The Nobel Prize in Physics 2019

James Peebles

"for theoretical discoveries in physical cosmology"

James Peebles Ill. Niklas Elmehed. © Nobel Media.

Michel Mayor

"for the discovery of an exoplanet orbiting a solar-type star"

Michel Mayor Ill. Niklas Elmehed. © Nobel Media.

Didier Queloz

"for the discovery of an exoplanet orbiting a solar-type star"

Didier Queloz Ill. Niklas Elmehed. © Nobel Media.

Jim Peebles and the Nascence of Physical Cosmology

福來正孝

Institute for Advanced Study, Princeton

16 March 2020

Chronicle of Cosmology — pre war period

1915/6 Einstein: General Relativity $R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R - \Lambda g_{\mu\nu} = -8\pi G T_{\mu\nu}$

1917 Einstein: GR applies to understanding the Universe

1922 Friedman: Cosmological solution: ODE

1927 Lemaître: Distance-Velocity relation ("Hubble law")

+ identified as the expansion in Einstein eq.

1929 Hubble: Distance-Velocity relation = Hubble law post war till 1965

Gamow 1946 + (Alpher, Herman 1948-1950)

extrapolate expansion to t=0: hot Big Bang

Lifshitz 1946 perturbation theory in expanding Universe

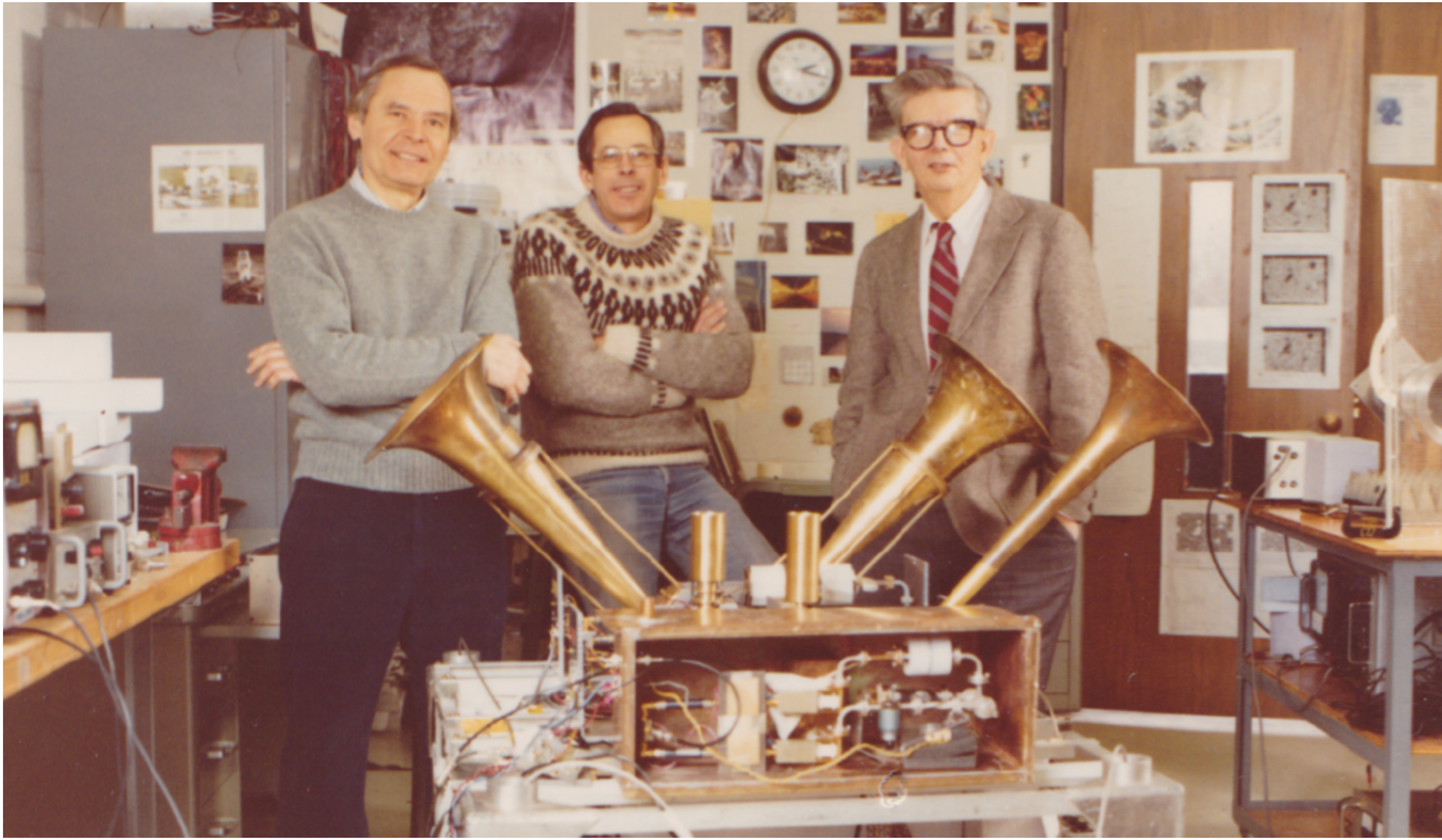
Hayashi 1950 beta equilibrium: (p,n) abundances

Peebles 1965; Dicke, Peebles, Roll, Wilkinson 1965
(8 III 1965) (7 V 1965)
prediction of CMB

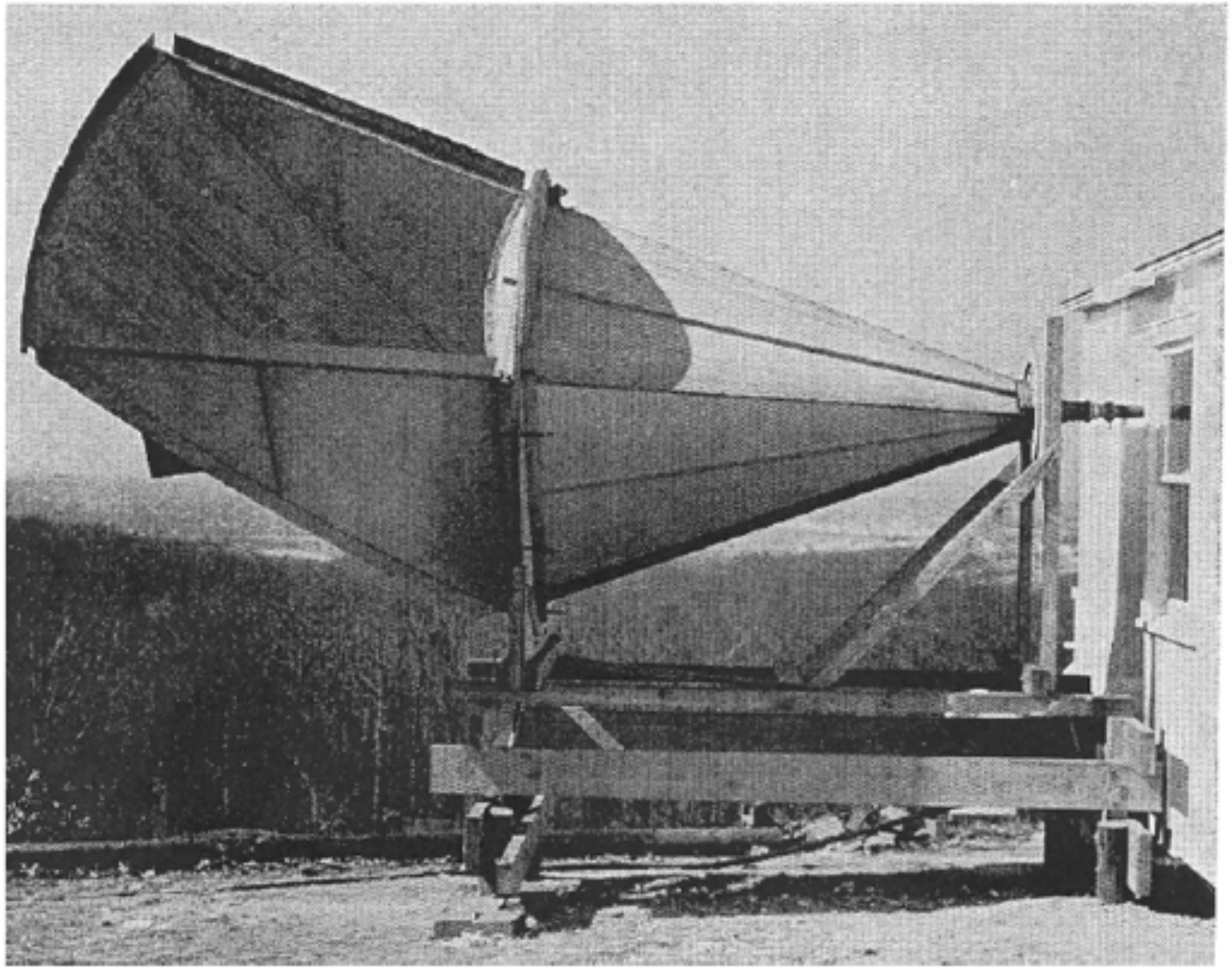
Penzias, Wilson 1965 (13 V 1965) CMB discovered!

Peebles 1968 generation of black-body radiation

6.2.3. The burst of energy after the war, in the late 1940s through the 1950s, gave us four remarkable cosmologists: Bob Dicke, George Gamow, Fred Hoyle, and Yakov Zel'dovich.



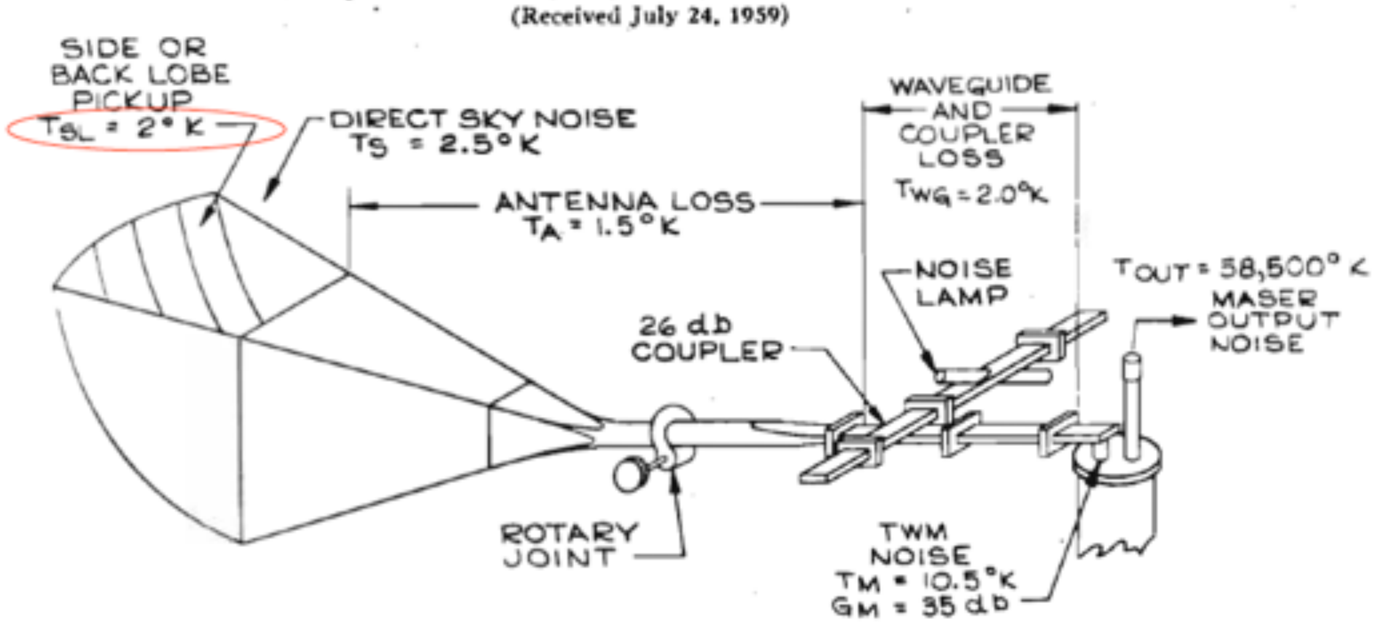
ca 1968

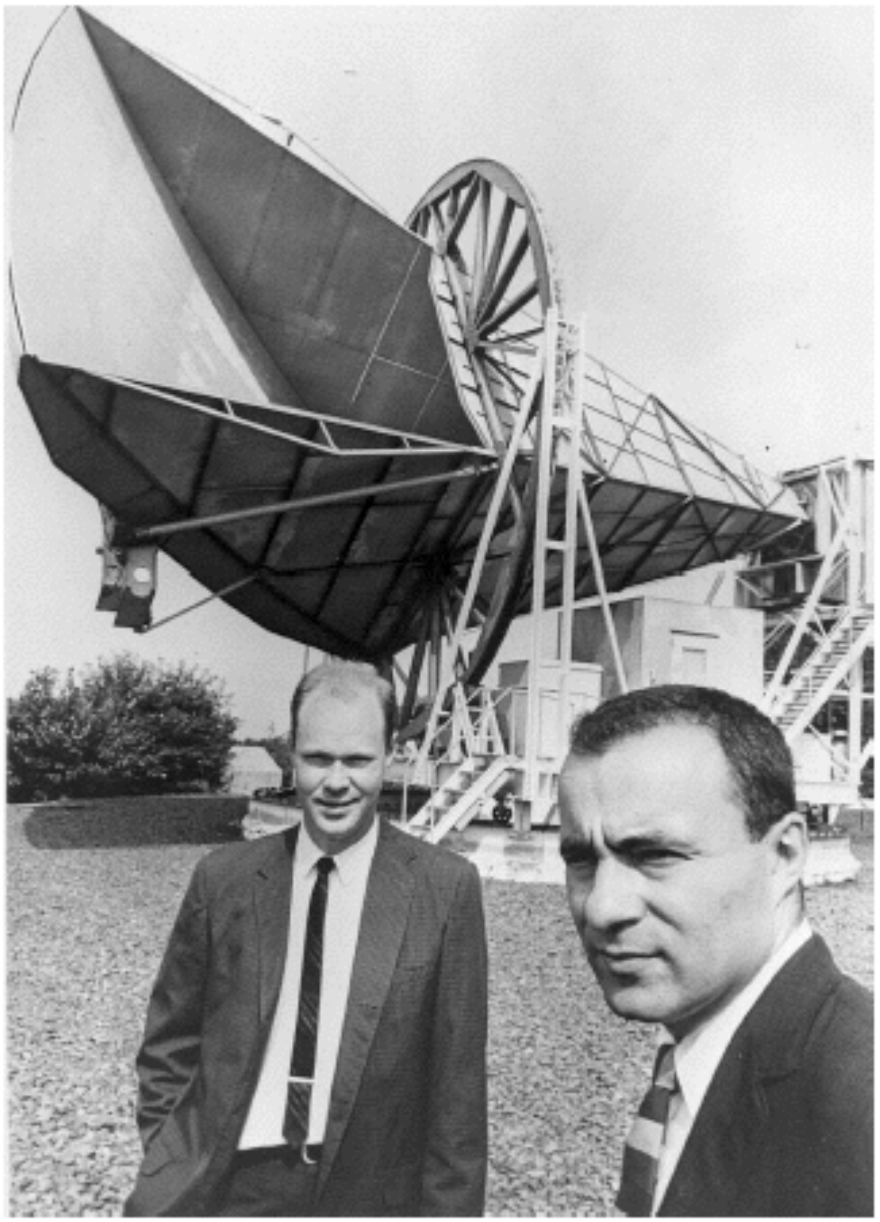


Bell Telephone Laboratories, Crawford Hill, New Jersey, about 1959

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)





Bob Wilson Arno Penzias

Peter Roll   David Wilkinson

COSMIC BLACK-BODY RADIATION*

One of the basic problems of cosmology is the singularity characteristic of the familiar cosmological solutions of Einstein's field equations. Also puzzling is the presence of matter in excess over antimatter in the universe, for baryons and leptons are thought to be conserved. Thus, in the framework of conventional theory we cannot understand the origin of matter or of the universe. We can distinguish three main attempts to deal with these problems.

1. The assumption of continuous creation (Bondi and Gold 1948; Hoyle 1948), which avoids the singularity by postulating a universe expanding for all time and a continuous but slow creation of new matter in the universe.

2. The assumption (Wheeler 1964) that the creation of new matter is intimately related to the existence of the singularity, and that the resolution of both paradoxes may be found in a proper quantum mechanical treatment of Einstein's field equations.

3. The assumption that the singularity results from a mathematical over-idealization,

390 citations
(164 to 1980)

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

VOLUME 142 NOVEMBER 15, 1965 NUMBER 4

177 citations
(97 to 1980)

THE BLACK-BODY RADIATION CONTENT OF THE UNIVERSE AND THE FORMATION OF GALAXIES*

P. J. E. Peebles
Palmer Physical Laboratory, Princeton University, Princeton, N J.
Received March 8, 1965; revised June 1, 1965

ABSTRACT

A critical factor in the formation of galaxies may be the presence of a black-body radiation content of the Universe. An important property of this radiation is that it would serve to prevent the formation of gravitationally bound systems, whether galaxies or stars, until the Universe has expanded to a critical epoch. There is good reason to expect the presence of black-body radiation in an evolutionary cosmology, and it may be possible to observe such radiation directly.

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

frequency range can be no steeper than $\lambda^{0.7}$. This clearly eliminates the possibility that the radiation we observe is due to radio sources of types known to exist, since in this event, the spectrum would have to be very much steeper.

A. A. Penzias
R. W. Wilson

May 13, 1965

Bell Telephone Laboratories, Inc
Crawford Hill, Holmdel, New Jersey

REFERENCES

see: ★Dicke, Behringer, Kyhl, Vene 1946 $T < 20\text{K}$

H.Tanaka, Kakinuma, Sindo, Takayanagi 1953 $T < 5\text{K}$

★Crawford, Hogg, Hunt (Bell Lab) 1961 $\Delta T = 3.5K$

★Legacy of war efforts:
advanced microwave technology!

1. Lamb shift
2. exploring microwave sky

Discovery of CMB: Great epoch for physical cosmology
Penzias-Wilson & Peebles

極波における天頂温度の置換測定について

田中寧夫　柿沼隆清
紳藤英彦　高柳利男

I. 緒言

天体電波の輻射強度を知る爲には天頂温度を正確に知る必要があるし，又天頂温度が分つていれば高温の精度所謂熱負荷を用いなくても radiometer を較正することが出来る．然るに天頂温度に関する二三の文献(1)(2)(3) を見てもこの温度を明記したものが見当らないので以下に述べる実験を行つた．

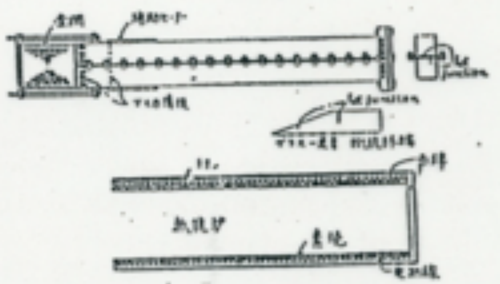
II. 置換法

置換法と云つても絶対零度附近(天頂温度は絶対零度近くである)の抵抗負荷と置換することは不可能である．併し i-f 出力を第1図の如く表わせば，

第1図

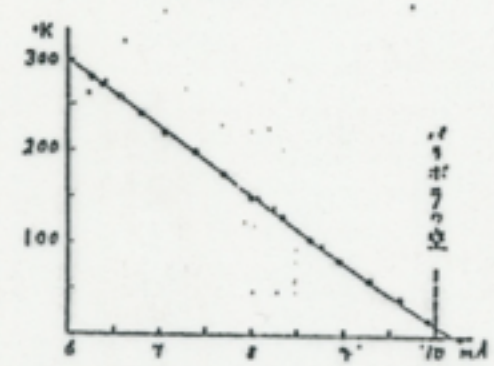
$N = FGkTB$

第2図



図の様に折り曲げて作り全部ビス止めとした．この様に中央で合せる様にした方が角をビス止めするより損失が少いと考えられる．抵抗膜はガラスの上にアカダックを塗布したものを2枚合せて用い，整温で整合をとつておくと 300°C にしても整合は VSWR にして 1.05 以内に保たれる．これを加熱するには第2図に示す様な炉の中に入れるのであるが，導波管の熱伝導が極めてよい爲金属導波管を入口につけて冷却するのを防いだ．測定中この金属の部分が動くと整合がくずれるので，支柱をつけて補強してある．又空気の対流による冷却を防止する爲に 0.1 mm 程度のマイカ板を2枚図の様に挿入した．以上の考慮を持つても入口

第9図



さて抛物面反射鏡には漏洩及び損失があるのでこれは天頂温度を示していない筈である．

そこで又これを長さ約 2 m の電磁ラッパにおきかえてその差を数回測定した．その結果約 10°K と云う値を得たので天頂温度は −2°〜3°K と云うことになるが，これが負であることは考えられないので 0°〜3°K と云うことになる．併し各部の誤差が全く除かれていると云うことはあり得ないから目下の所大体 0°〜5°K と云うことしか云えない．

IX. 螢光燈雑音源の等価温度の測定

以上述べた測定により天頂温度が求められ受信機の較正が出来たので螢光灯の雑音等価温度を測定してみた．

変動の可能性については触れなかつたが，この測定については別に考えなければならない．

末筆ながら本研究に絶大なる御支援を賜わつた東大高周波研究室霜田助教授，板井助教授，田宮潤氏並びに東京芝浦電気株式会社の方々に厚く感謝の意を表する．

文献

(1) A. E. Covington: Proc. I. R. E. (April, 1948).
(2) A. E. Covington: "Microwave Sky Noise." Jour. Geophys. Res. 55, No. 1 (March, 1950).
(3) J. L. Lawson, G. E. Uhlenbeck: "Threshold Signals." M. I. T. Rad. Lab. Series. 24.
(4) C. G. Montgomery: "Technique of Microwave Measurement." M. I. T. Rad. Lab. Series. 11.

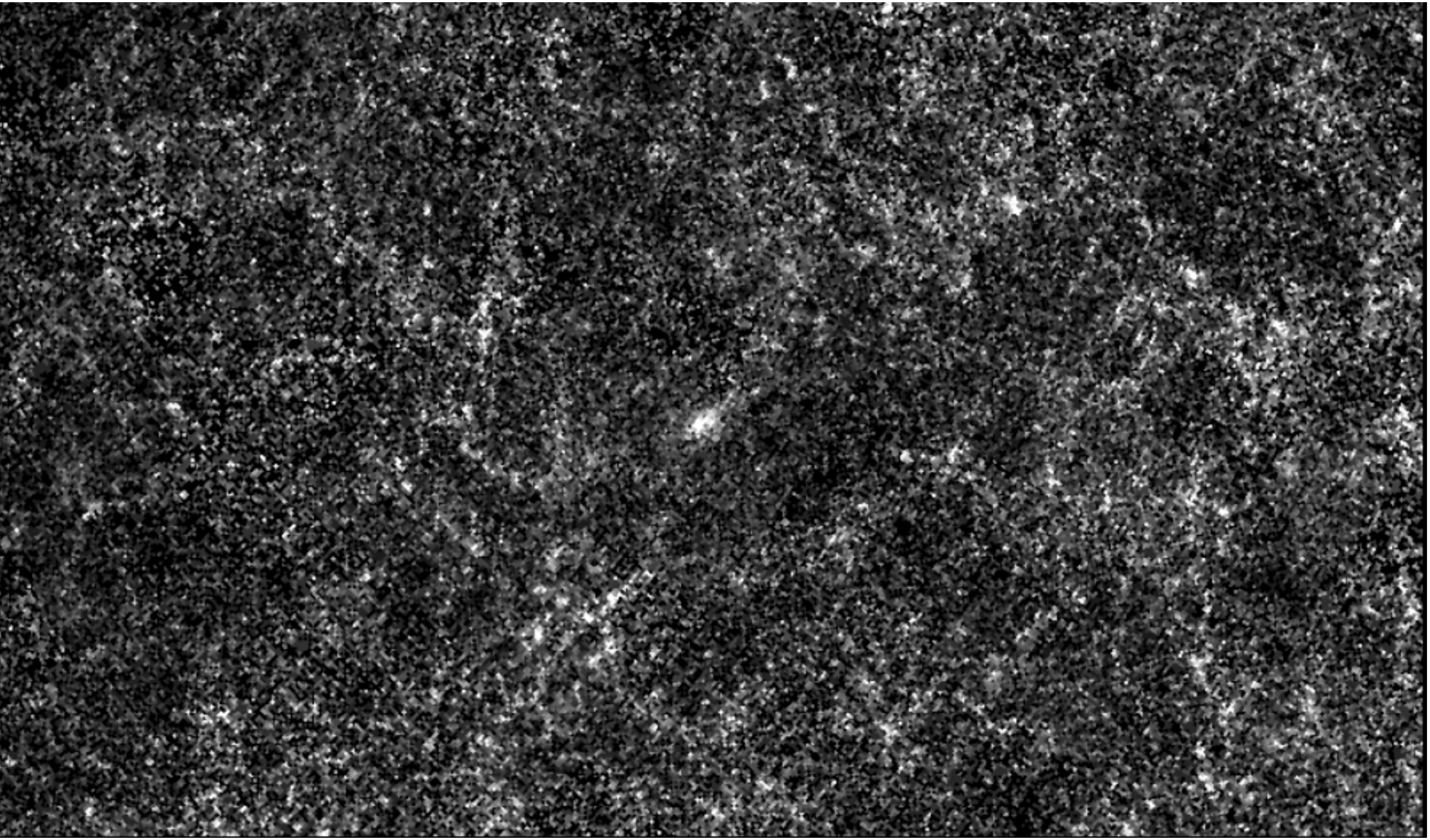
附記

文献(2)によれば大氣の吸收が大きければ，次の方法によつても天頂温度を求め得る．

T_θ を天頂から角 θ の方向にアンテナを向けたときのアンテナ等価温度，T を大氣温とすれば

$T_\theta/T = 1-(1-T_0/T)^{\sec\theta}$ なる関係がある．

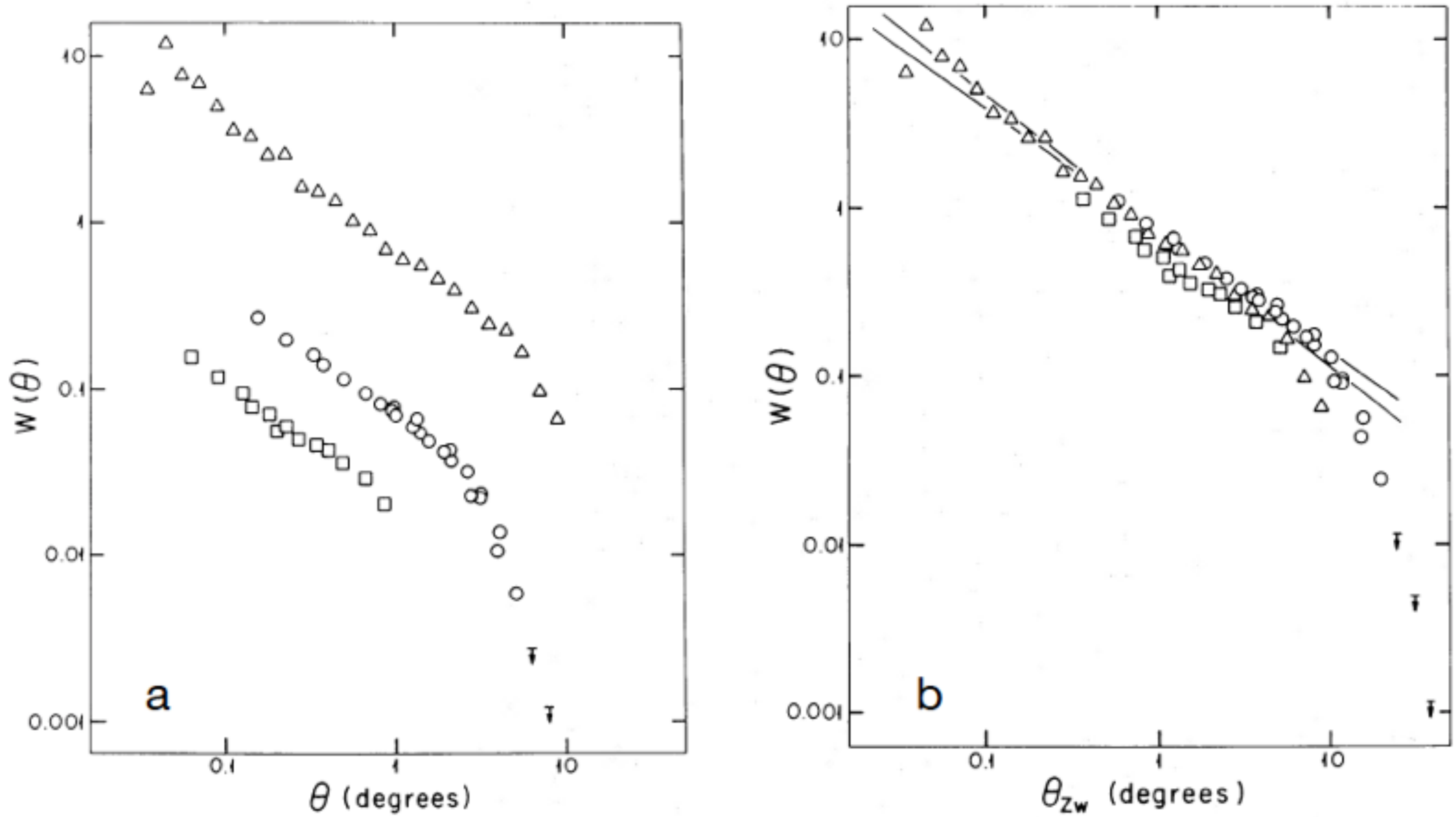
今アンテナを天頂に向けた時の振れを D_0，天頂か



Shane-Wirtanen (Seldner) sky 1967

statistic introduced: two point correlation function $\xi(r) = \langle \rho(x+r)\rho(x) \rangle$

$2D$ projection : $\mathrm{w}(\theta)$



Groth and Peebles 1977

CMB fluctuations - cosmic structure connexion: $\Delta T/T$ vs $\Delta\rho/\rho$

Sunyaev Zeldovich 1970

Peebles Yu 1970

Statistical distribution of galaxies Peebles 1973 -

w/ Ed Groth, Jim Fly, Mike Seldner, Mark Davis, …

$$2D \rightarrow 3D$$

$$\xi(r) = \langle \rho(x+r)\rho(x) \rangle$$

$$w(\theta) \sim \int \xi(x) dz$$

Infinite amount of work created!

1992 COBE DMR brought us a very good news
that we are on the right track:
gravitational instability theory is correct
but amplitudes are too small by 100 times

COBE DMR temp. fluctuation

$$\Delta T/T \sim 10^{-5}$$

convincing evidence for ‘dark matter’

Dark matter

massive neutrinos:

Cowsik, McClelland 1972 $m_\nu \leq 30\text{eV}$

heavier neutrinos: May-June 1977:

Hut, Lee-Weinberg, Sato-Kobayashi,

Dicus-Kolb-Teplitz, Vysotskii et al.

heavy hypothetical neutral particles = ‘cold dark matter’

$\sim$ keV neutrinos

Pagels-Primack 17 Aug 1981

give a right characteristic mass for galaxies $M \sim 10^{12} M_\odot$

Bond-Szalay-M.Turner 4 Dec 1981

Blumenthal-Pagels-Primack 5 Jan 1982

Peebles 2 July 1982

they give a proper perturbation spectrum

→ Era of simulations

THE ASTROPHYSICAL JOURNAL, 263:L1–L5, 1982 December 1

The CDM Cosmology

LARGE-SCALE BACKGROUND TEMPERATURE AND MASS FLUCTUATIONS DUE TO SCALE-INVARIANT PRIMEVAL PERTURBATIONS

P. J. E. PEEBLES
Joseph Henry Laboratories, Physics Department, Princeton University
Received 1982 July 2; accepted 1982 August 13

ABSTRACT

The large-scale anisotropy of the microwave background and the large-scale fluctuations in the mass distribution are discussed under the assumptions that the universe is dominated by very massive, weakly interacting particles and that the primeval density fluctuations were adiabatic with the scale-invariant spectrum $P \propto$ wavenumber. This model yields a characteristic mass comparable to that of a large galaxy independent of the particle mass, m_x, if $m_x \gtrsim 1$ keV. The expected background temperature fluctuations are well below present observational limits.

Subject headings: cosmic background radiation — cosmology — galaxies: formation

By equations (18) and (19), the expected quadrupole moment of the microwave background is

$$a_2 = 3.5 \times 10^{-6}. \qquad (20)$$

The WMAP satellite (2003) measurements found $a_2 = 5 \pm 1 \times 10^{-6}$

From observeational indicateons

Cosmological constant = vacuum energy (dark energy)

Modern view:

Peebles save speed of the evolution of structure formation

MF-Takahara-Yamashita-Yoshii March 1990 $N(m)$

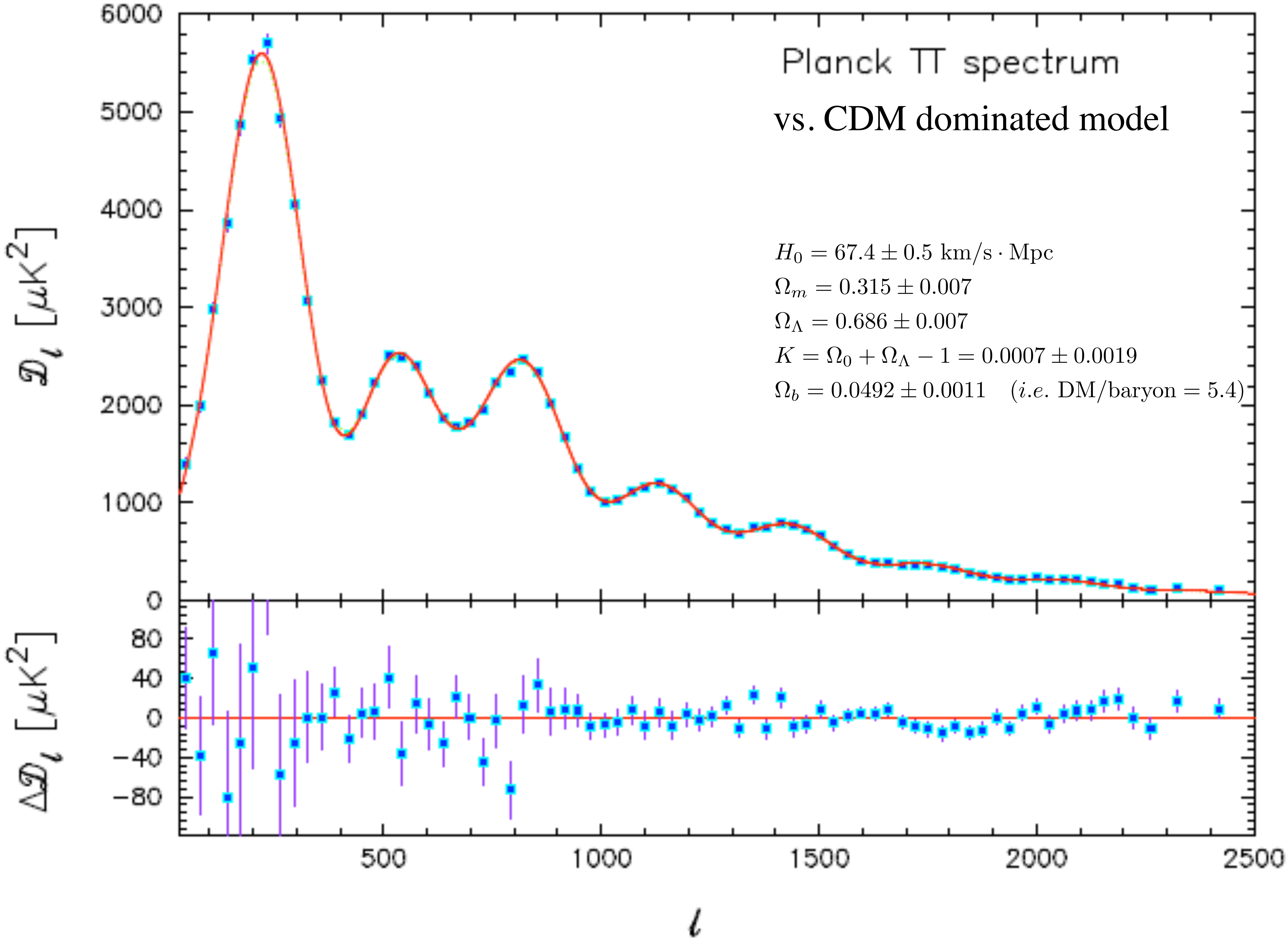
Efstathiou-Sutherland-Maddox 1990 $w(\theta)$

Established with CMB C_ℓ : peak at $\ell \approx 200$

SNIa m-z fainter at high z

ΛCDM cosmology as the standard paradigm

Planck Collaboration: Cosmological parameters



from Peebles' Nobel Lecture 2019

Lessons

The natural sciences operate on the postulate that nature operates by rules we can discover, sometimes

1. by pure thought, which can be remarkably effective, on occasion, or
2. by a community feeling, maybe not explicitly stated, that an idea seems interesting because
   (a) the times are "right,"
   (b) or because there is an unspoken "feeling in the air,"
3. or on occasion because we're by driven by the brutal weight of the evidence.

But the greatest lesson is that the established social constructions of science are buttressed by rich and deep webs of evidence.


THE
NOBEL
PRIZE

受賞前

受賞後

Cosmology started off with pure thought

To 1965 (= discovery of CMB)

with little pieces of observational indications

1965 to Post CMB   Here the great role of Jim Peebles!

What is CMB

CMB - cosmic structure connexion

Studies of large scale structure

→

Observational cosmology, or observationally driven, …

END