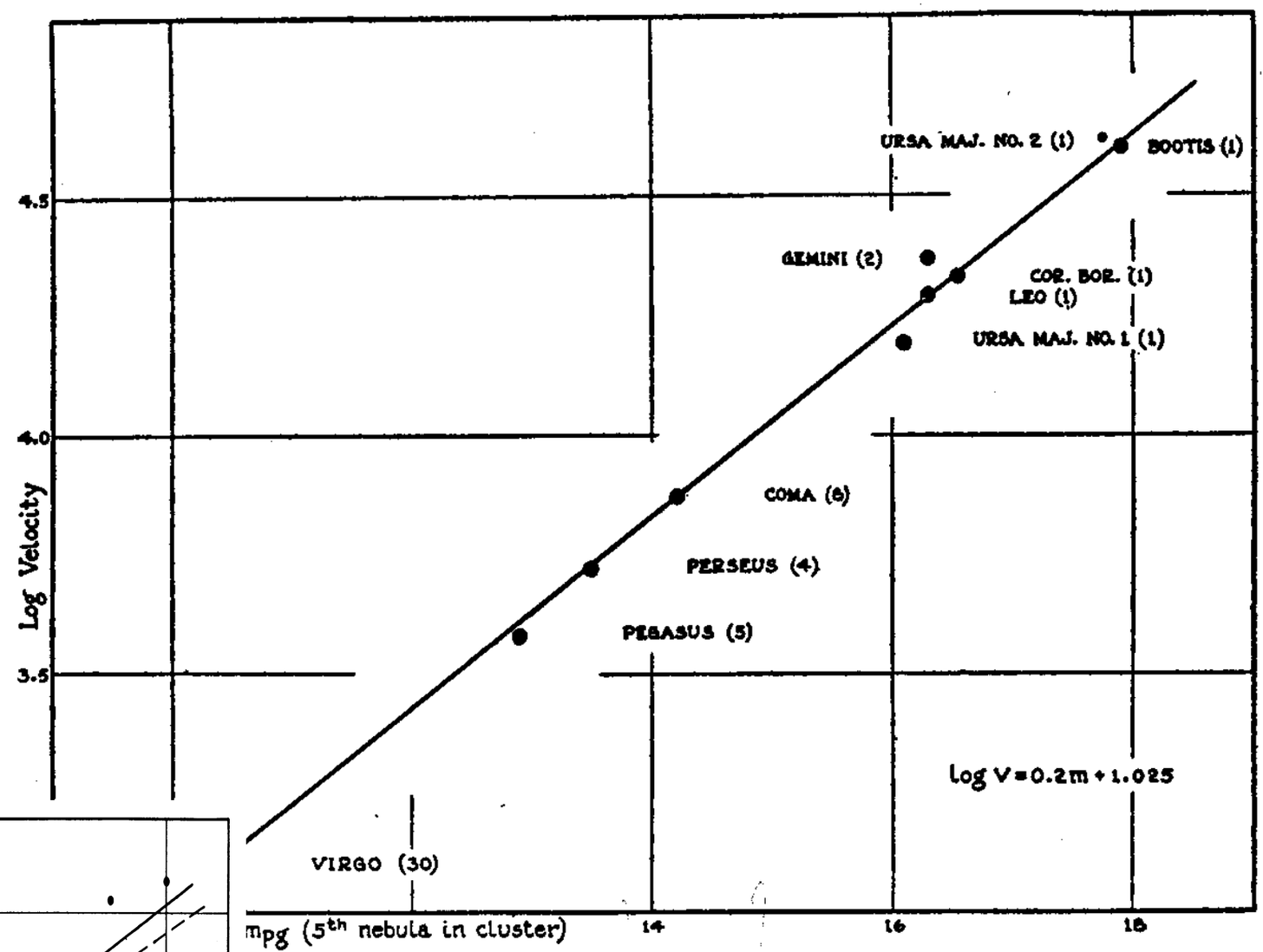
Melvin Slipher

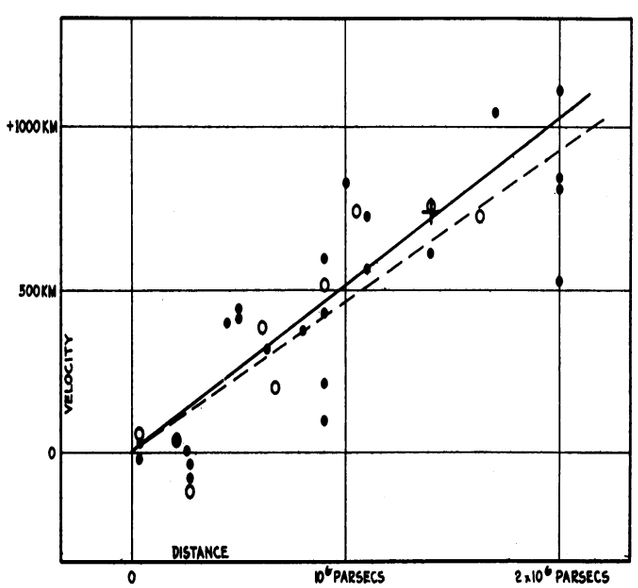
Henrietta Leavitt

Edwin Hubble

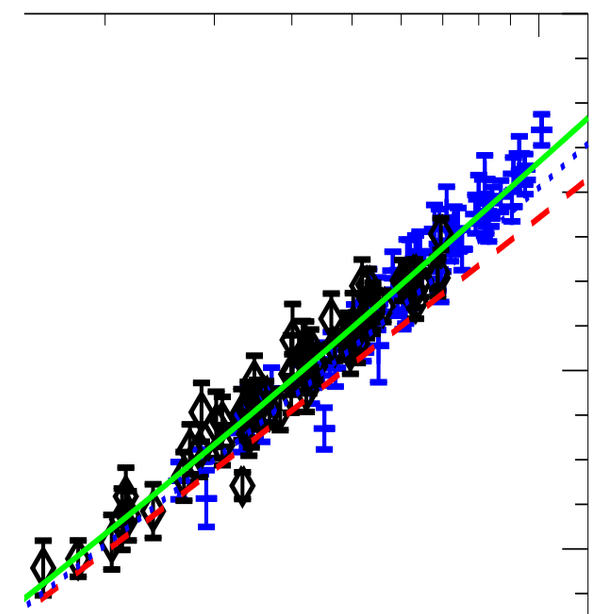
So now we are in Boston, the home of the bean and the cod, where Cabots speak only to Lowells, and Lowells speak only to God.

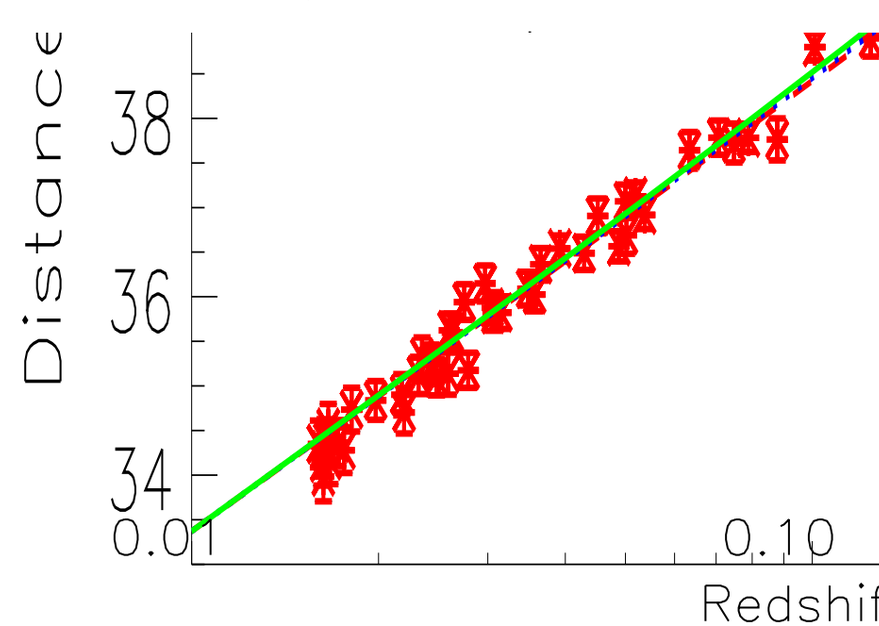
Hubble and Humason ~ 1936





Hubble 1929

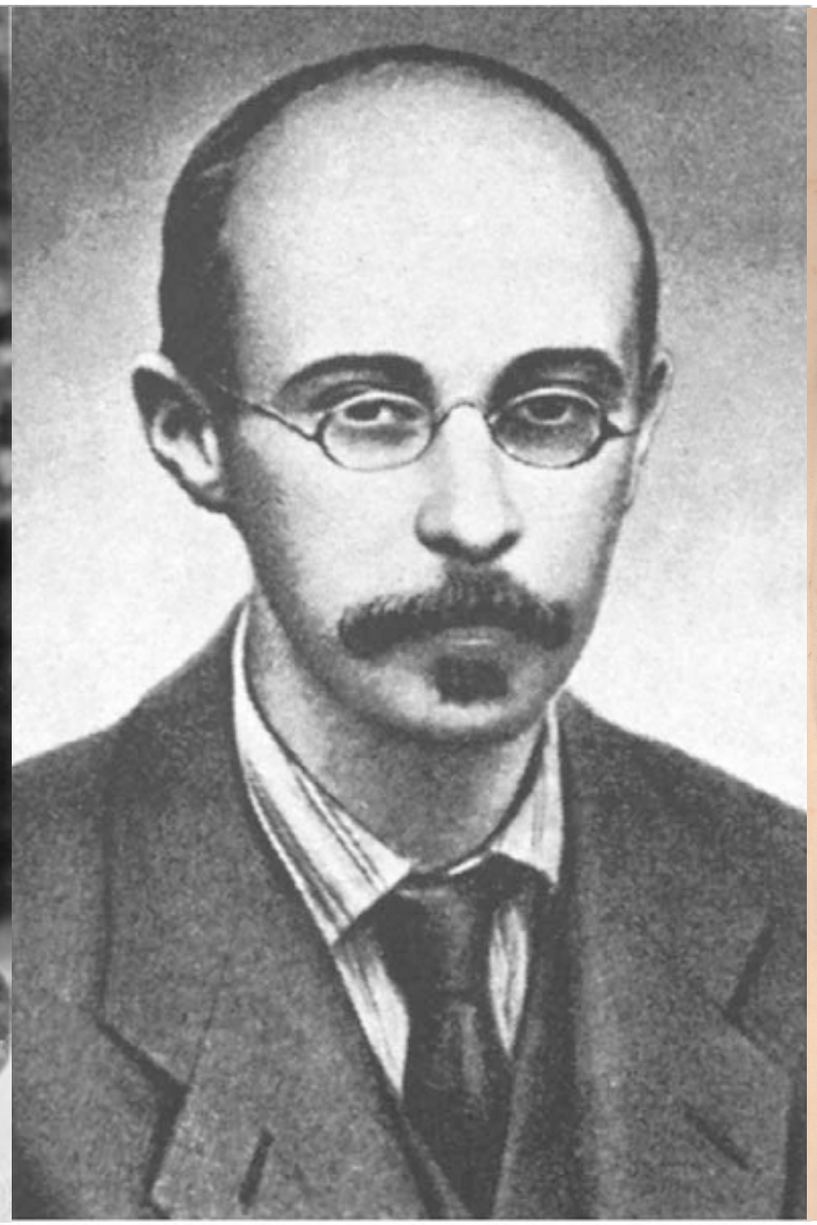




Essence Supernova Survey, Wood-Vasey et al. 2006

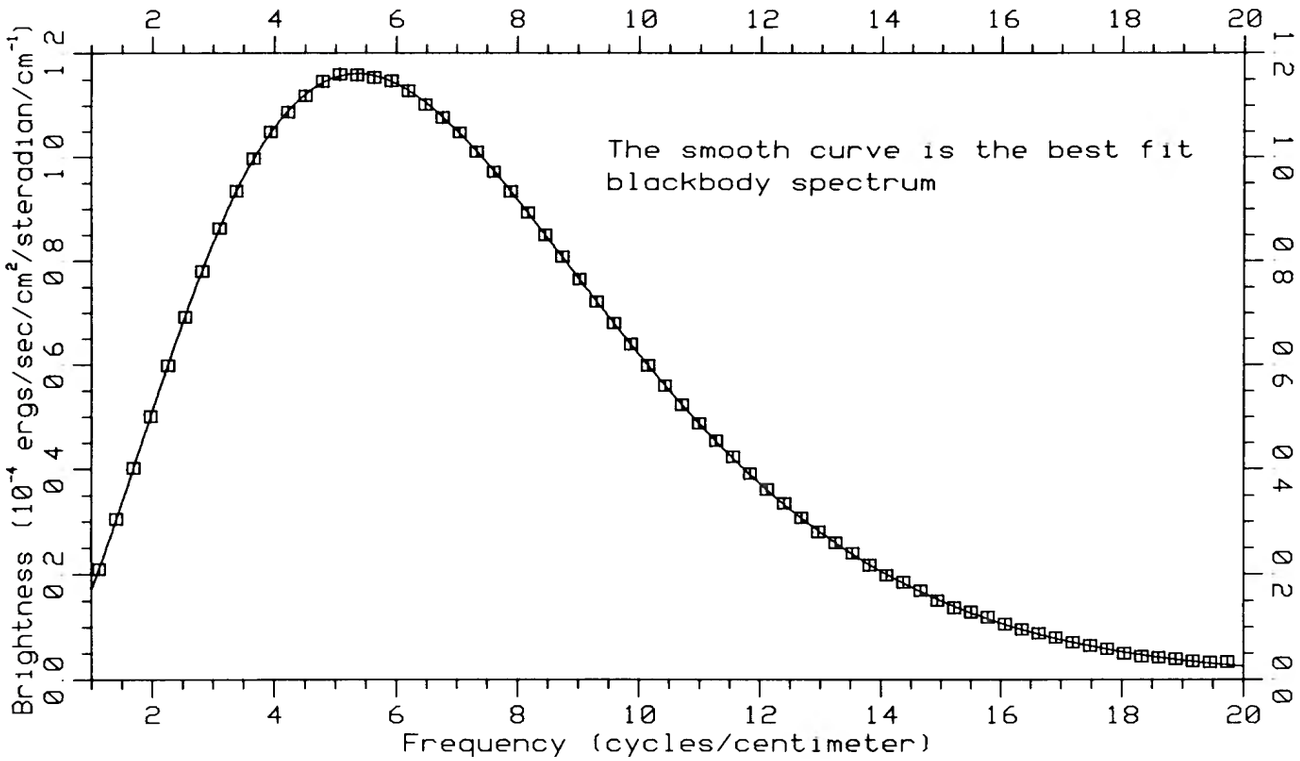
Hermann Weyl

Alexsander Friedman



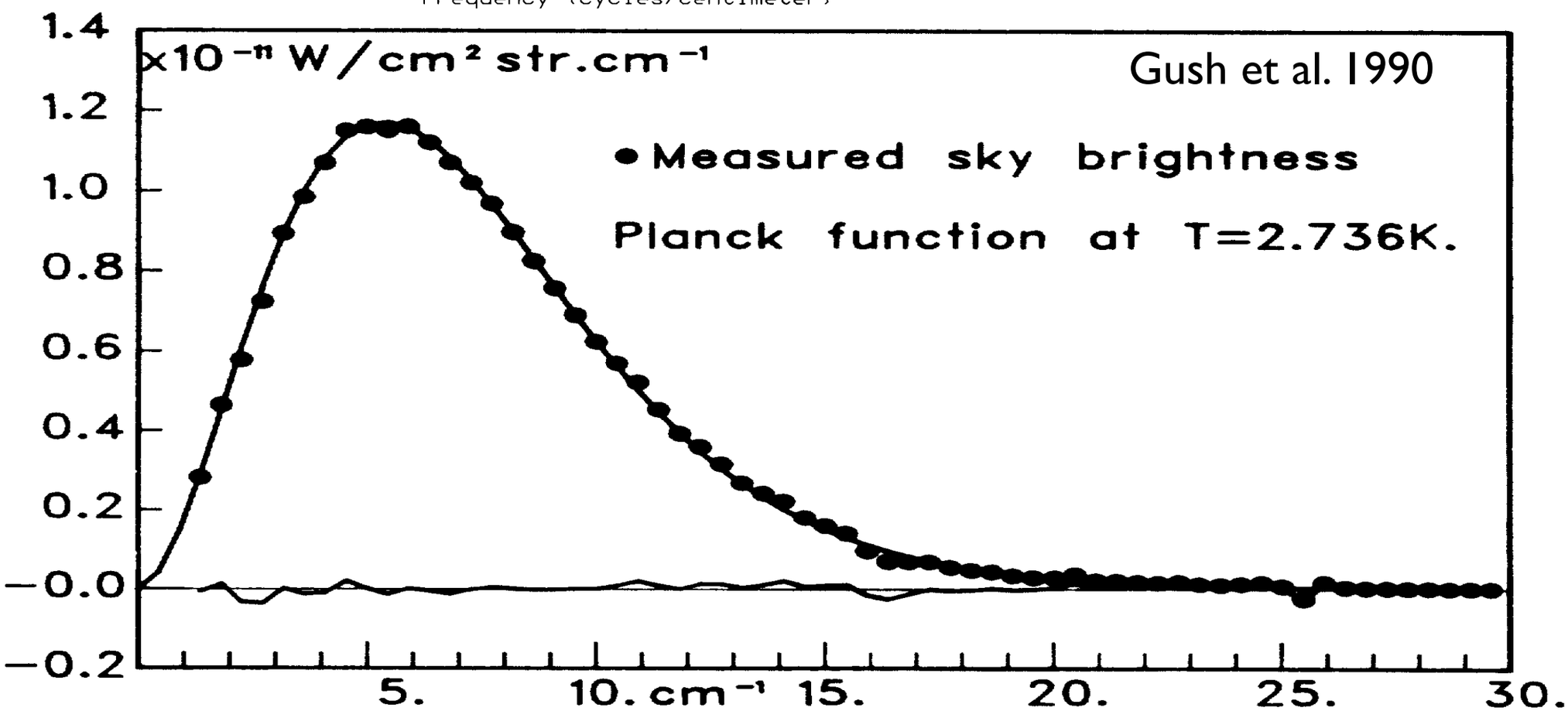
Georges Lemaître, 1924

These three hit on the picture of an expanding universe, a case of multiple discoveries. Lemaître best applied theory and observation.



Space is filled with sea of thermal radiation. It is compelling evidence of the evolution of the universe, expansion from a hot dense state.

Mather et al. 1990



Gush et al. 1990

Examples of multiple discoveries made and missed in the establishment of the hot big bang

A multiple in missed scientific discovery

AN ATTEMPT TO INTERPRET THE RELATIVE ABUNDANCES
OF THE ELEMENTS AND THEIR ISOTOPES

S. CHANDRASEKHAR AND LOUIS R. HENRICH ApJ 1942

The equilibrium between the successive isotopes of an element differing by one mass number is maintained according to the scheme

$$ {}^{A}_{Z}X + \nu \rightleftarrows {}^{A+1}_{Z}X \,. \tag{1} $$

Accordingly, we have

$$ \frac{n_Z^A n_\nu}{n_Z^{A+1}} = 2\,\frac{G_Z^A}{G_Z^{A+1}}\left(\frac{A}{A+1}\right)^{3/2}\frac{(2\pi MkT)^{3/2}}{h^3}\; e^{-E_A/kT}\,, \tag{2} $$

Equation (1) should read

$$ {}^{\mathrm{A}}_{\mathrm{Z}}X + n \leftrightarrow {}^{\mathrm{A+1}}_{\mathrm{Z}}X + \gamma. $$

Chandrasekhar and Henrich (1942) do not seem to have noticed that their implicit assumption of a sea of thermal radiation in the early stages of expansion of the universe would imply a sea of thermal radiation in the present universe, cooled by the expansion of the universe.


A multiple in missed scientific discovery
Yerkes Observatory Staff, 1940

A multiple in missed scientific discovery

The Origin of Chemical Elements

R. A. ALPHER*
Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland

AND

H. BETHE
Cornell University, Ithaca, New York

AND

G. GAMOW
The George Washington University, Washington, D. C.

February 18, 1948

AS pointed out by one of us,[1] various nuclear species must have originated not as the result of an equilibrium corresponding to a certain temperature and density, but rather as a consequence of a continuous building-up process arrested by a rapid expansion and cooling of the primordial matter. According to this picture, we must imagine the early stage of matter as a highly compressed

This widely cited paper is a pioneering exploration of what might have happened during the dense early stages of expansion of the universe. Not so commonly noticed is that the theory presented in this paper is wildly inconsistent.

Gamow 1948 got it right in this paper

The Origin of Elements and the Separation of Galaxies

G. Gamow
George Washington University, Washington, D. C.
June 21, 1948

Gamow applied the Saha relation to $\mathrm{n} + \mathrm{p} \leftrightarrow \mathrm{d} + \gamma$ to show deuterons start accumulating at $T \sim 10^9$ K. Knowing σv the condition that this produces a reasonable abundance of heavier elements requires nucleon number density $n \sim 10^{18}$ cm^{-3}.

(Thus we have $\rho_{\mathrm{mat.}}{}^{\circ} \cdot \Delta t \cong 10^{-4}$ g·cm^{-3}·sec. and not 10^{+4} g·cm^{-3} sec. as was given incorrectly in the previous paper[2] because of a numerical error in the calculations.)

With Gamow's estimate of the matter density, $n \sim 10^{18}$ cm^{-3}, at nucleosynthesis at $T \sim 10^9$ K, Alpher and Herman pointed out that this scales to present CMB temperature $T \sim 8$ K.

Gamow 1948 got it right in these two papers.

The Origin of Elements and the Separation of Galaxies

G. Gamow
George Washington University, Washington, D. C.
June 21, 1948

THE successful explanation of the main features of the abundance curve of chemical elements by the hypothesis of the "unfinished building-up process,"[1,2] permits us to get certain information concerning the densities and temperatures which must have existed in the universe during the early stages of its expansion. We want to discuss here some interesting cosmogonical conclusions which can be based on these informations.

(Thus we have $\rho_{\text{mat.}}{}^{\circ}\cdot\Delta t \cong 10^{-4}\,\text{g}\cdot\text{cm}^{-3}\cdot\text{sec.}$ and not 10^{+4} $\text{g}\cdot\text{cm}^{-3}$ sec. as was given incorrectly in the previous paper[2] because of a numerical error in the calculations.)

THE EVOLUTION OF THE UNIVERSE

By Dr. G. GAMOW
George Washington University, Washington, D.C.

THE discovery of the red shift in the spectra of distant stellar galaxies revealed the important fact that our universe is in the state of uniform expansion, and raised an interesting question as to whether the present features of the universe could be understood as the result of its evolutionary development, which must have started a few thousand million years ago from a homogeneous state of extremely high density and temperature. We conclude first of all that the relative abundances of various atomic species (which were found to be essentially the same all over the observed region of the universe) must represent the most ancient archæological document pertaining to the history of

NATURE October 30, 1948

THE EVOLUTION OF THE UNIVERSE

By Dr. G. GAMOW
George Washington University, Washington, D.C.

Gamow (1948b): “hydrogen is known to form about 50 per cent of all matter.” That wasn’t known; it was a good educated guess.

Fermi and Turkevitch soon checked that in Gamow’s picture the expected hydrogen abundance is large, and almost all the rest is helium.

This means two signatures of Gamow’s relativistic hot big bang cosmology would be

- a sea of thermal radiation at a temperature of several Kelvins, and
- a large abundance of helium prior to star formation.

Ann Arbor 1953

A multiple in missed scientific discovery

NUCLEAR ENERGY GENERATION AND DISSIPATION IN GALAXIES

G. R. Burbidge
Yerkes Observatory, University of Chicago

PASP 1958

conservative estimate is that 10% of the total mass of all of the Galaxy has been converted to helium. The energy released by this fusion process would amount to 8.7×10^{61} ergs.

This is far more energy than would be released as starlight if the luminosity of the Milky Way were constant during the expansion time of the universe.

Burbidge suggested this energy had been radiated away in violent explosions, or maybe the Milky Way galaxy is much older, as would be allowed in the steady state cosmology. But in a steady state we ought to see these explosions nearby.

Not mentioned: maybe this is helium remnant from Gamow's hot big bang.

A multiple in missed scientific discovery

Hoyle's (1958) thinking about helium is indicated by a discussion recorded at the 1957 Vatican Conference on Stellar Populations:

Hoyle: The difficulty about helium still remains, however.

Martin Schwarzschild: The evidence for the increase in heavy elements with the age of the galaxy supports [the idea of element formation in stars]. However, it does not necessarily mean that He production occurs mainly in stars. Gamow's mechanism may work up to mass 4.

Hoyle: That is why a knowledge of the He concentration in extreme population II is so important.

A multiple in scientific discovery

THE HELIUM AND HEAVY-ELEMENT CONTENT OF GASEOUS NEBULAE AND THE SUN

D. E. Osterbrock*
Institute for Advanced Study
Princeton, New Jersey
and
J. B. Rogerson, Jr.
Princeton University Observatory

PASP 1961

The helium abundance $Y = 0.32$ existing since such an early epoch could be at least in part the original abundance of helium from the time the universe formed, for the build-up of elements to helium can be understood without difficulty on the explosive formation picture.[21]

[21] G. Gamow, *Revs. Modern Phys.*, **21**, 367, 1949.

But nobody else who could have understood the possible significance of this remark seems to have noticed, and Osterbrock and Rogerson had other things to do.

A multiple in scientific discovery

NUCLEAR ASTROPHYSICS[1,2]

By Geoffrey Burbidge
University of California at San Diego, La Jolla, California

Annual Review of Nuclear Science 1962

Since the material of the sun condensed about 5×10^9 yr ago, we need to explain both the comparatively high value of the He/H ratio as compared with the estimates [of production in stars] made earlier, and the fact that there has been little change in the relative abundance in the intervening 5×10^9 yr.

The bulk of the transmutation of H to He took place in the first few minutes in the expansion of the Universe.

This was a side remark in a long review paper. I guess Burbidge was not impressed by the Gamow theory, and again no one else seems to have recognized this potentially important point.

A multiple in missed scientific discovery

THE PLANETARY NEBULA IN THE GLOBULAR CLUSTER M15

C. R. O'Dell and M. Peimbert
Berkeley Astronomical Department, Berkeley, California

T. D. Kinman
Lick Observatory, Mount Hamilton, California
Received February 10, 1964

ABSTRACT

The results of a photographic spectrophotometric investigation of the nebulous object K648 in the globular cluster M15 are presented. On the basis of a discussion of the size, density, and mass it is shown that K648 represents a typical example of the planetary nebula phenomena. The relative abundances of hydrogen, helium, oxygen, and neon were determined. The oxygen abundance, relative to hydrogen, is deficient by a factor of 61 relative to the Sun. The helium abundance, $N(\mathrm{He})/N(\mathrm{H}) = 0.18 \pm 0.03$, is compared with that found in field planetary nebulae, a very high-velocity planetary nebula, and the Orion Nebula. It is shown that strong arguments can be presented, supporting the hypothesis that the original helium content of the globular clusters was much higher than the very low values usually assumed.

The mass fraction in helium in the planetary is Y = 0.42 ± 0.08.

"The oxygen abundance, relative to hydrogen, is deficient by a factor of 61 relative to the Sun."

O'Dell told me that at the time they did not "fully appreciate" the significance for cosmology. John Faulkner argues that this O'Dell et al. paper led Hoyle to recruit Tayler to write their paper, "The Mystery of the Cosmic Helium Abundance."

THE MYSTERY OF THE COSMIC HELIUM ABUNDANCE

By PROF. F. HOYLE, F.R.S., and DR. R. J. TAYLER
University of Cambridge

This brings us back to our opening remarks. There has always been difficulty in explaining the high helium content of cosmic material in terms of ordinary stellar processes. The mean luminosities of galaxies come out appreciably too high on such a hypothesis. The arguments presented here make it clear, we believe, that the helium was produced in a far more dramatic way. Either the Universe has had at least one high-temperature, high-density phase, or massive objects must play (or have played) a larger part in astrophysical evolution than has hitherto been supposed. Clearly the approxim-

A multiple in missed scientific discovery

PUBLICATIONS

OF THE

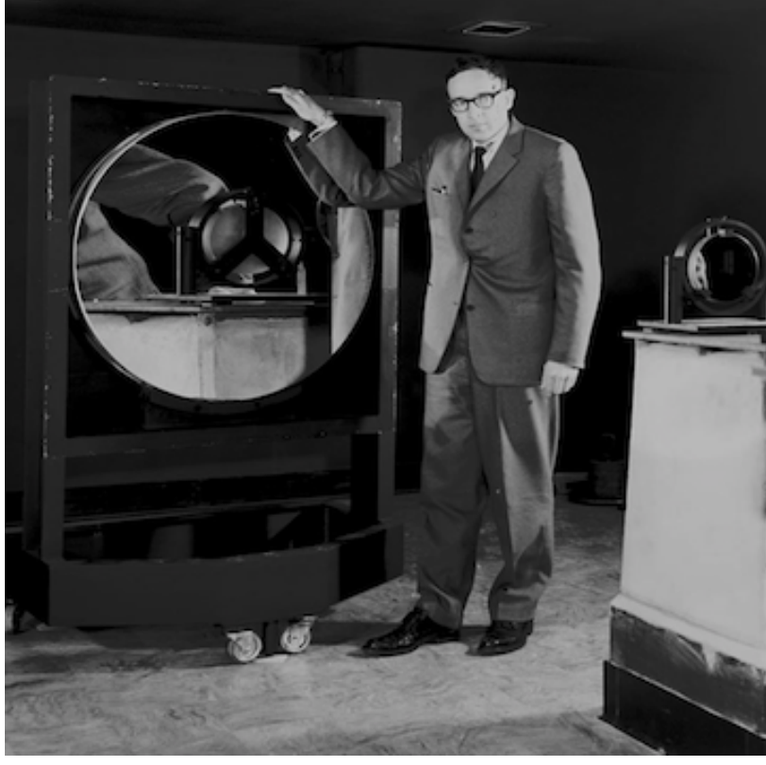
Dominion Astrophysical Observatory

VICTORIA, B.C.

Volume VII, No. 15 1941

MOLECULAR LINES FROM THE LOWEST STATES OF DIATOMIC MOLECULES COMPOSED OF ATOMS PROBABLY PRESENT IN INTERSTELLAR SPACE

BY ANDREW McKELLAR



With the 1.2 m McKellar DAO Spectrograph

The results of Adams, showing that only the lowest and next higher rotational states of CN are sufficiently populated to give interstellar lines, are of particular interest. They allow the determination of a "rotational" temperature for the region where the CN absorption takes place. This temperature, 2°.3*K*, is compared with the temperatures estimated by Eddington for matter in interstellar space.

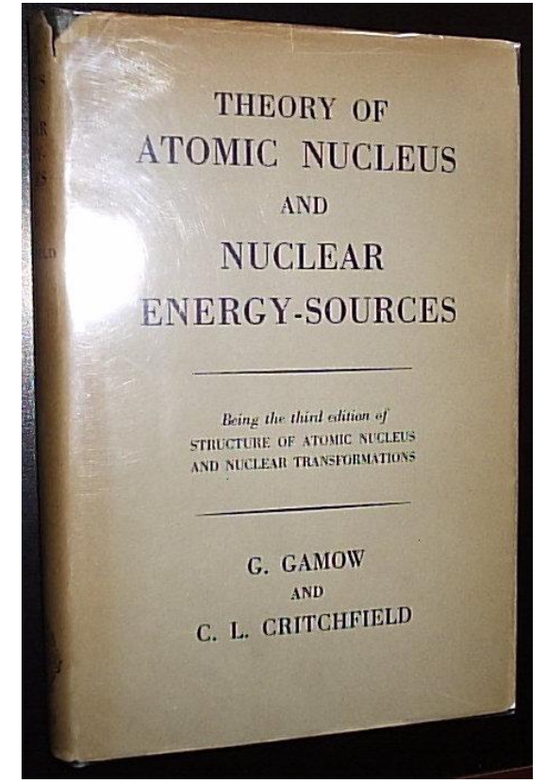
Within measurement uncertainties the interstellar CN spin temperature, 2.3 K, agrees with the CMB temperature, 2.725 K, measured much later.

Alpher and Herman (1948) found that Gamow's hot big bang predicts the present temperature of about 5 K. It is consistent with McLellar's CN temperature, within uncertainties.

This was a detection of the sea of fossil thermal radiation from the hot big bang, recognized much later.

A multiple in missed scientific discovery

Fred Hoyle, 1950, The Observatory, in a review of Gamow and Critchfield's book, with an appendix on Gamow's hot big bang.



NUCLEAR ENERGY

This book* is mainly concerned with the properties of atomic nuclei. The first nine chapters and the eleventh are clearly written and provide a store of information indispensable to the astrophysicist, indeed the book is one of the best aids to astrophysical research that has become available in post-war years.

Let all this be emphasised before the faults of the book are mentioned.

direct conflict with more widely accepted results. The age of the Universe in this model is appreciably less than the agreed age of the Galaxy. Moreover it would lead to a temperature of the radiation at present maintained throughout the whole of space much greater than McKellar's determination for some regions within the Galaxy. Also it is difficult to see how

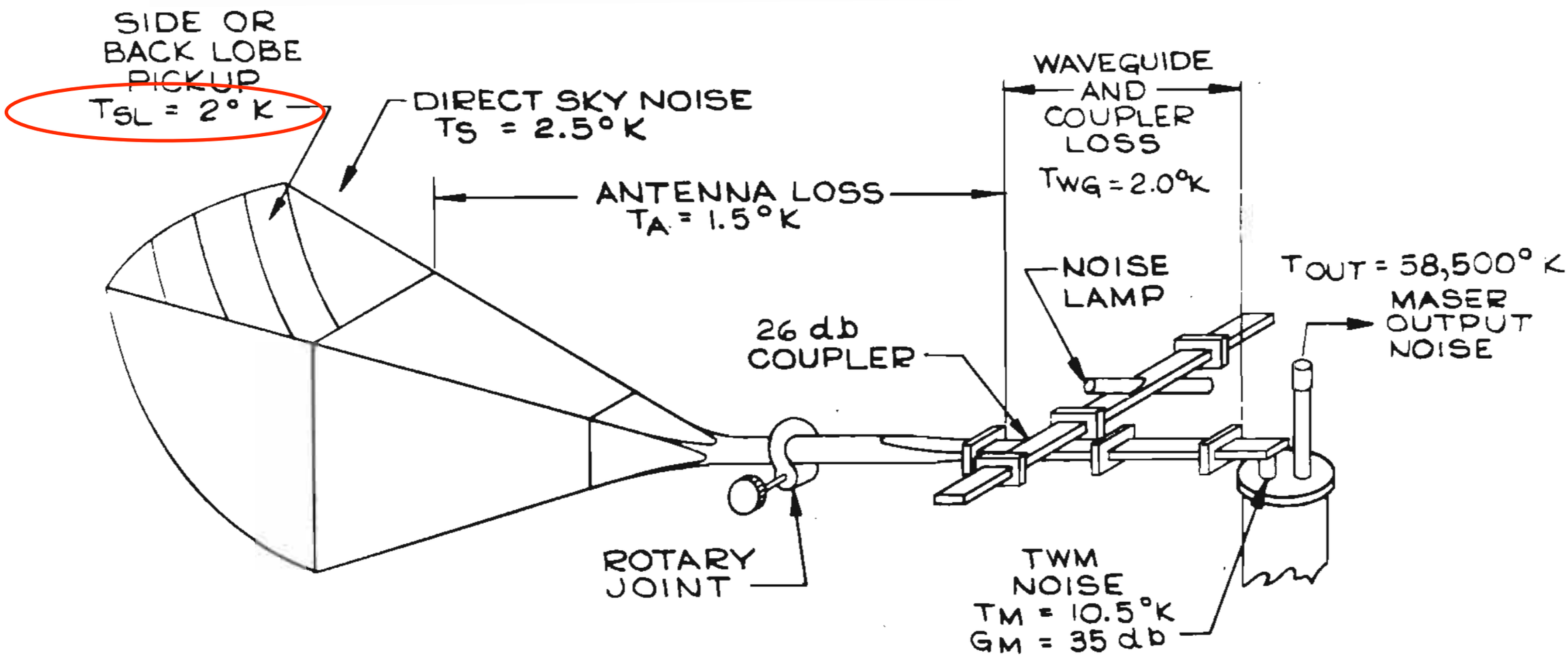
* 'Theory of Atomic Nucleus and Nuclear Energy-Sources'. By G. Gamow and C. L. Critchfield. International Series of Monographs on Physics. Pp. vi + 344, with 5 plates and 62 figs. (London: Geoffrey Cumberlege, Oxford University Press, 1949). Price 30*s*. net.

A multiple in missed scientific discovery

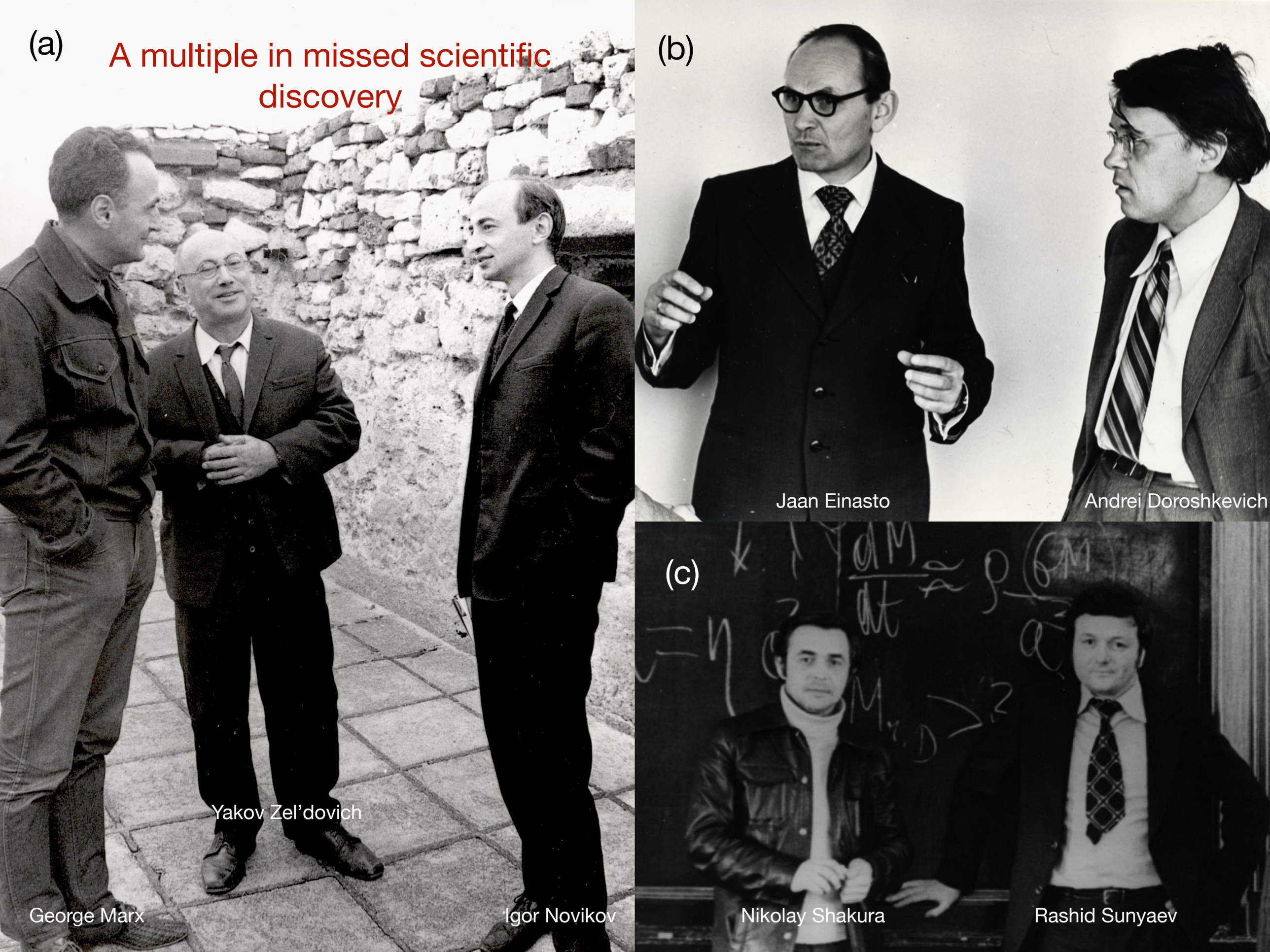
Ultra-Low-Noise Measurements Using a Horn Reflector Antenna and a Traveling-Wave Maser

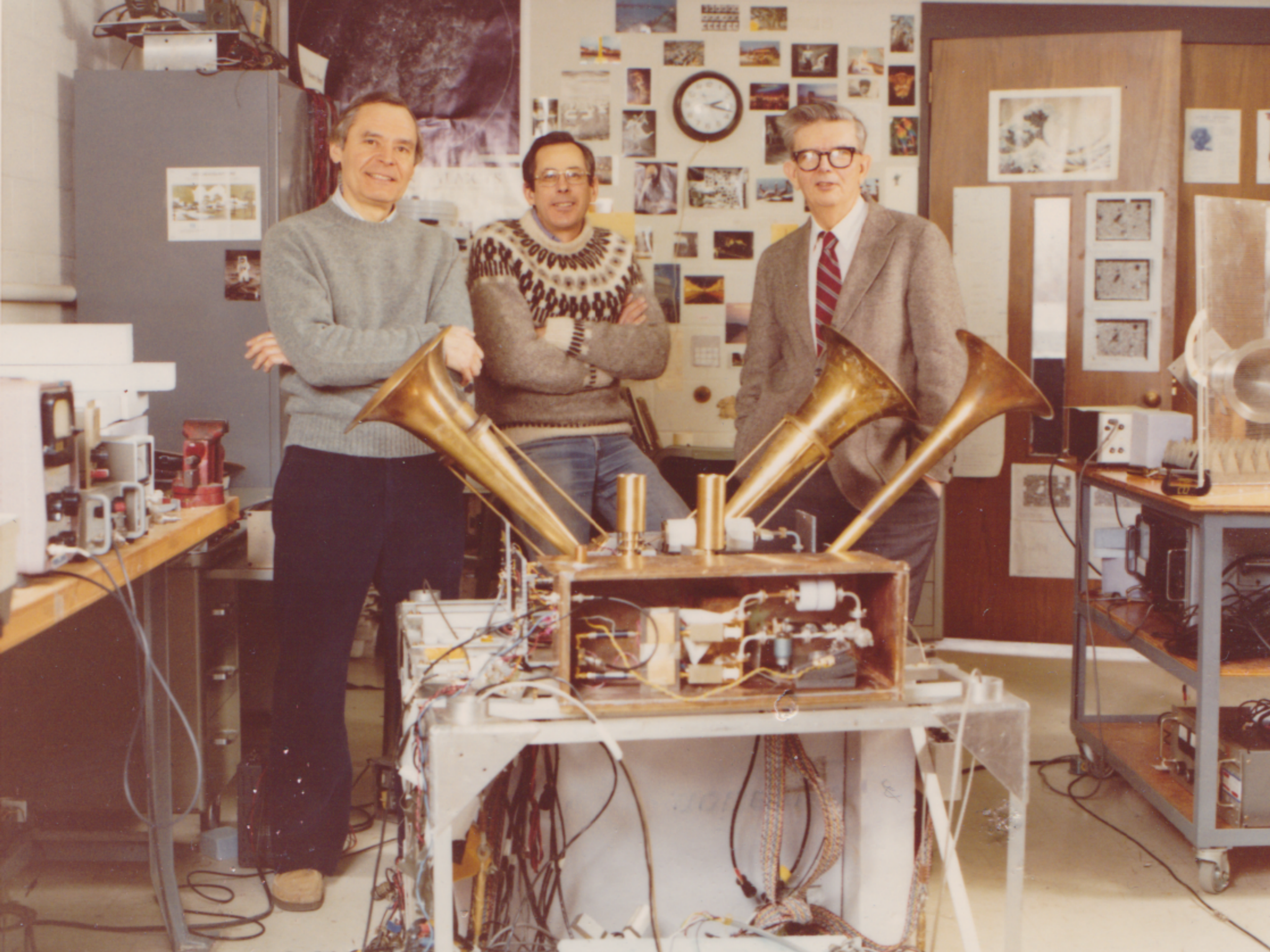
R. W. DeGrasse, D. C. Hogg, E. A. Ohm, and H. E. D. Scovil
Bell Telephone Laboratories, Inc., Murray Hill and Holmdel, New Jersey

(Received July 24, 1959)



A multiple in missed scientific discovery





A multiple in scientific discovery

A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE AT 4080 Mc/s

Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value about 3.5° K higher than expected. This excess temperature is, within the limits of our observations, isotropic, unpolarized, and

A. A. Penzias
R. W. Wilson

May 13, 1965
Bell Telephone Laboratories, Inc
Crawford Hill, Holmdel, New Jersey

We deeply appreciate the helpfulness of Drs. Penzias and Wilson of the Bell Telephone Laboratories, Crawford Hill, Holmdel, New Jersey, in discussing with us the result of their measurements and in showing us their receiving system. We are also grateful for several helpful suggestions of Professor J. A. Wheeler.

R. H. Dicke
P. J. E. Peebles
P. G. Roll
D. T. Wilkinson

May 7, 1965
Palmer Physical Laboratory
Princeton, New Jersey

REFERENCES

Alpher, R. A , Bethe, H. A , and Gamow, G 1948, *Phys. Rev.*, **73**, 803
Alpher, R A., Follin, J W., and Herman, R. C. 1953, *Phys. Rev* , **92**, 1347.
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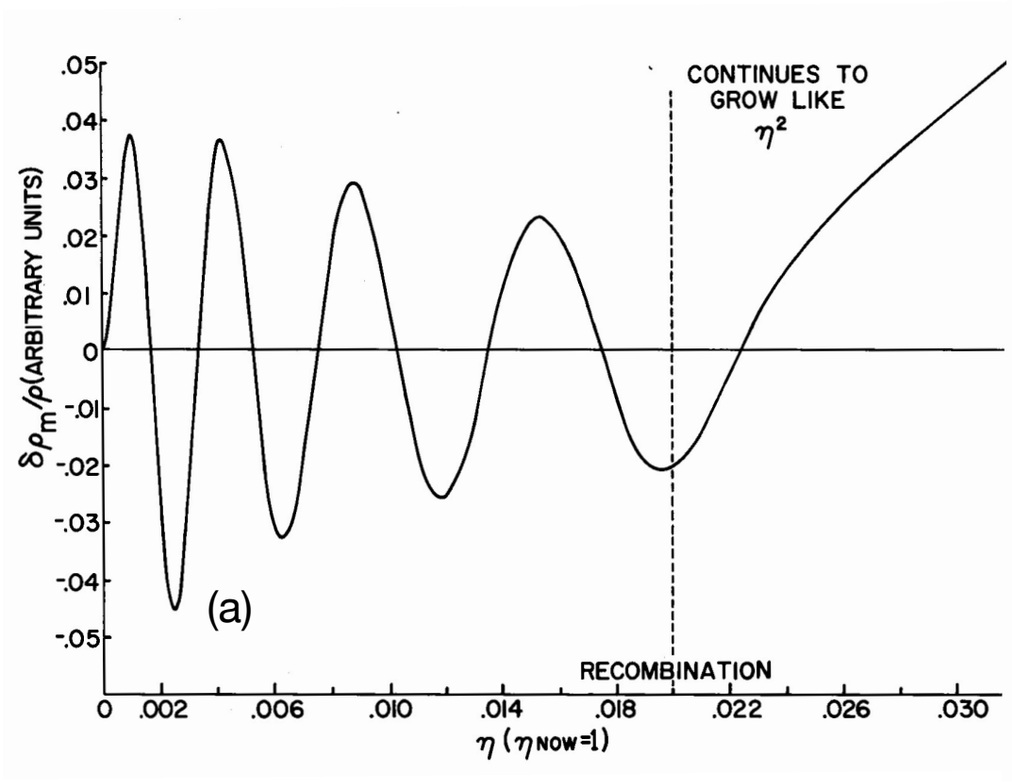
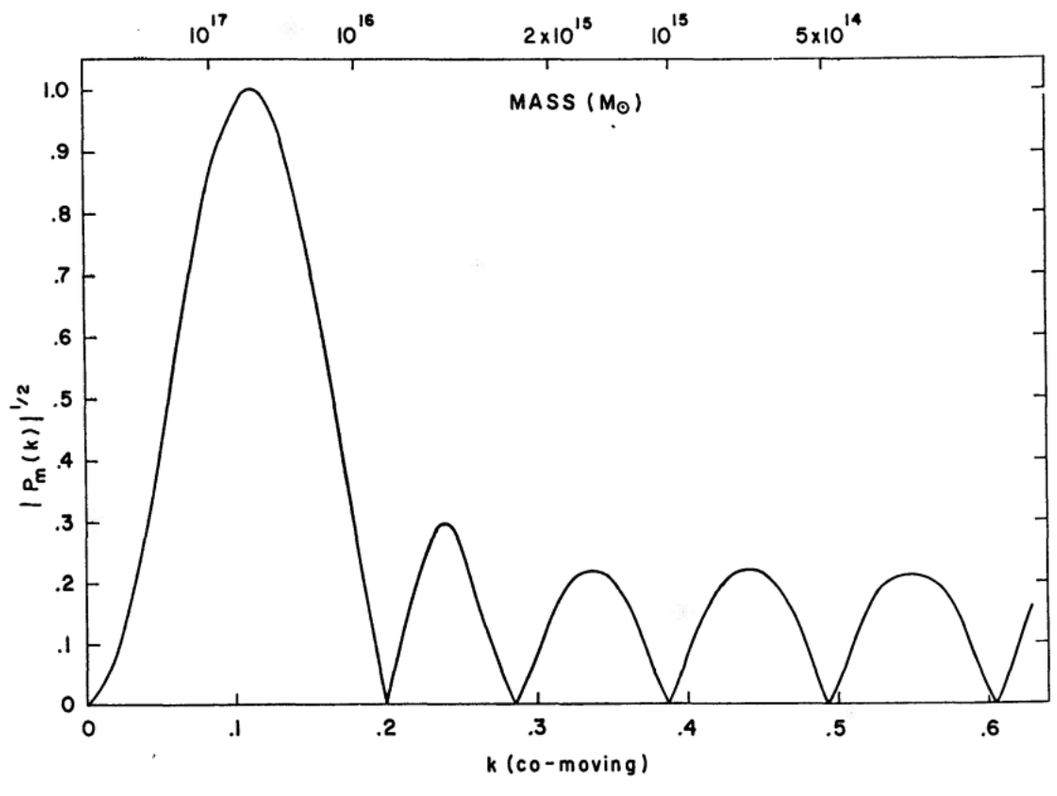
Another Multiple: Baryon Acoustic Oscillations

In the “Cold Dark Matter” cosmology the early universe was hot, baryons were thermally ionized, and plasma and radiation behaved as a viscous fluid. At redshift z~ 1000 the plasma combines, largely to atomic hydrogen and helium, and the radiation then propagates almost freely.

The results are patterns in the distributions of matter and radiation.



October 1968. Preliminary but reasonable



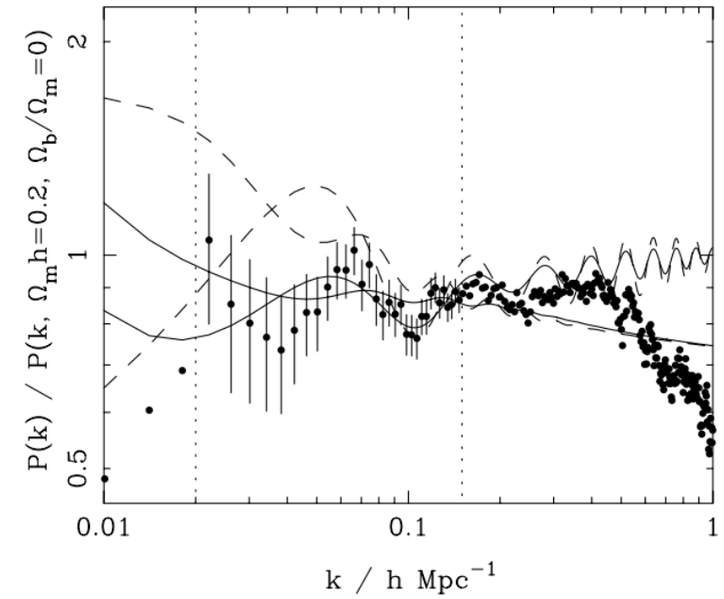
Peebles and Yu 1970

More multiples in scientific discovery

2001

The 2dF Galaxy Redshift Survey: the power spectrum and the matter content of the Universe

Will J. Percival,[1★] Carlton M. Baugh,[2] Joss Bland-Hawthorn,[3] Terry Bridges,[3] Russell Cannon,[3] Shaun Cole,[2] Matthew Colless,[4] Chris Collins,[5] Warrick Couch,[6] Gavin Dalton,[7] Roberto De Propris,[6] Simon P. Driver,[8] George Efstathiou,[9] Richard S. Ellis,[10] Carlos S. Frenk,[2] Karl Glazebrook,[11] Carole Jackson,[4] Ofer Lahav,[9] Ian Lewis,[3] Stuart Lumsden,[12] Steve Maddox,[13] Stephen Moody,[9] Peder Norberg,[2] John A. Peacock,[1] Bruce A. Peterson,[4] Will Sutherland[1] and Keith Taylor[3]

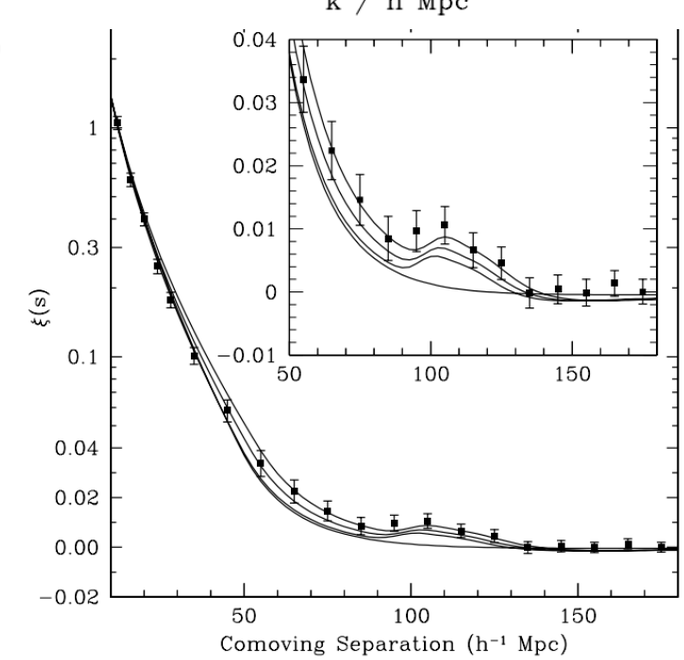


2005

DETECTION OF THE BARYON ACOUSTIC PEAK IN THE LARGE-SCALE CORRELATION FUNCTION OF SDSS LUMINOUS RED GALAXIES

Daniel J. Eisenstein,[1,2] Idit Zehavi,[1] David W. Hogg,[3] Roman Scoccimarro,[3] Michael R. Blanton,[3] Robert C. Nichol,[4] Ryan Scranton,[5] Hee-Jong Seo,[1] Max Tegmark,[6,7] Zheng Zheng,[8] Scott F. Anderson,[9] Jim Annis,[10] Neta Bahcall,[11] Jon Brinkmann,[12] Scott Burles,[7] Francisco J. Castander,[13] Andrew Connolly,[5] Istvan Csabai,[14] Mamoru Doi,[15] Masataka Fukugita,[16] Joshua A. Frieman,[10,17] Karl Glazebrook,[18] James E. Gunn,[11] John S. Hendry,[10] Gregory Hennessy,[19] Zeljko Ivezić,[9] Stephen Kent,[10] Gillian R. Knapp,[11] Huan Lin,[10] Yeong-Shang Loh,[20] Robert H. Lupton,[11] Bruce Margon,[21] Timothy A. McKay,[22] Avery Meiksin,[23] Jeffery A. Munn,[19] Adrian Pope,[18] Michael W. Richmond,[24] David Schlegel,[25] Donald P. Schneider,[26] Kazuhiro Shimasaku,[27] Christopher Stoughton,[10] Michael A. Strauss,[11] Mark SubbaRao,[17,28] Alexander S. Szalay,[18] István Szapudi,[29] Douglas L. Tucker,[10] Brian Yanny,[10] and Donald G. York[17]

Received 2004 December 31; accepted 2005 July 15

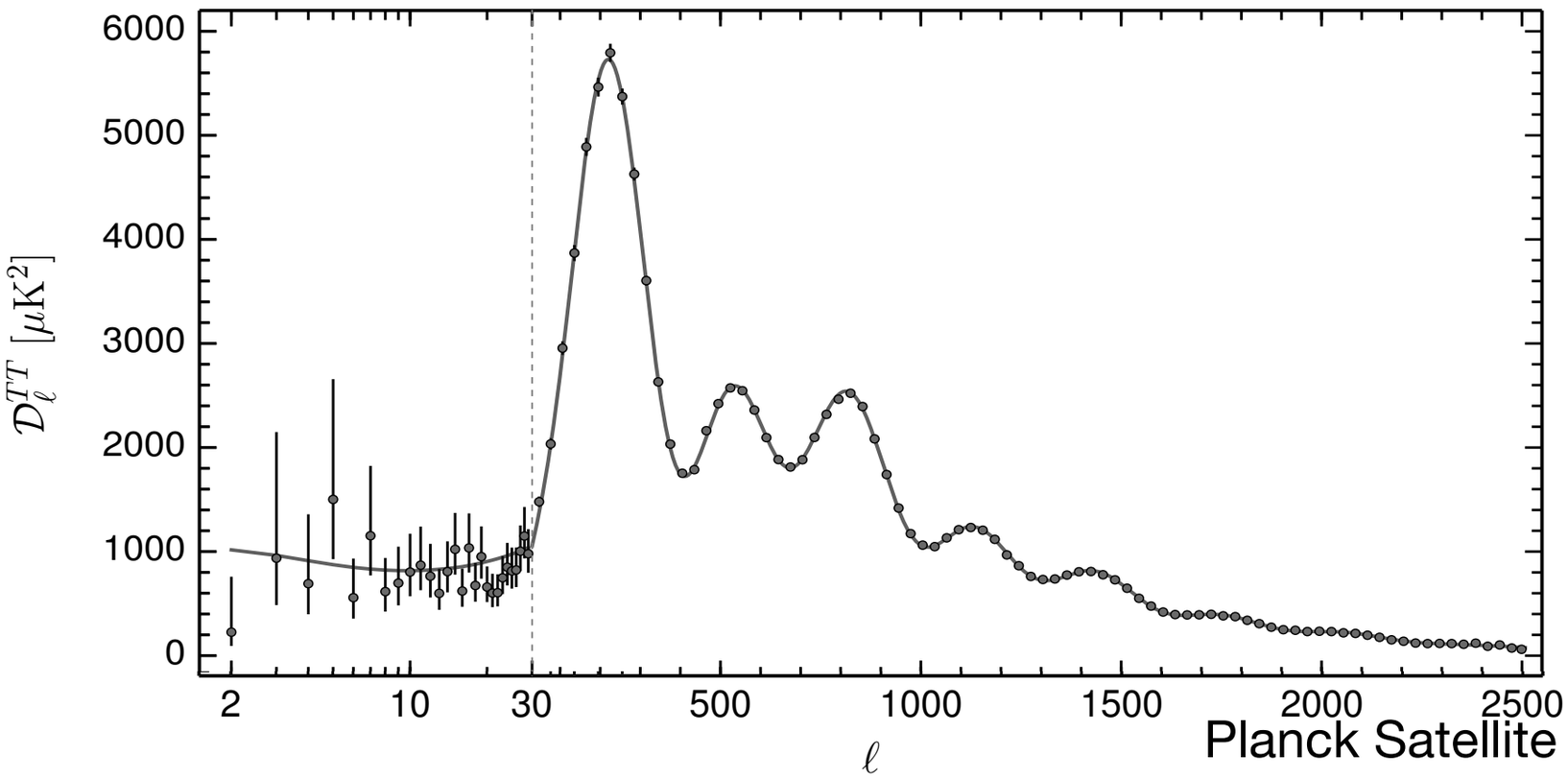


The effect was understood in the 1960s, computed by Peebles and Yu in 1970.

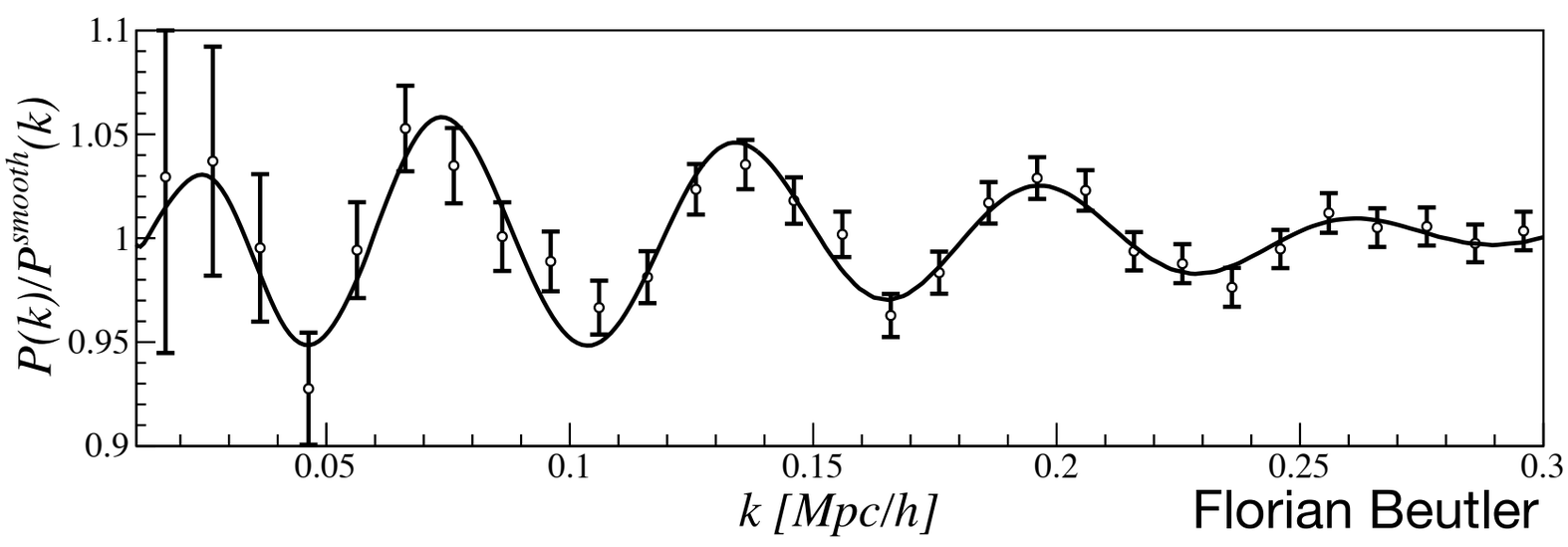
It was first observed in the galaxy distribution by Percival, Baugh, Bland-Hawthorn, et al 2001, MN 327.

The effect was independently predicted and detected in the galaxy two-point correlation function by Eisenstein et al. in 2005, ApJ 633.

Such is the nature of progress in physical science.

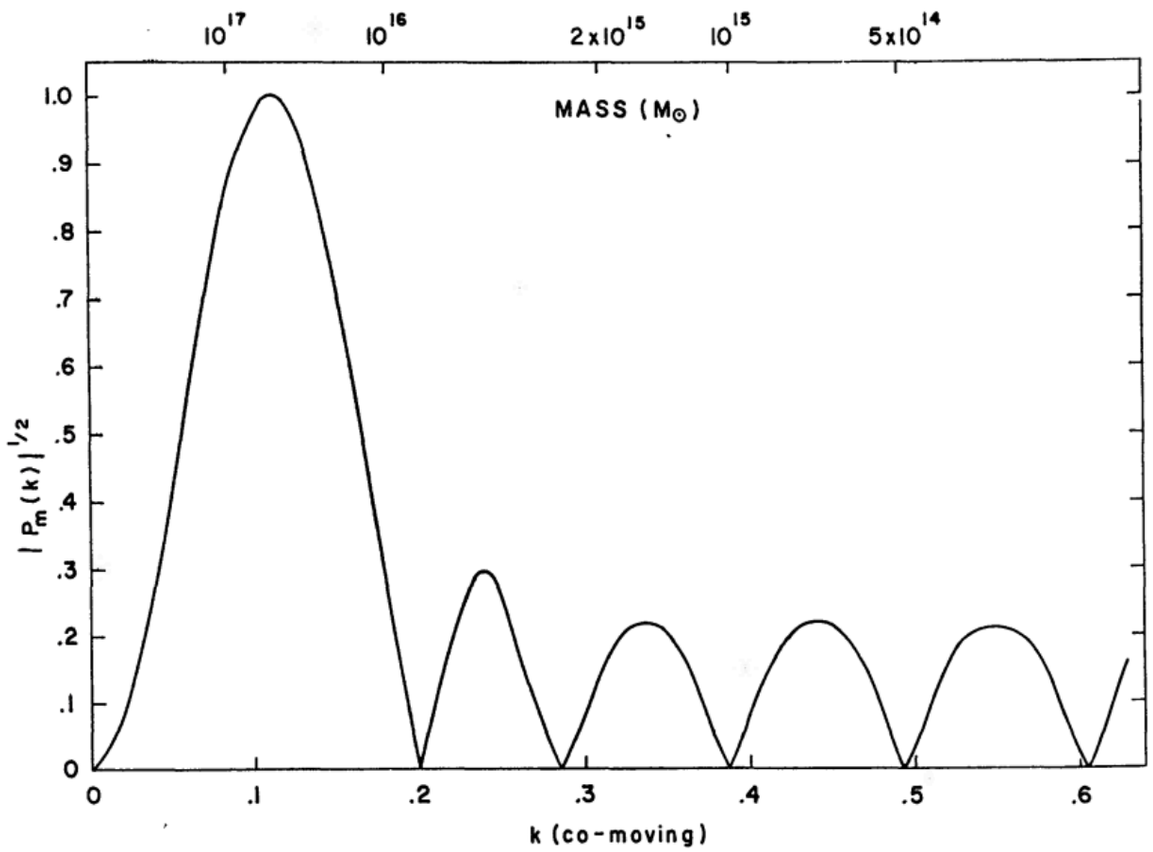


Planck Satellite

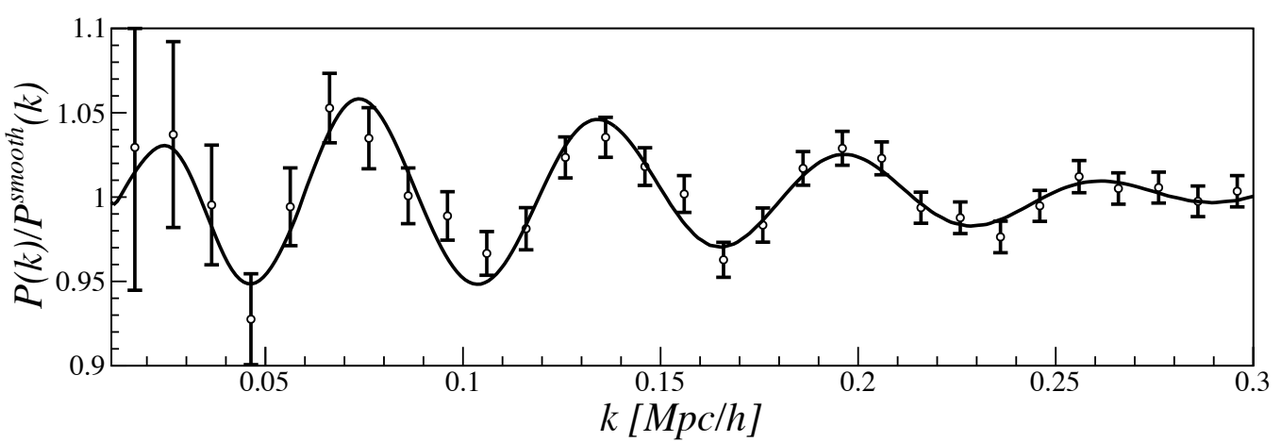


Florian Beutler

The theory of these acoustic oscillations in the measured angular distribution of the fossil thermal radiation and the measured spatial distribution of the galaxies requires the cosmological constant that Einstein introduced in 1917 and later regretted. Nature continues to surprise us.



Peebles and Yu 1970



Florian Beutler, from BOSS collaboration 2017

The 1970 computation assumed matter is baryonic. Hence the zeros in the matter power spectrum.

The amplitude is much smaller in Beutler's spectrum, because the dark matter does not take part in the acoustic oscillations, apart from gravity.

Dark matter was introduced in 1982 to take care of another problem, the small CMB anisotropy. The low amplitude of the oscillations in the power spectrum is independent evidence of dark matter.

We care a lot about independent evidence; recall Charles Saunders Pierce's comments a century ago.

Osterbrock and Rogerson recognized evidence of Gamow's hot big bang, the large abundance of helium. They published, but the community noticed only much later. Here is an example of the sociologist's multiples in scientific discovery.

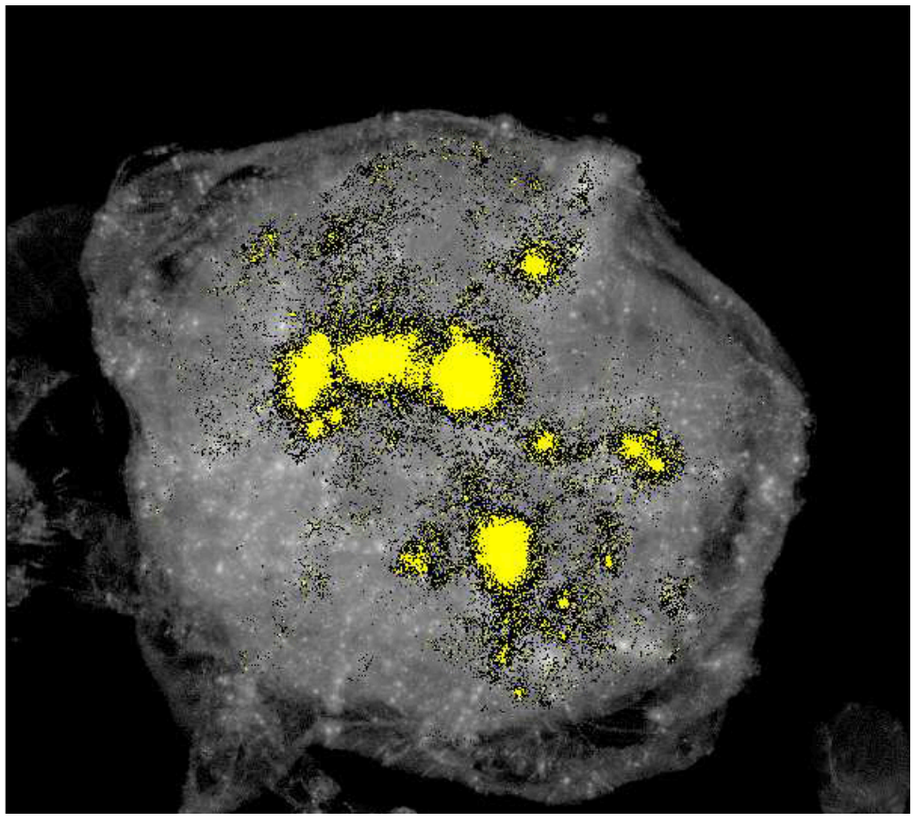
Along with multiples of discovery there have to be discoveries just missed. Hoyle knew evidence of the radiation from Gamow's hot big bang in 1950, but forgot by 1964.

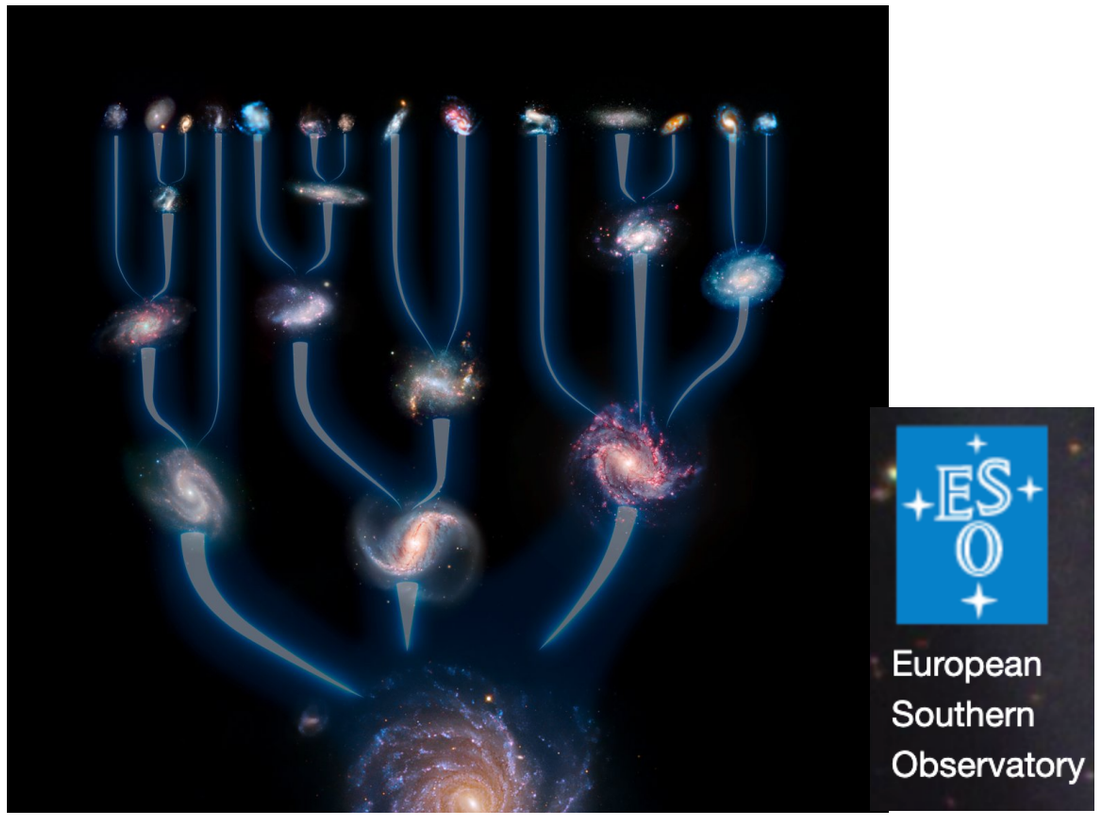
Zel'dovich thought the helium abundance is too small for Gamow's picture. A short conversation with a knowledgable astronomer would have set Zel'dovich straight, but that was not allowed; Zel'dovich knew too much about the Soviet nuclear weapons program.

Along with multiple earlier overlooked scientific discoveries I expect (hope) there are other hints to important discoveries yet to be recognized. Here is a possible example.

1. The Halo Merger Tree Paradigm

z=3.1

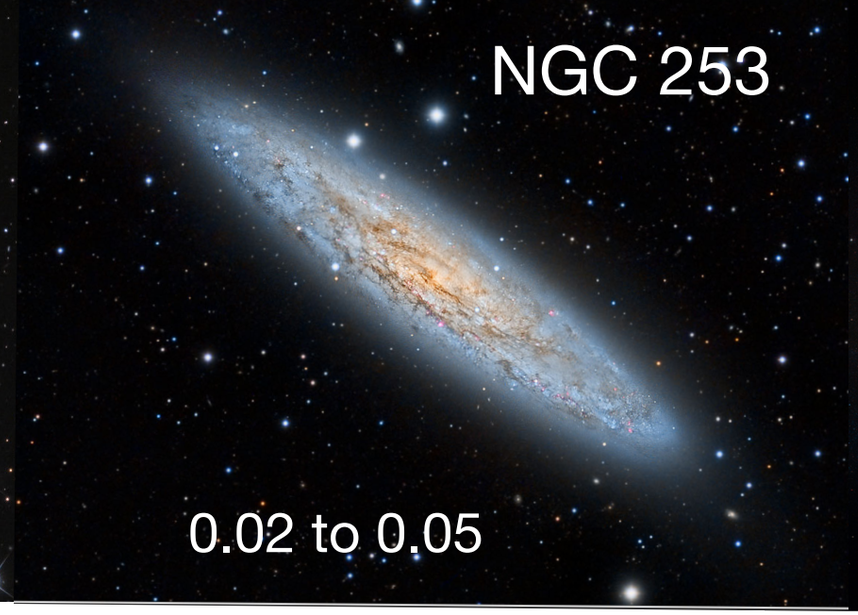


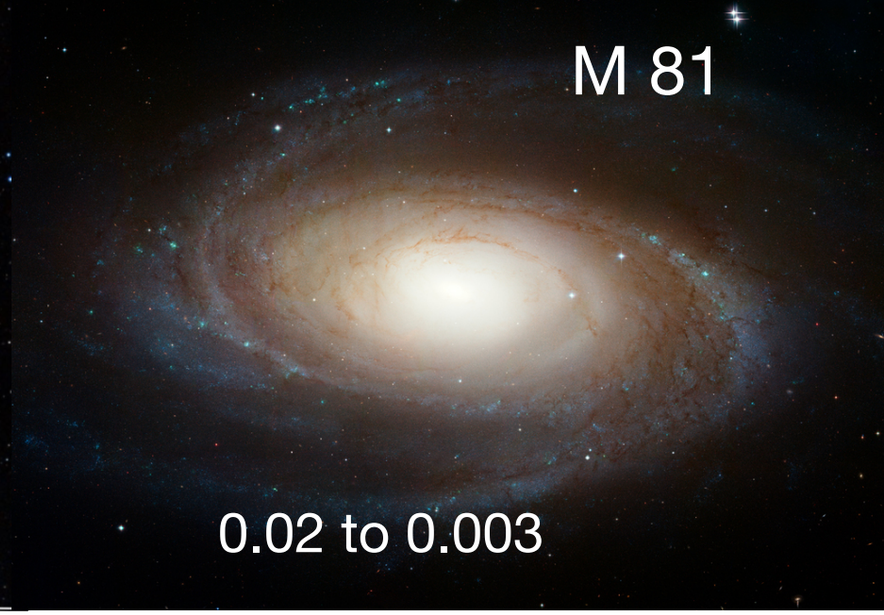


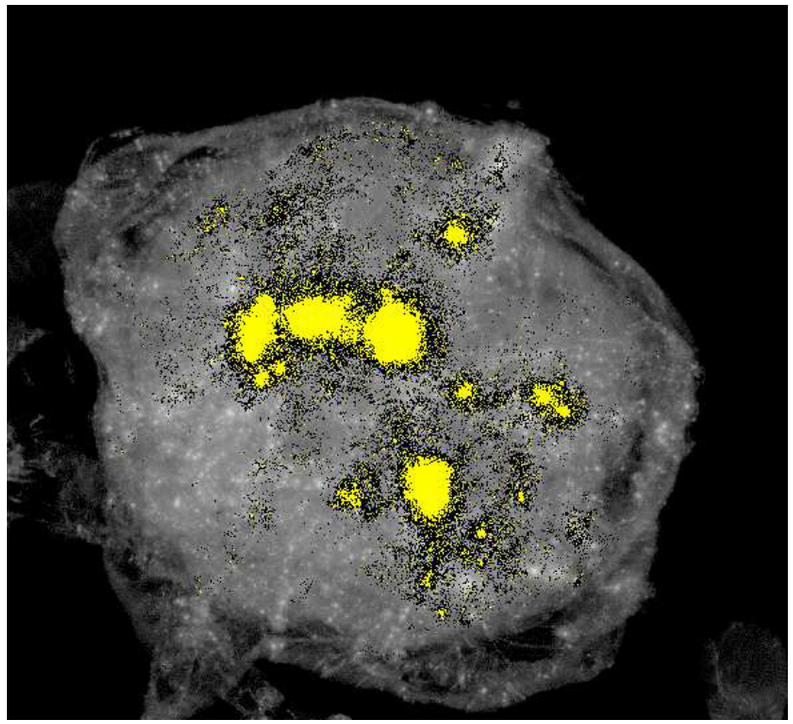
Auriga simulation, image by Jie Wang

The merger tree concept is inspired by the standard ΛCDM theory. It is influential; ADS astronomy lists “merger tree” in the contents of

327 papers in 2022,
268 papers in 2021,
274 papers in 2020.







Auriga simulation, Redshift z = 3.1. Image by Jie Wang.

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **466,** 1491–1512 (2017)
Advance Access publication 2016 November 22
doi:10.1093/mnras/stw2992

Diverse stellar haloes in nearby Milky Way mass disc galaxies

Benjamin Harmsen,[1★] Antonela Monachesi,[2★] Eric F. Bell,[1★] Roelof S. de Jong,[3] Jeremy Bailin,[4,5] David J. Radburn-Smith[6] and Benne W. Holwerda[7]

If these disk galaxies grew by merging of subhalos, as expected in ΛCDM, then star formation had to have been almost entirely confined to just one of the subhalos. How could that have happened?

The merger tree is a social construction, supported by theory but not observation. Nothing wrong with that; so was GR. But this one seems unlikely.

COSMOLOGY MARCHES ON

I don’t imagine natural science ever will be in a position to say with certainty “where it all came from.”

But consider:

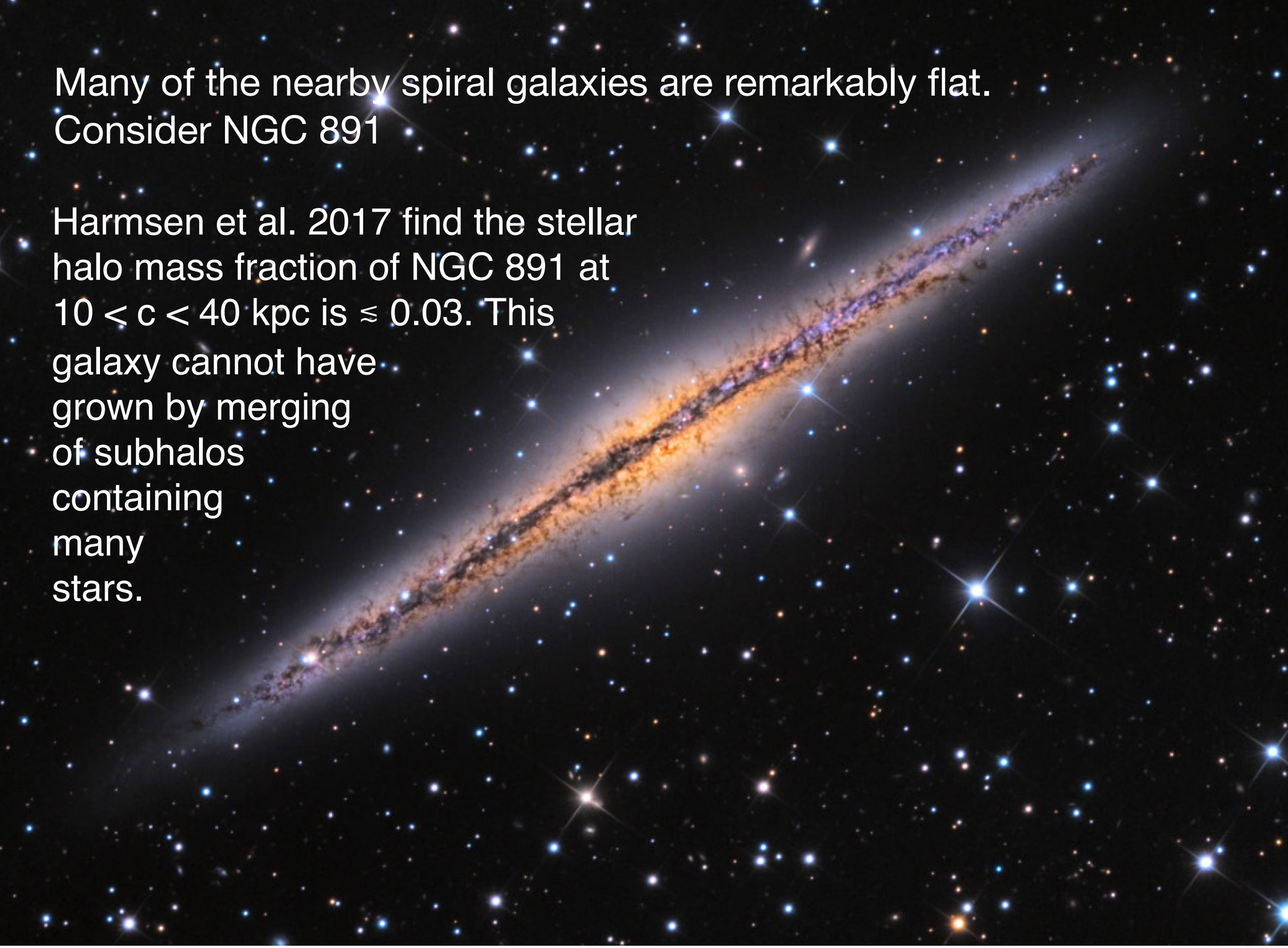
“The world is full of a number of things,
I'm sure we should all be as happy as kings.”
Robert Louis Stevenson

The world around us is full of a vast number of things, and we continue to learn how to find and make sense of them, in the tradition of natural science.

Mergers happen, in the ΛCDM theory and in nature.

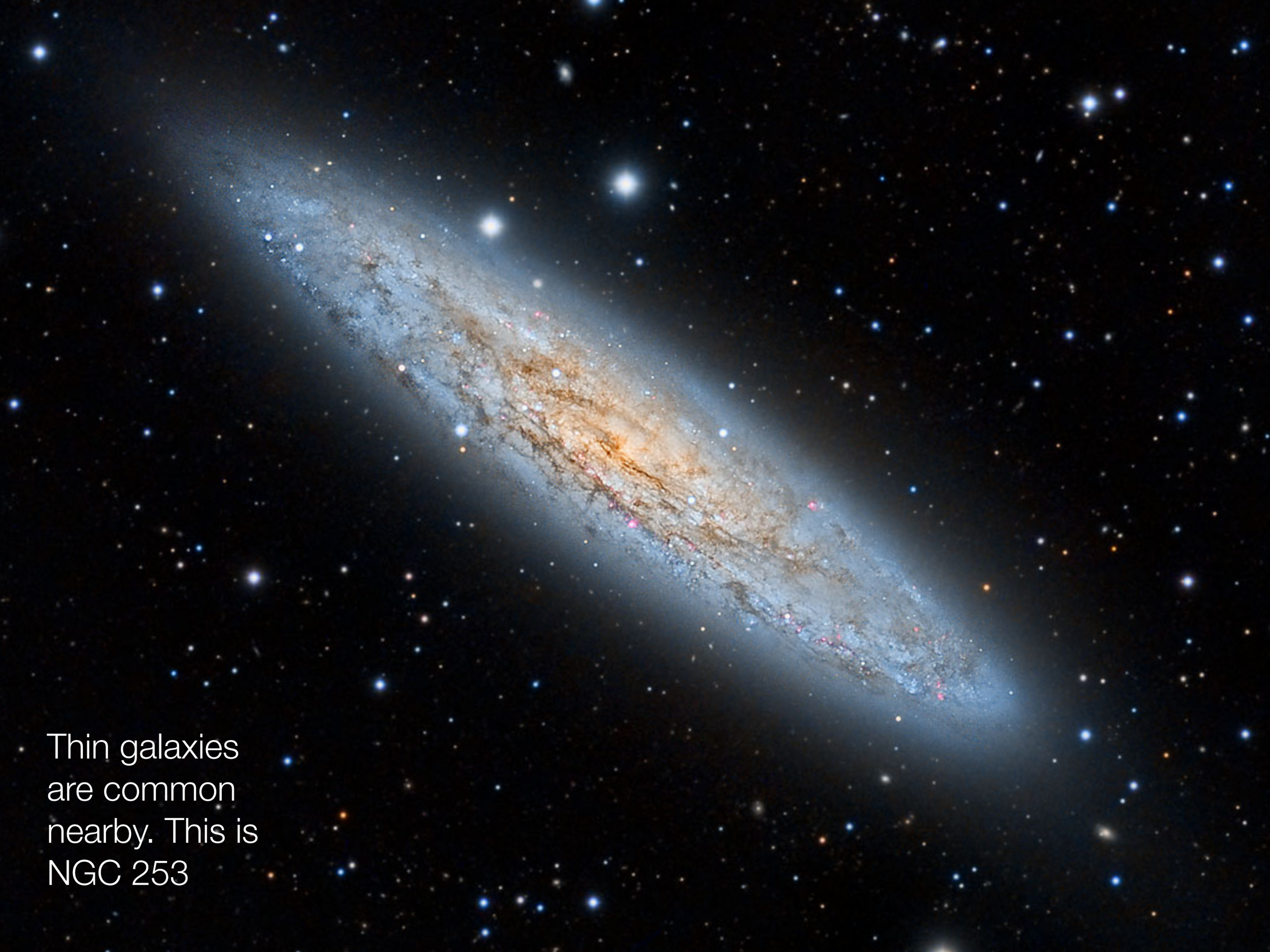
But there are observational challenges to the merger tree concept.

We can’t blame the galaxy formation theorists for these challenges; they’re doing the best they can with the theory they’ve been given. Let us consider instead the thought that these challenges a hint to an even better theory than ΛCDM.



Many of the nearby spiral galaxies are remarkably flat. Consider NGC 891

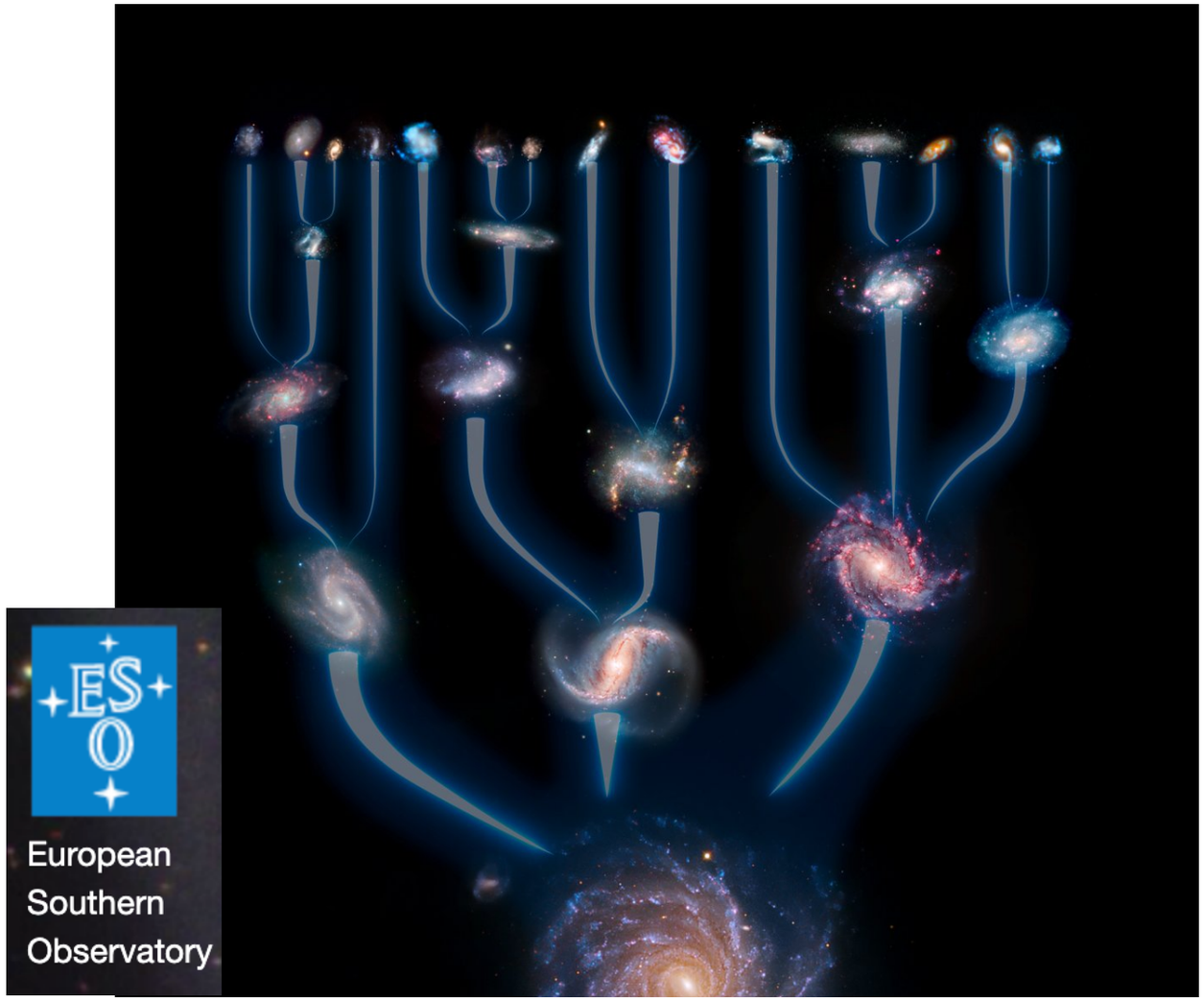
Harmsen et al. 2017 find the stellar halo mass fraction of NGC 891 at $10 < c < 40$ kpc is $\lesssim 0.03$. This galaxy cannot have grown by merging of subhalos containing many stars.



Thin galaxies are common nearby. This is NGC 253


M101, Kormendy, Drory, Bender & Cornell, ApJ **273** 2010
$M_{\rm BH} < 3 \times 10^6 m_\odot$
HST image
M 101
R. Gendler
HST images plus H-α and some ground-based data

The halo merger tree



This is a useful approximation to cosmic structure formation according to the standard ΛCDM theory.

The merger tree concept is influential: ADS astronomy lists “merger tree” in the text of
327 entries in 2022,
268 entries in 2021,
274 entries in 2020.

The merger tree concept is influential, but a social construction. There’s nothing wrong with that; GR was a social construction in the 1950s. But promotion does not always happen.

full:"merger tree" collection:astronomy year:2022