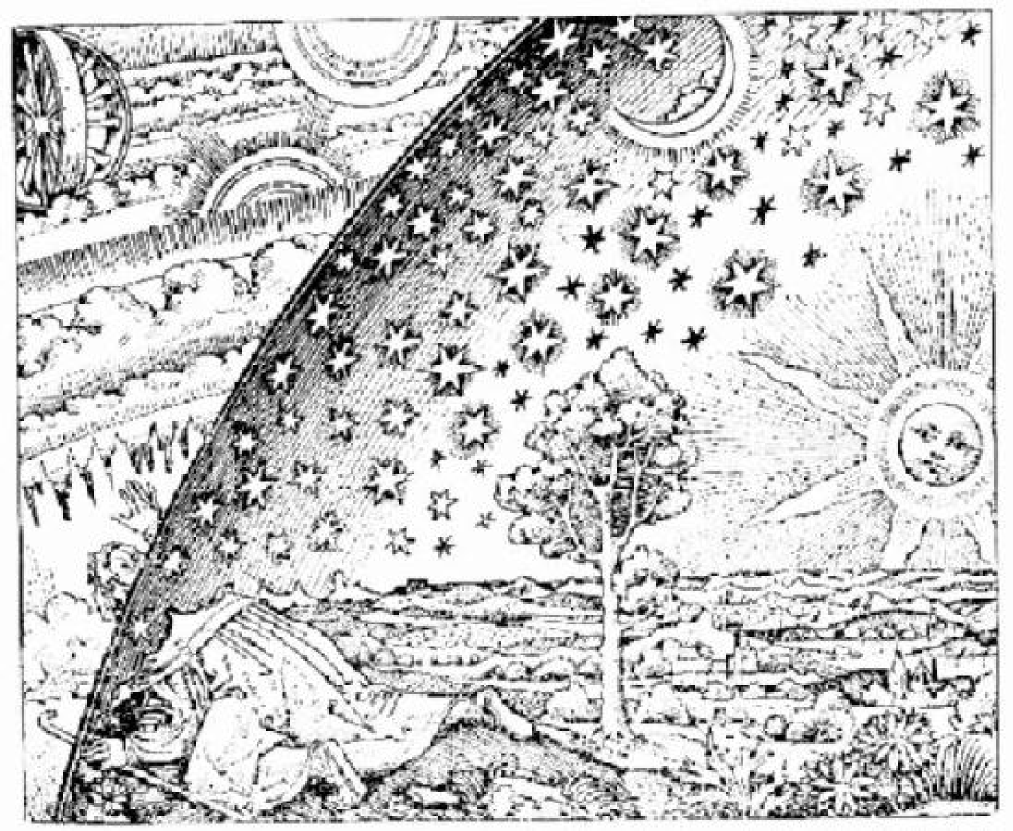
Najstarsze światło we Wszechświecie –

mikrofalowe promieniowanie tła



Stanisław Bajtlik

Centrum Astronomiczne im. M. Kopernika, PAN, Warszawa

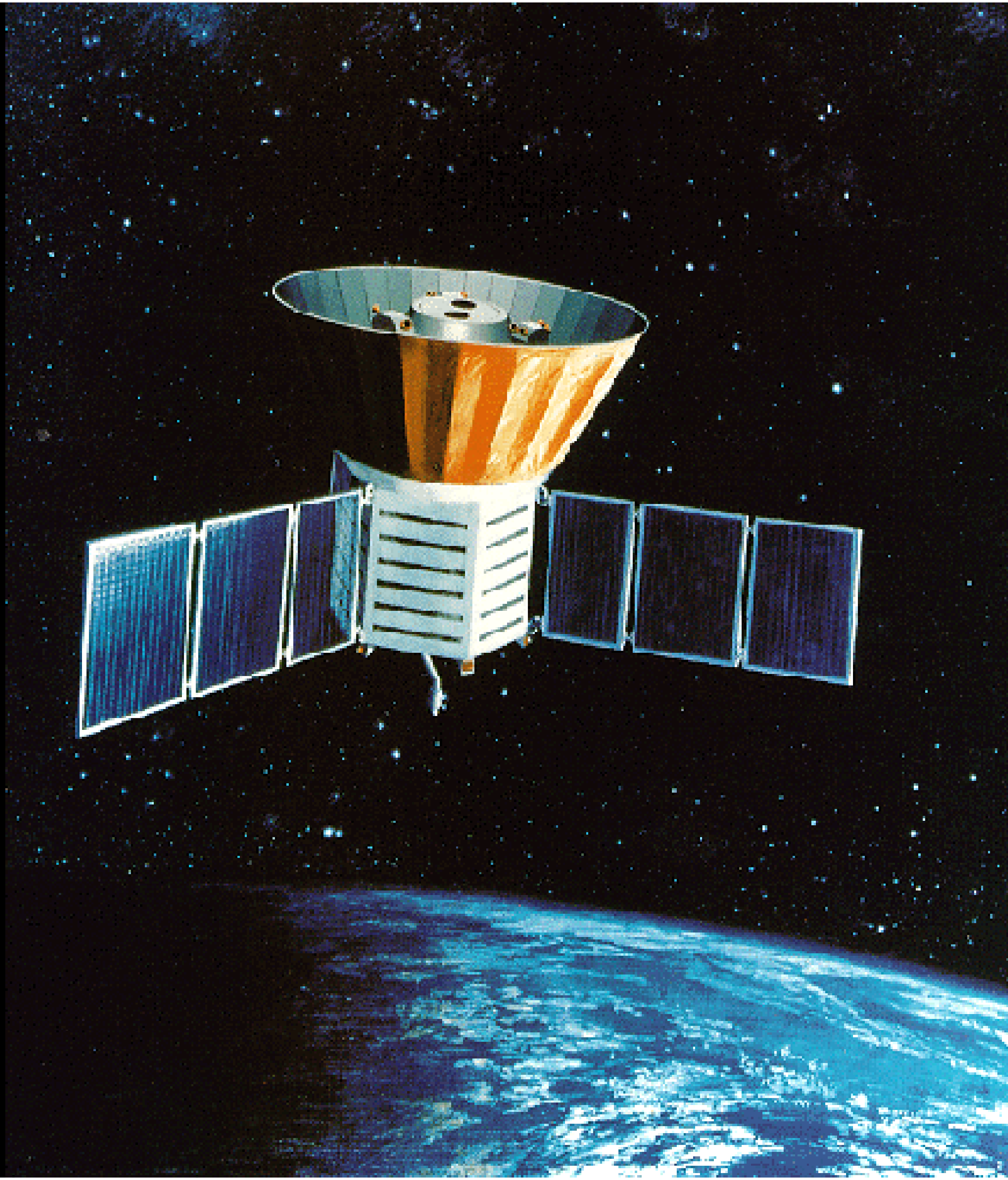
CERN, 18 IV 2007

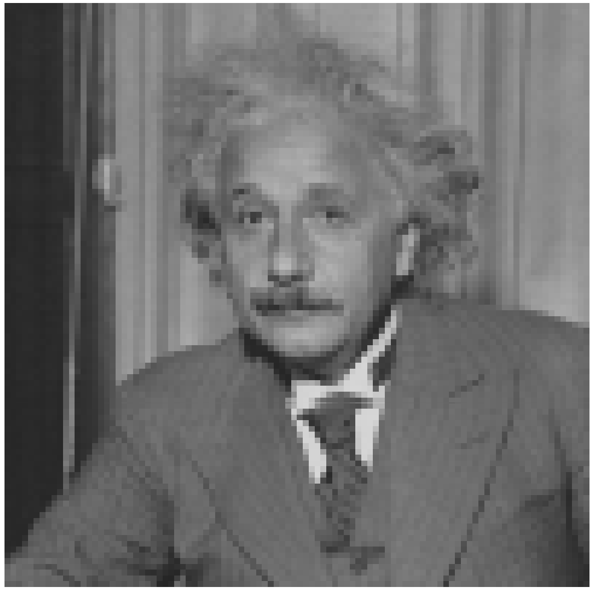
John C.Mather

ur. 1945

George F. Smoot

ur. 1945





Albert Einstein

1879 - 1955

General Relativity (1915):

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

geometry *matter*

Teoria Wielkiego Wybuchu:

-prawo Hubble'a $v = H r$

- skład chemiczny Wszechświata

Helium-4. $[^4He/(H+He)] = 0.23$

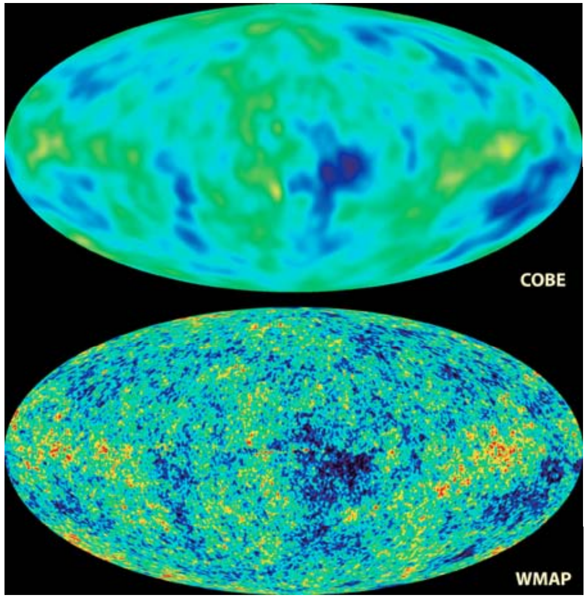
Deuterium. $[^2H/H] = 1.5 \times 10^{-5}$

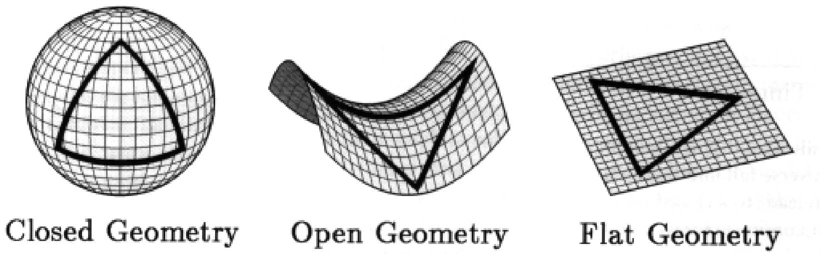
Helium-3. $[^3He/H] = (1.2\text{-}15) \times 10^{-5}$

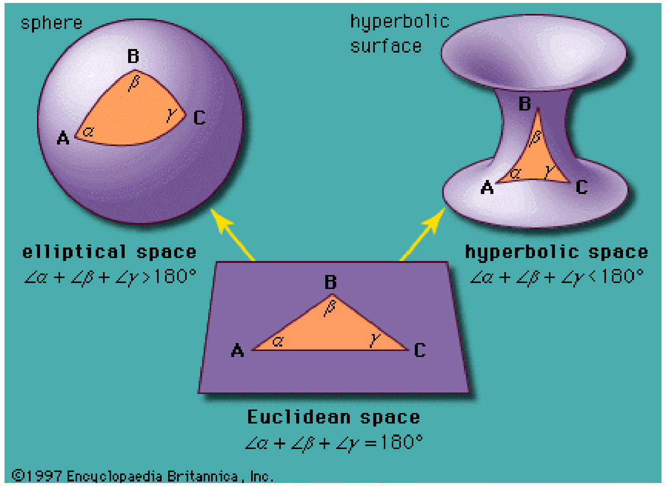
Lithium-7. $\log[^7Li/H] = -9.8$

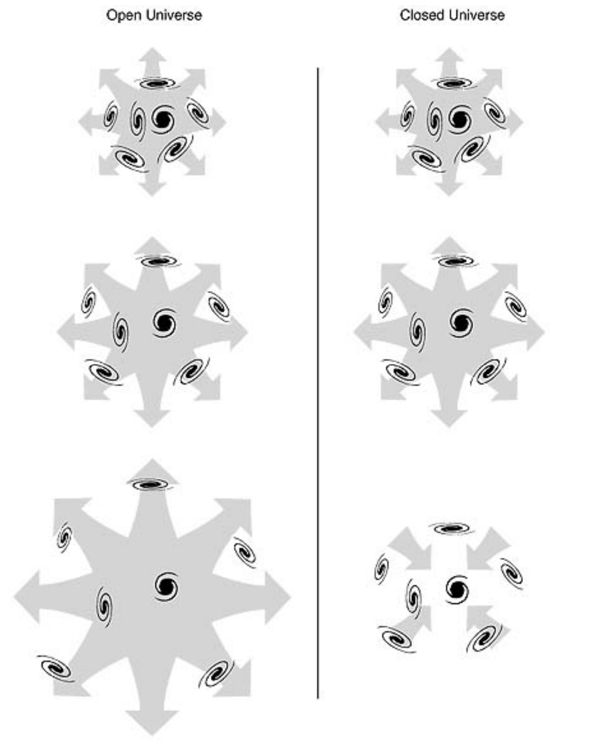
Tritium ^3H is unstable with a half-life of 12.46 years.

- istnienie i własności MPT









An open universe expands forever because it does not contain enough mass, and so does not have enough gravity slow the expansion of space. A closed universe contains enough mass to halt the expansion, and eventually collapses universe with a "critical density" of matter in space is exactly balanced between these two alternatives, and expands an ever-slowing rate.

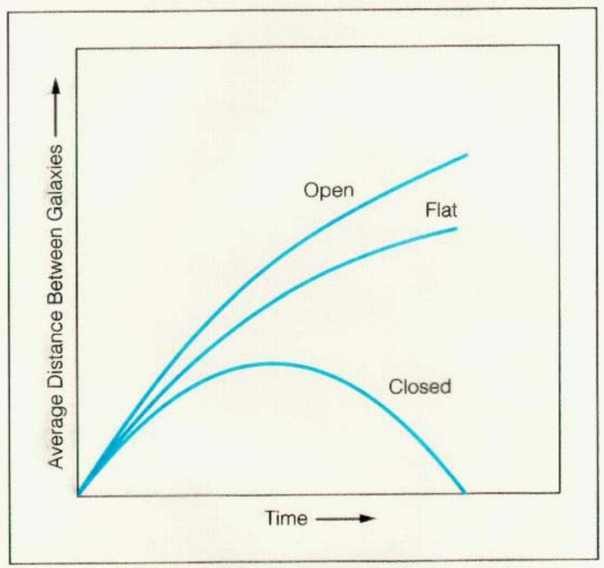
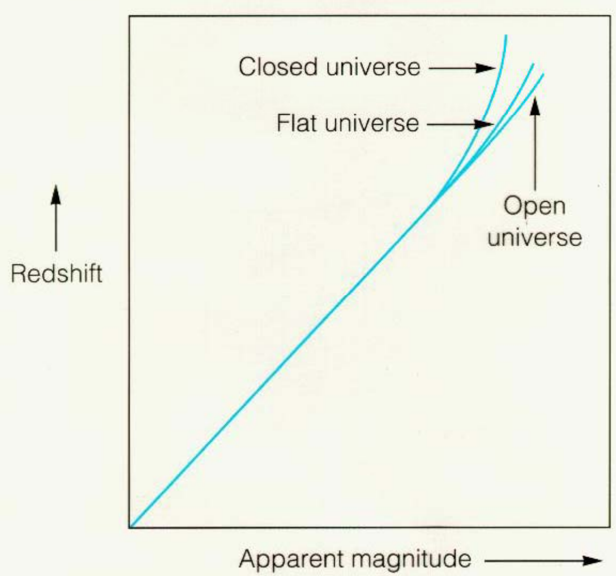


Figure 21.6 **The three possible fates of the universe.**



$$\Omega = \rho/\rho_{crit}$$

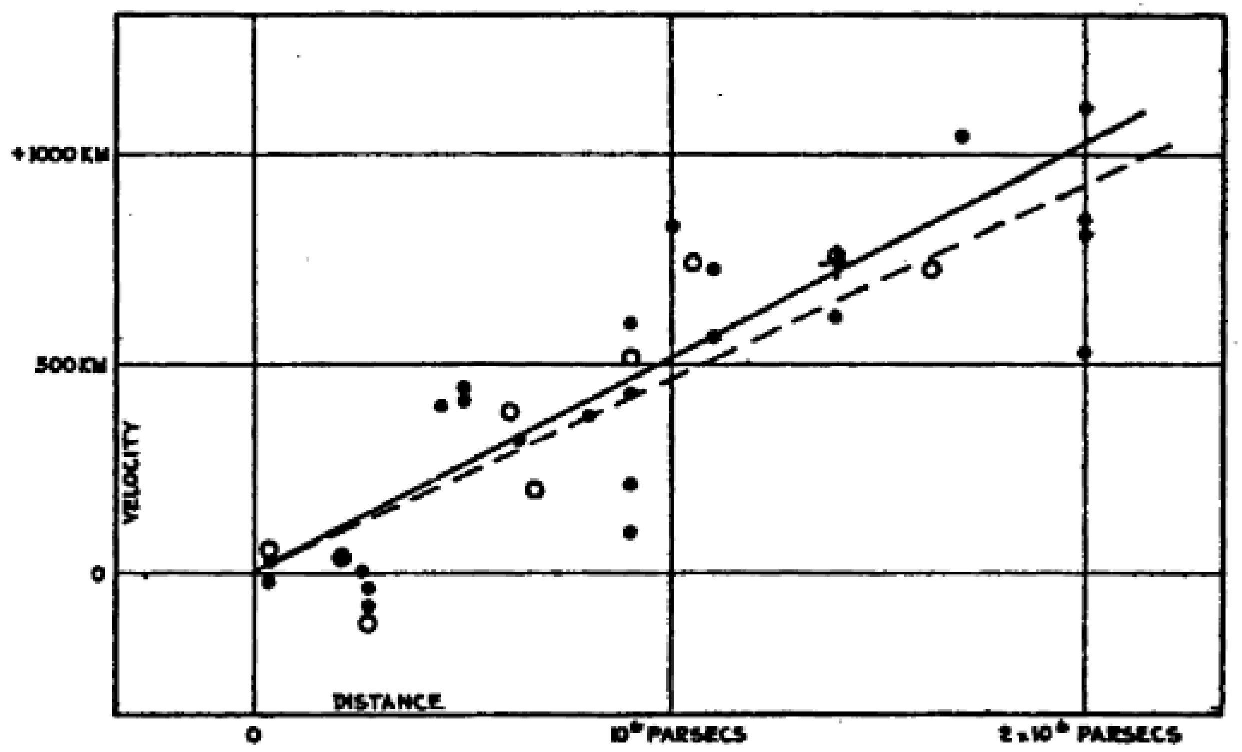
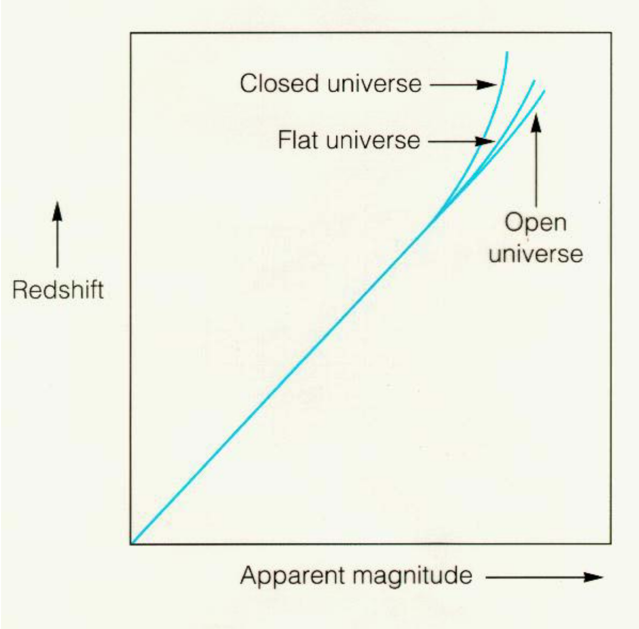
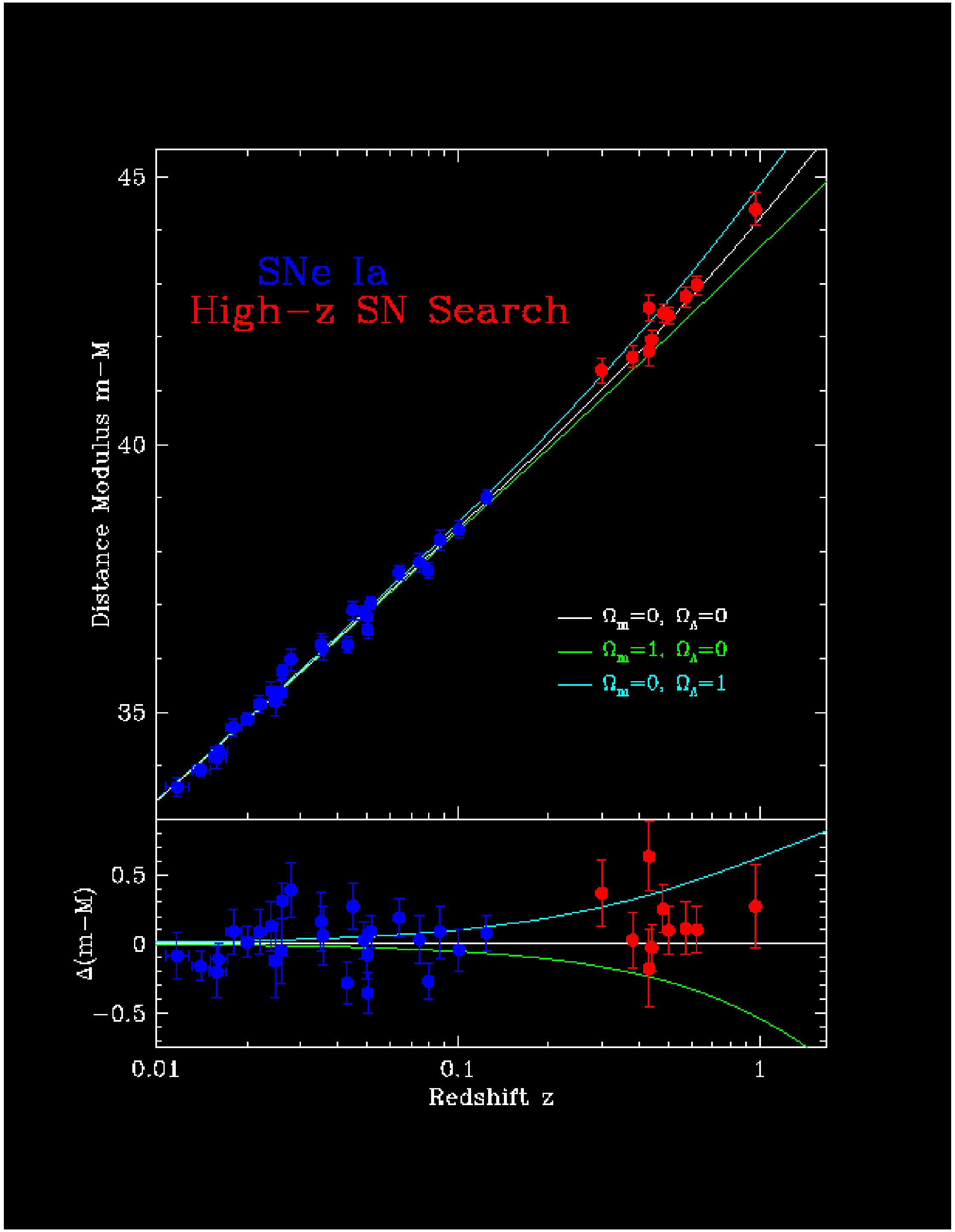


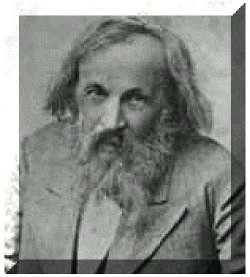
FIG. 2—Reproduced from Hubble (1929). The first "Hubble diagram" including galaxies with redshifts up to 1100 km s^{-1} and implying a Hubble constant near 500 km s^{-1} Mpc.

Hubble's Cepheids is often wrongly cited (e.g., by de Vaucouleurs 1982) as PASP, 5, 261, 1925. In fact, Vol. 5 of PASP appeared in 1893 or thereabouts. Probably the short-lived *Publications of the American Astronomical Society* is meant, but I have not checked this.

mentions 465, 513, and 530; the graph shows lines for 465 and 513. A modern eye examining the plotted points inevitably concludes that Hubble was perfectly honest about the random errors of the result. The problem lay, as nearly always, in systematic errors.


Closed universe
Flat universe
Open universe
Redshift
Apparent magnitude


SNe Ia
High-z SN Search
Distance Modulus m−M
45
40
35
Ωm=0, ΩΛ=0
Ωm=1, ΩΛ=0
Ωm=0, ΩΛ=1
Δ(m−M)
0.5
0
−0.5
0.01
0.1
1
Redshift z



Periodic Table of the Elements

- Alkali Metals
- Alkaline earth Metals
- Transition metals
- Lanthanide series
- Actinide series
- Other Metals
- Nonmetals
- Noble gases

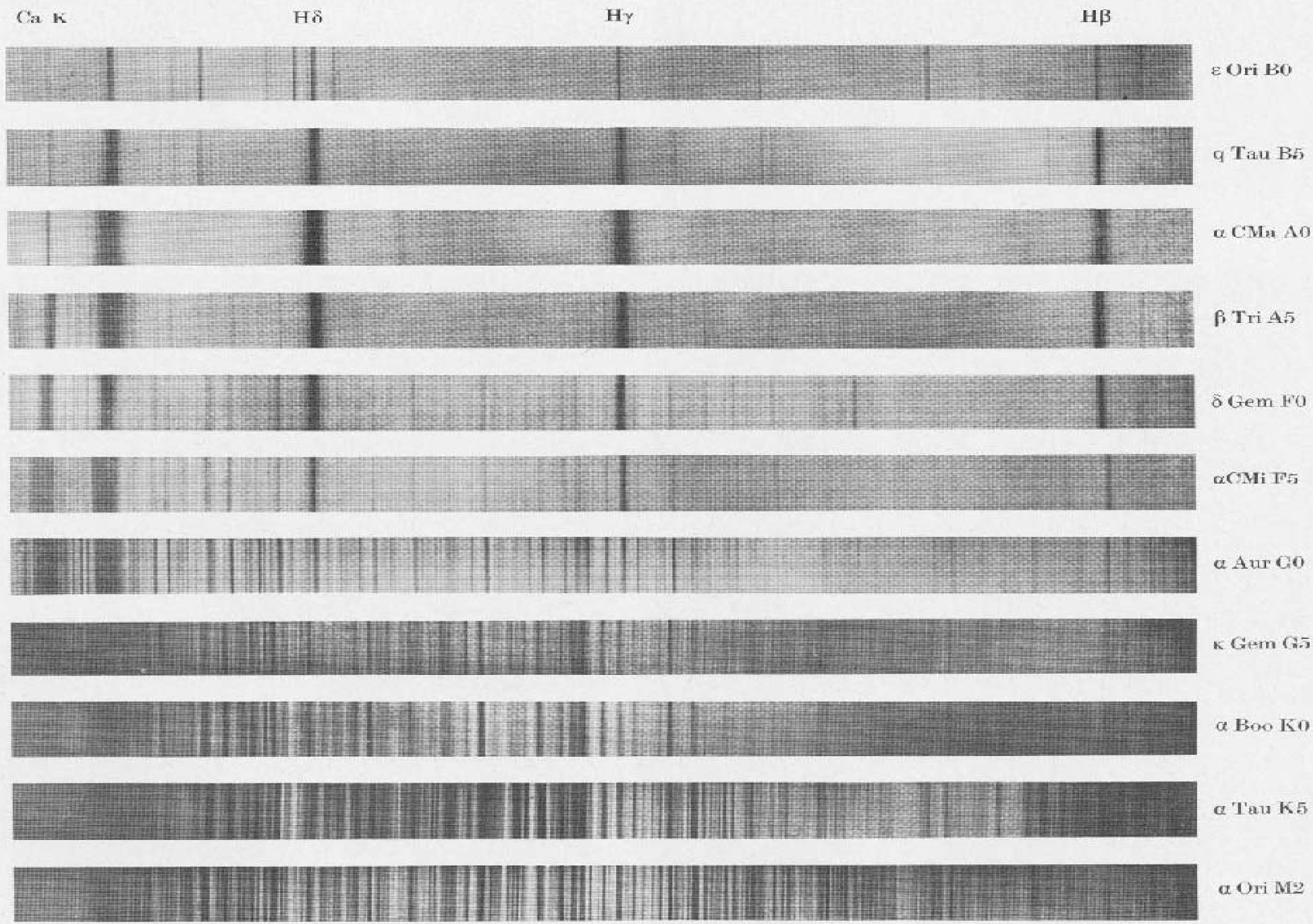
- C Solid
- Br Liquid
- H Gas
- Tc Synthetic

New	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Original	IA	IIA	IIIB	IVB	VB	VIB	VIIB	——	VIIIB	——	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 H Hydrogen 1.00794																	2 He Helium 4.002602
2	3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
3	11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.8457	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
6	55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 to 71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
7	87 Fr Francium (223)	88 Ra Radium (226)	89 to 103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Uun Ununnilium (269)	111 Uuu Unununium (272)	112 Uub Ununbium (277)	113	114 Uuq Ununquadium (285)	115	116 Uuh Ununhexium (289)	117	118 Uuo Ununoctium (293)

Atomic masses in parentheses are those of the most stable or common isotope.

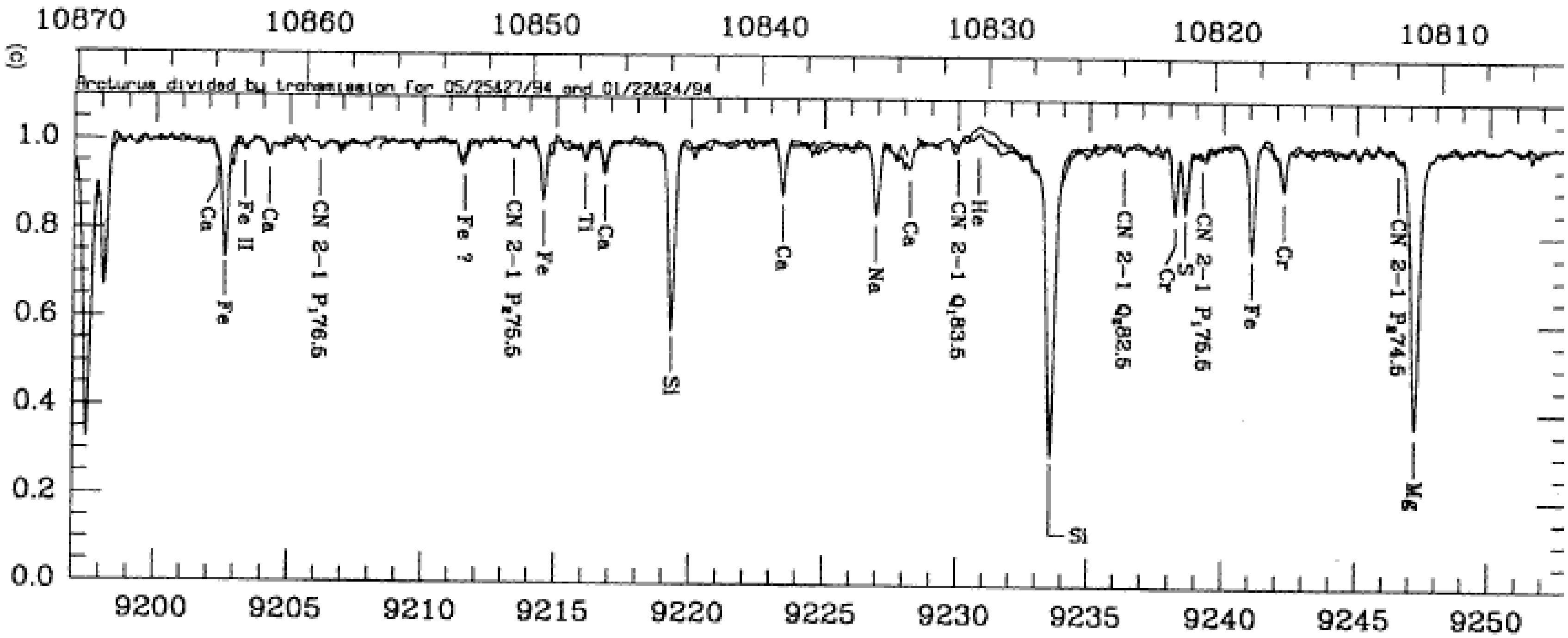
57 La Lanthanum 138.9055	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
89 Ac Actinium (227)	90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

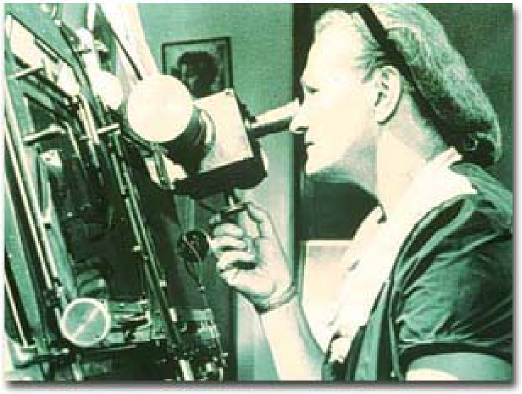
Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 110-118 are the Latin equivalents of those numbers.


Ca K
Hδ
Hγ
Hβ
ε Ori B0
q Tau B5
α CMa A0
β Tri A5
δ Gem F0
αCMi F5
α Aur G0
κ Gem G5
α Boo K0
α Tau K5
α Ori M2

The chemical composition of the stars

In the early days of astrophysics, scientists thought that the stars were probably similar to the Earth in chemical composition. When they passed starlight through a prism and examined the resulting spectrum, they found absorption (and occasionally emission) lines of many elements common here on Earth. For example, here's a portion of the spectrum of Arcturus (taken from a paper by Hinkle, Wallace and Livingstone, PASP 107, 1042, 1995):





In the nineteen-twenties, Cecilia Payne studied the spectra of stars, and devised a way to figure out the temperature and true chemical composition of stars. She concluded that the atmospheres of stars were

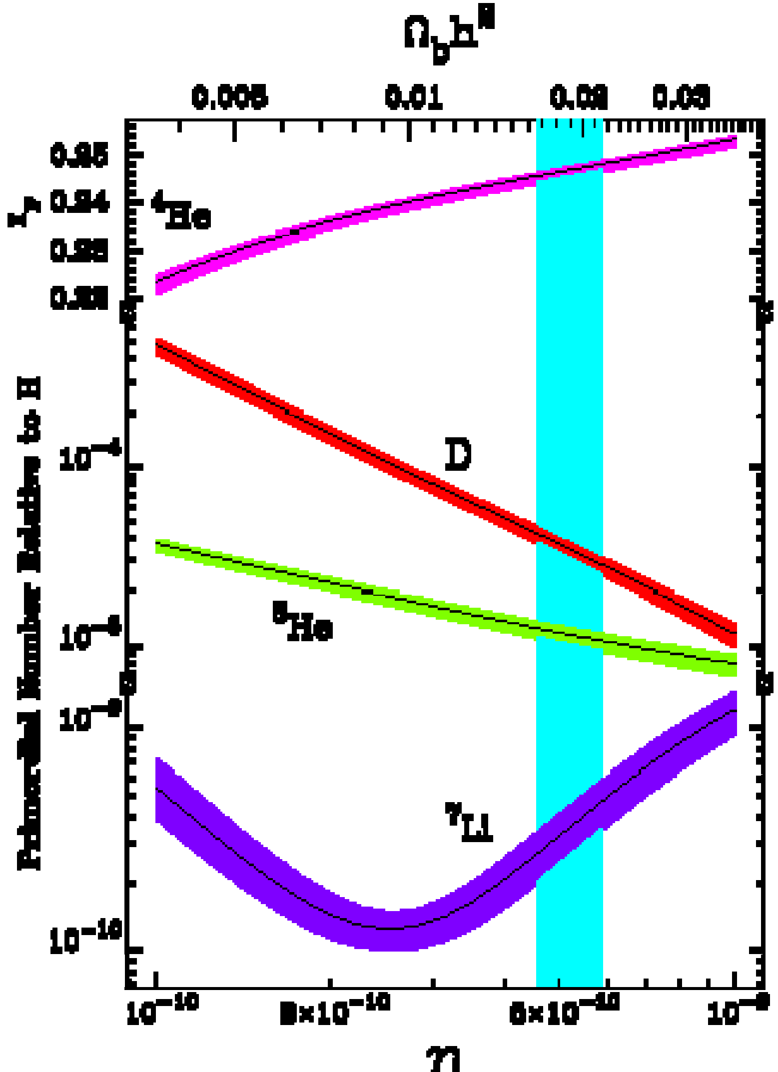
- **NOT made up of the same mix of elements as the Earth**
- **NOT wildly variable in composition**

but in fact,

- **almost entirely hydrogen, in almost all stars**

This was so surprising that scientists ignored or rejected the idea for several years. Eventually, after further study confirmed Payne's work, the astronomical community had to concede that the stars were, in fact, very different from the Earth. They appeared to be made up of

- **90% hydrogen (by number of atoms)**
- **10% helium**
- **tiny traces of heavy elements (everything else)**



$\Omega_b h^2$
0.005
0.01
0.02
0.05
Y_p
0.25
0.24
0.23
0.22
^{4}He
D
^{3}He
^{7}Li
10^{-4}
10^{-5}
10^{-9}
10^{-10}
Primordial Number Relative to H
10^{-10}
2×10^{-10}
5×10^{-10}
10^{-9}
η

•Helium-4. $[^4He/(H+He)] = 0.23$

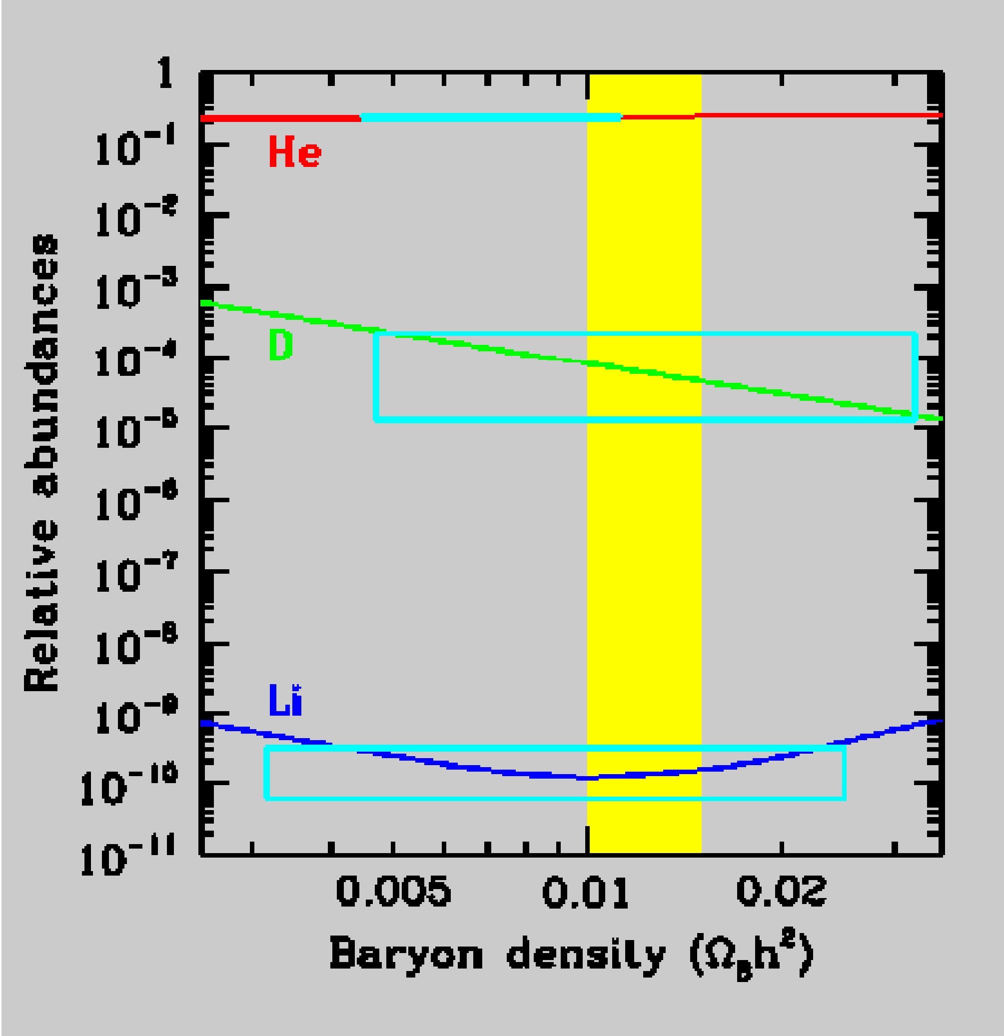
•Deuterium. $[^2H/H] = 1.5 \times 10^{-5}$

•Helium-3. $[^3He/H] = (1.2\text{-}15) \times 10^{-5}$

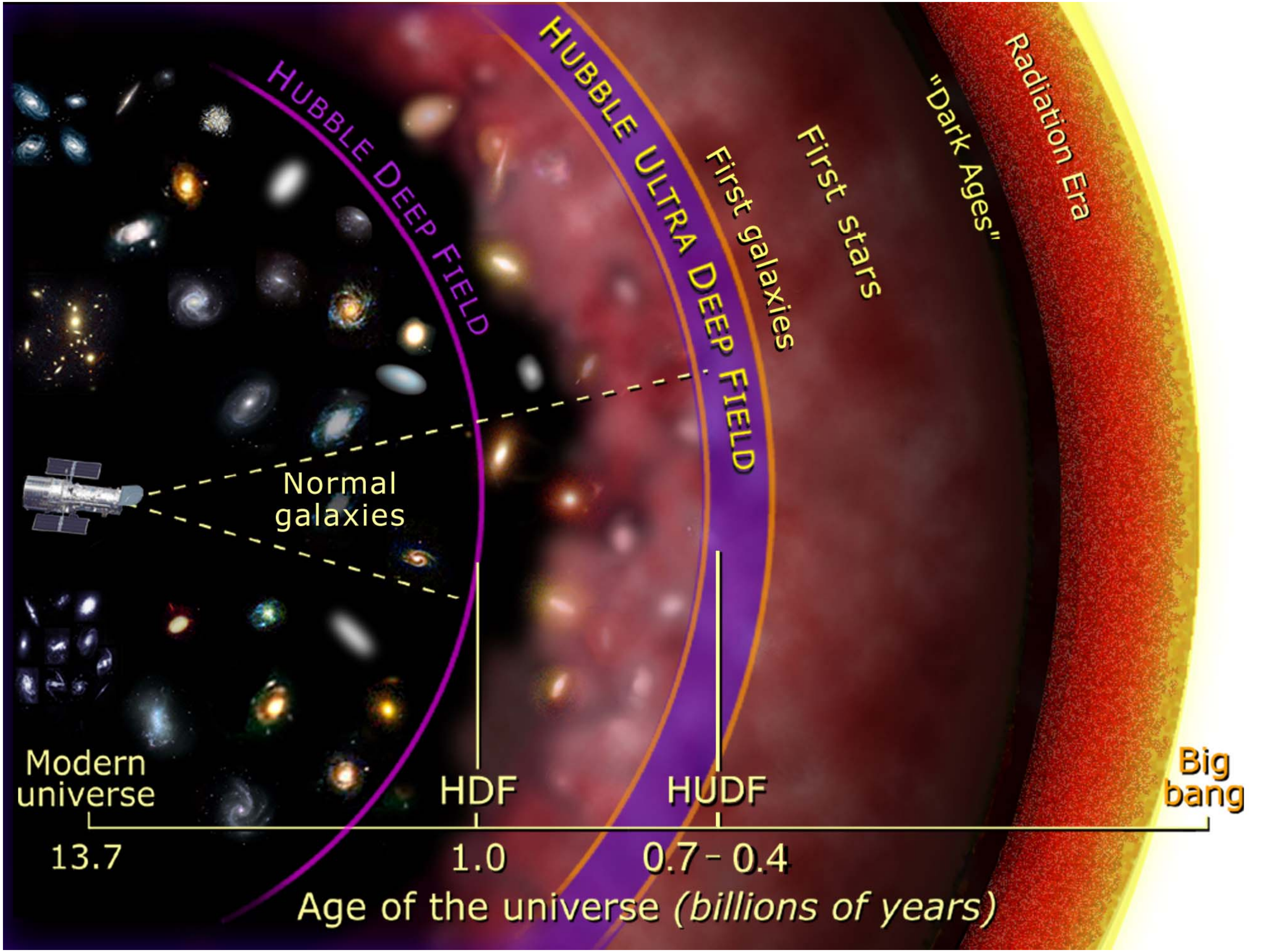
•Lithium-7. $\log[^7Li/H] = -9.8$

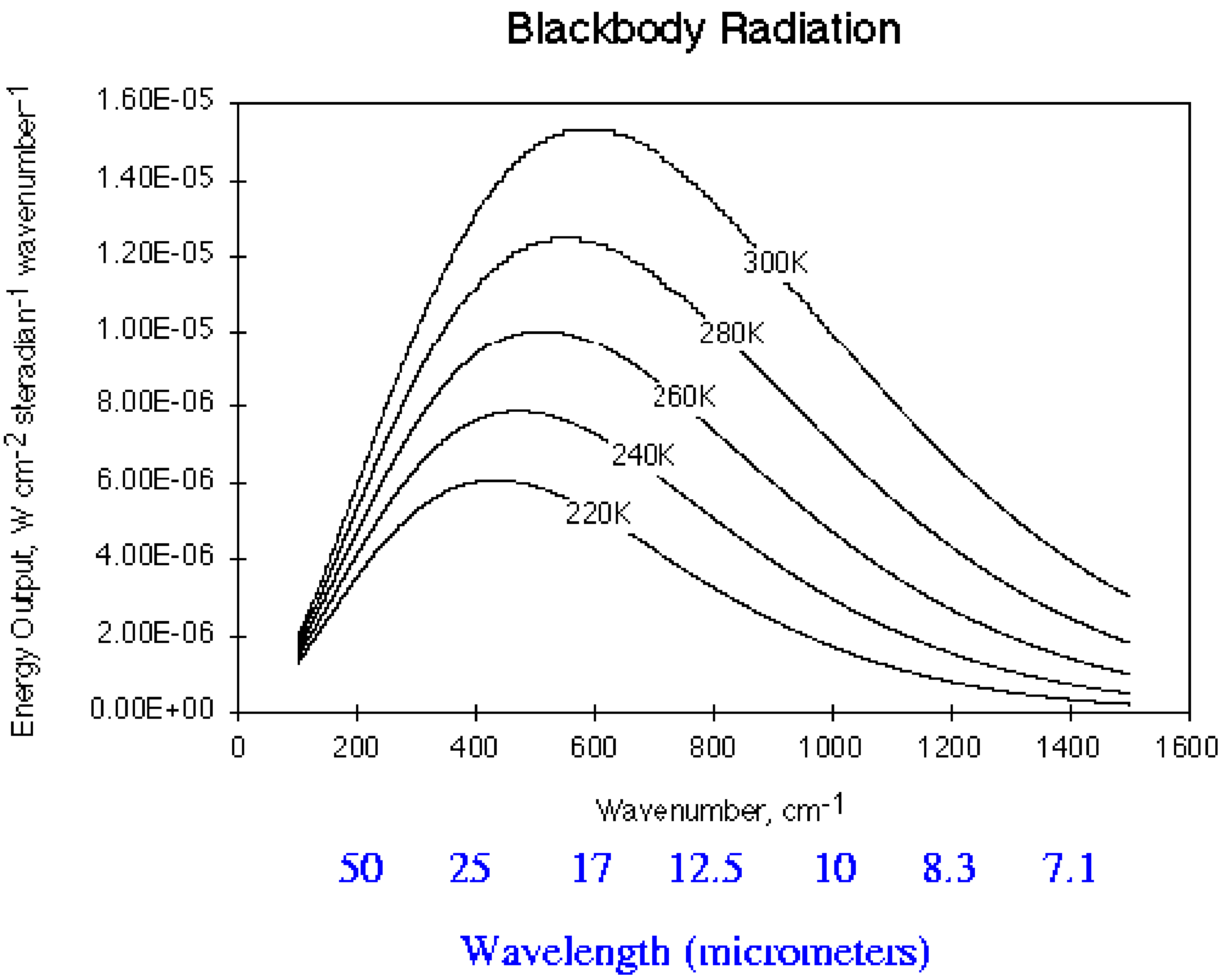
•Tritium ^3H is unstable with a half-life of 12.46 years.

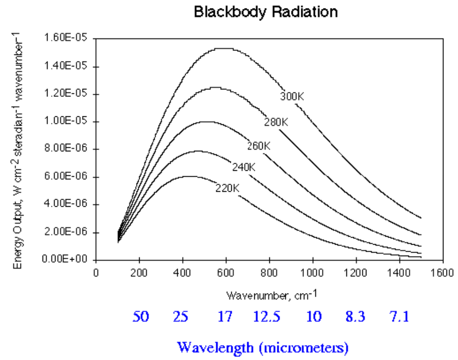
•Observational Abundances of Light Elements: ^2H, ^3H, ^3He, ^4He, ^7Li



$$\Omega_b \approx 0.03$$


Hubble Deep Field
Hubble Ultra Deep Field
First galaxies
First stars
"Dark Ages"
Radiation Era
Normal galaxies
Modern universe
HDF
HUDF
Big bang
13.7
1.0
0.7 – 0.4
Age of the universe (billions of years)


Blackbody Radiation
Energy Output, W cm-2 steradian-1 wavenumber-1
1.60E-05
1.40E-05
1.20E-05
1.00E-05
8.00E-06
6.00E-06
4.00E-06
2.00E-06
0.00E+00
300K
280K
260K
240K
220K
0
200
400
600
800
1000
1200
1400
1600
Wavenumber, cm-1
50
25
17
12.5
10
8.3
7.1
Wavelength (micrometers)



Note that the peak wavelength at which a blackbody emits becomes shorter as the object becomes warmer:

Object	Temperature (K)	Peak wavelength	Radiation
cold molecular cloud	10	2.9 mm	microwave
warm gas cloud	100	0.29 mm	far infrared
live human	310	9355 nm	infrared
Sun	5770	530 nm	visible

Podstawowe pojęcia:

Kosmiczne Mikrofalowe promieniowanie tła – relikt Wielkiego Wybuchu

3 stopnie powyżej zera absolutnego (-270 stopni Celsjusza)

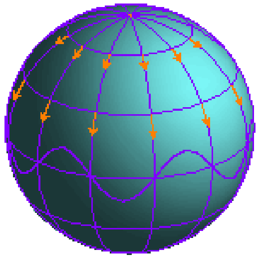
mm-cm długości fal

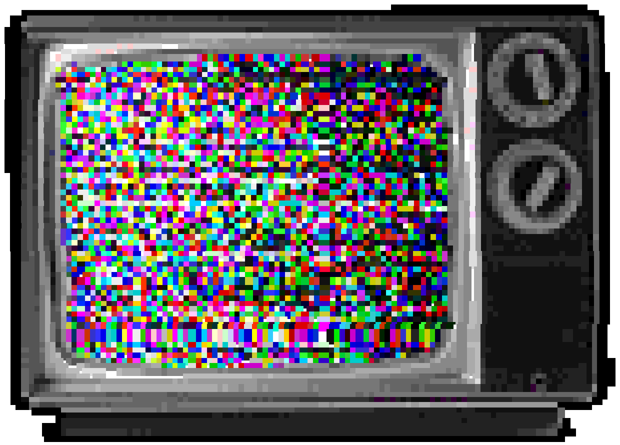
400 fotonów na centymetr sześcienny

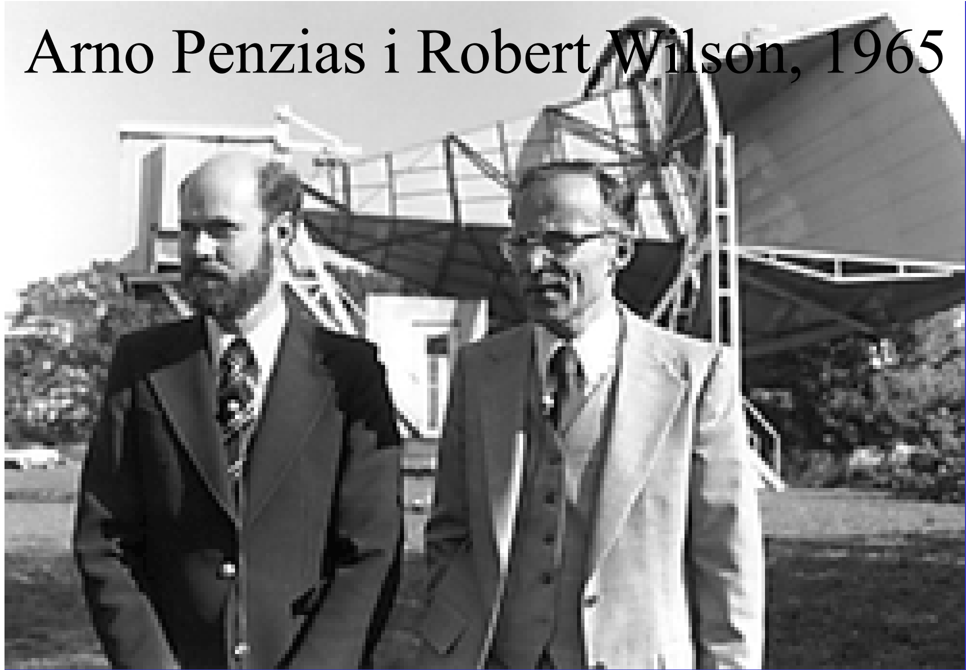
10 biliardów fotonów na sekundę na centymeter kwadratory

Kilka % „śniegu„ na ekranie TV

Temperatura nieco różna w różnych miejscach na niebie - 1 część na 100,000.



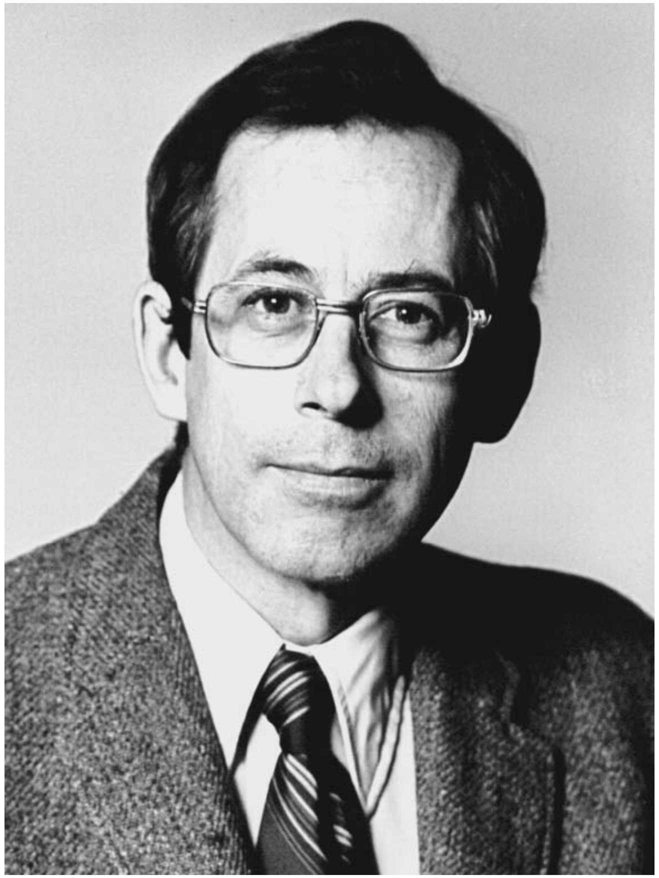




Arno Penzias i Robert Wilson, 1965

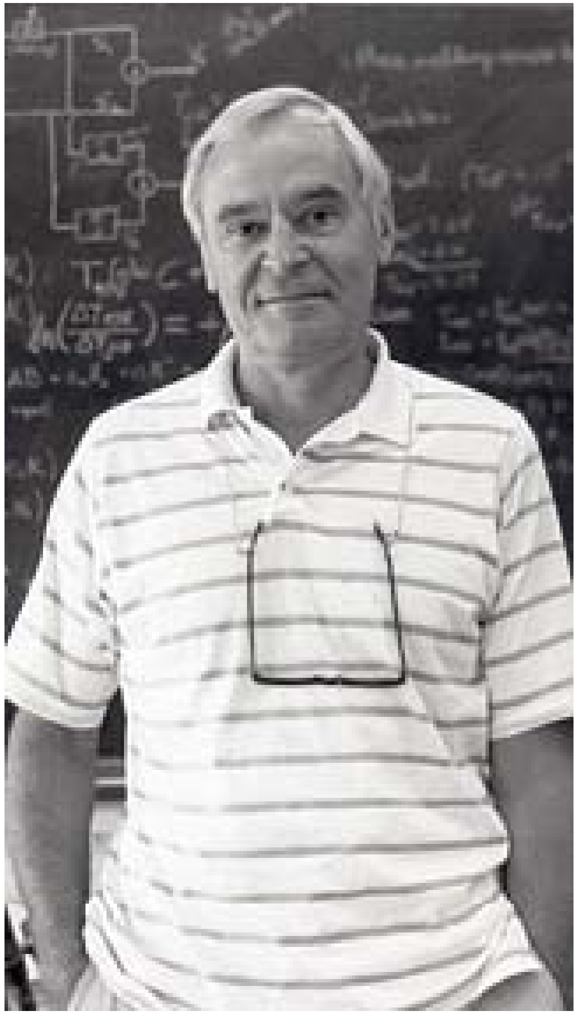
George Gamow, 1904 - 1975

Sztokholm, 1978



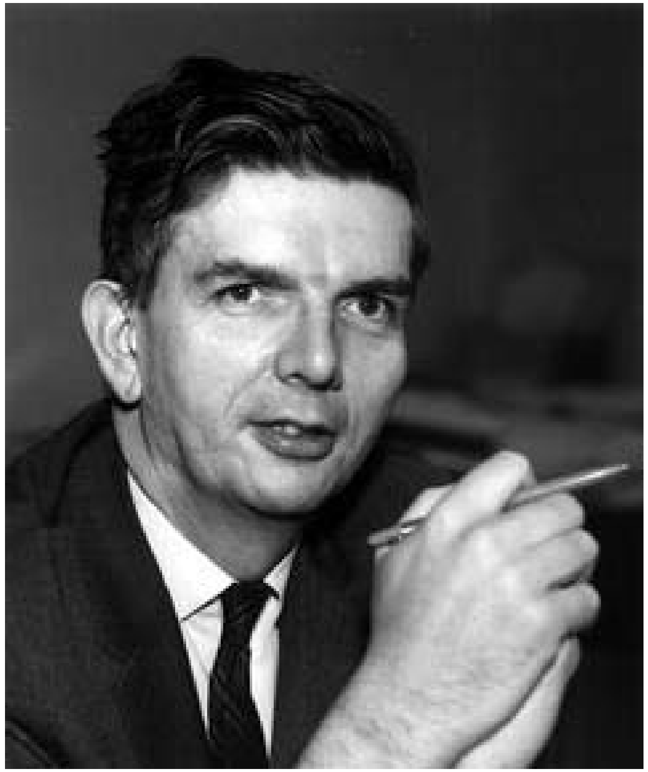
James Peebles

ur. 1935



David Wilkinson

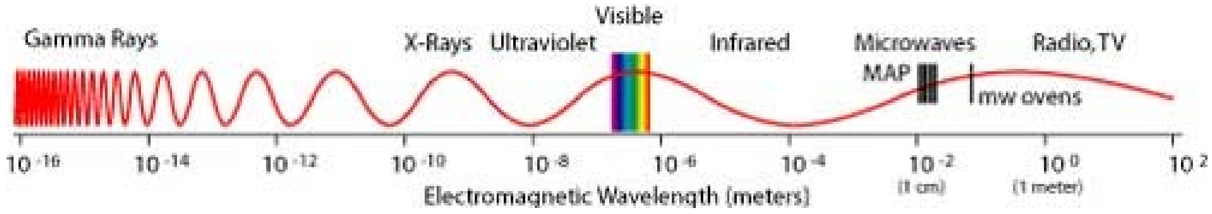
1935-2002



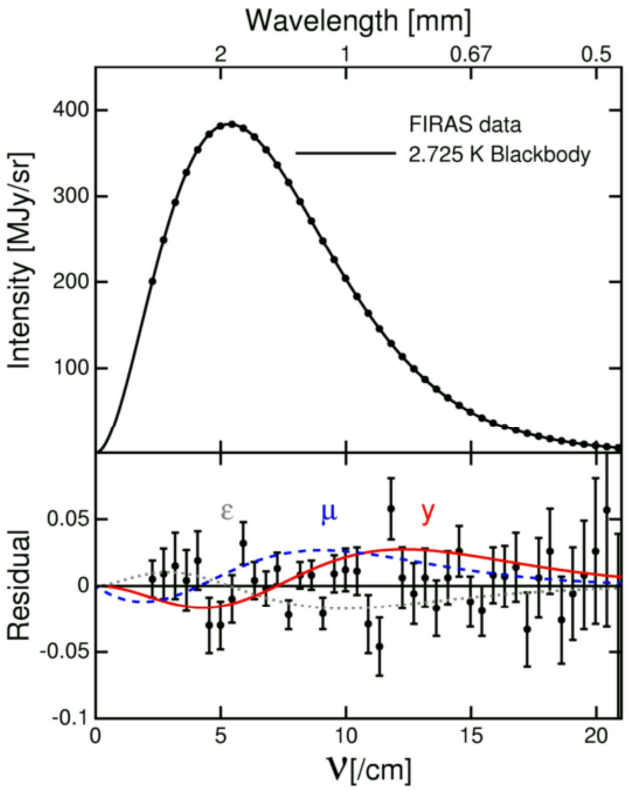
Robert Dicke

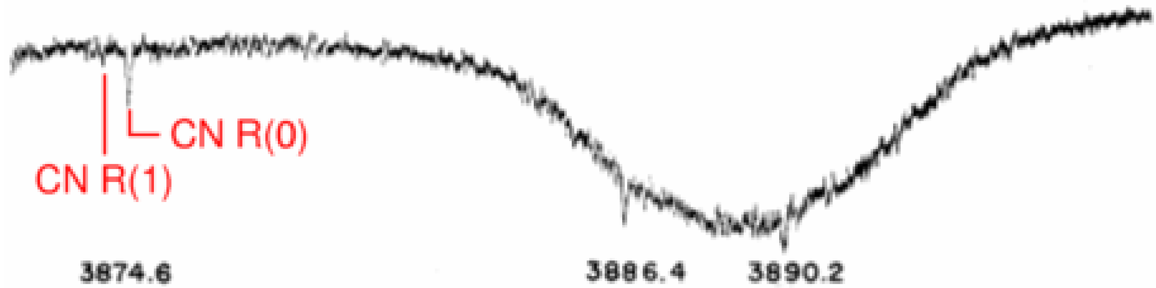
1916-1987

1934:
Richard Tolman shows that blackbody radiation in an expanding universe cools, but retains its thermal distribution and remains a blackbody.
1941:
Andrew McKellar uses the excitation of CN doublet lines to measure that the "effective temperature of space" is about 2.3° K. [CN is the cyanide or nitrile radical]
1948:
George Gamow, Ralph Alpher, and Robert Herman predict that a Big Bang universe will have a blackbody cosmic microwave background with temperature about 5° K.
1955:
Tigran Shmaonov finds excess microwave emission with a temperature of roughly 3° K. So do several other researchers, starting with Andrew McKellar's 1941 observations of the excitation of interstellar CN molecules, but they do not follow through sufficiently, until Penzias and Wilson in 1964.
1964:
A.G. Doroshkevich and Igor Novikov write an unnoticed paper suggesting microwave searches for the blackbody radiation predicted by Gamow, Alpher, and Herman.
1965:
Arno Penzias and Robert Wilson discover the 3° K cosmic microwave background radiation. Through the connection of Bernie Burke, Robert Dicke, James Peebles, Roll, and Wilkinson, they learn about and interpret the measurement.
1966:
Rainer Sachs and Arthur Wolfe theoretically predict microwave background fluctuation amplitudes created by gravitational potential variations between observers and the "last scattering surface".
1968:
Martin Rees and Dennis Sciama theoretically predict microwave background fluctuation amplitudes created by photons traversing time-dependent potential wells.
1969:
R.A. Sunyaev and Yakov Zel'dovich study the inverse Compton scattering of microwave background photons by hot electrons.
1990:
The COBE satellite shows that the microwave background has a nearly perfect blackbody spectrum and thereby strongly supports the hot Big Bang model and the thermal history of the Universe, and constrains the density of the intergalactic medium.
1992:
The COBE satellite discovers anisotropy in the cosmic microwave background, this strongly supports the Big Bang model, with gravitational instability as the source of large scale structure. This discovery energizes and motivates the field in both theory and experiment, leading to an explosion of activity.
2001:
MAP (Microwave Anisotropy Probe) to be launched as a NASA MidEX mission.
2004:
Planck (Max Planck Surveyor formerly known as COBRAS/SAMBA) to be launched as an ESA (European Space Agency) Mission.

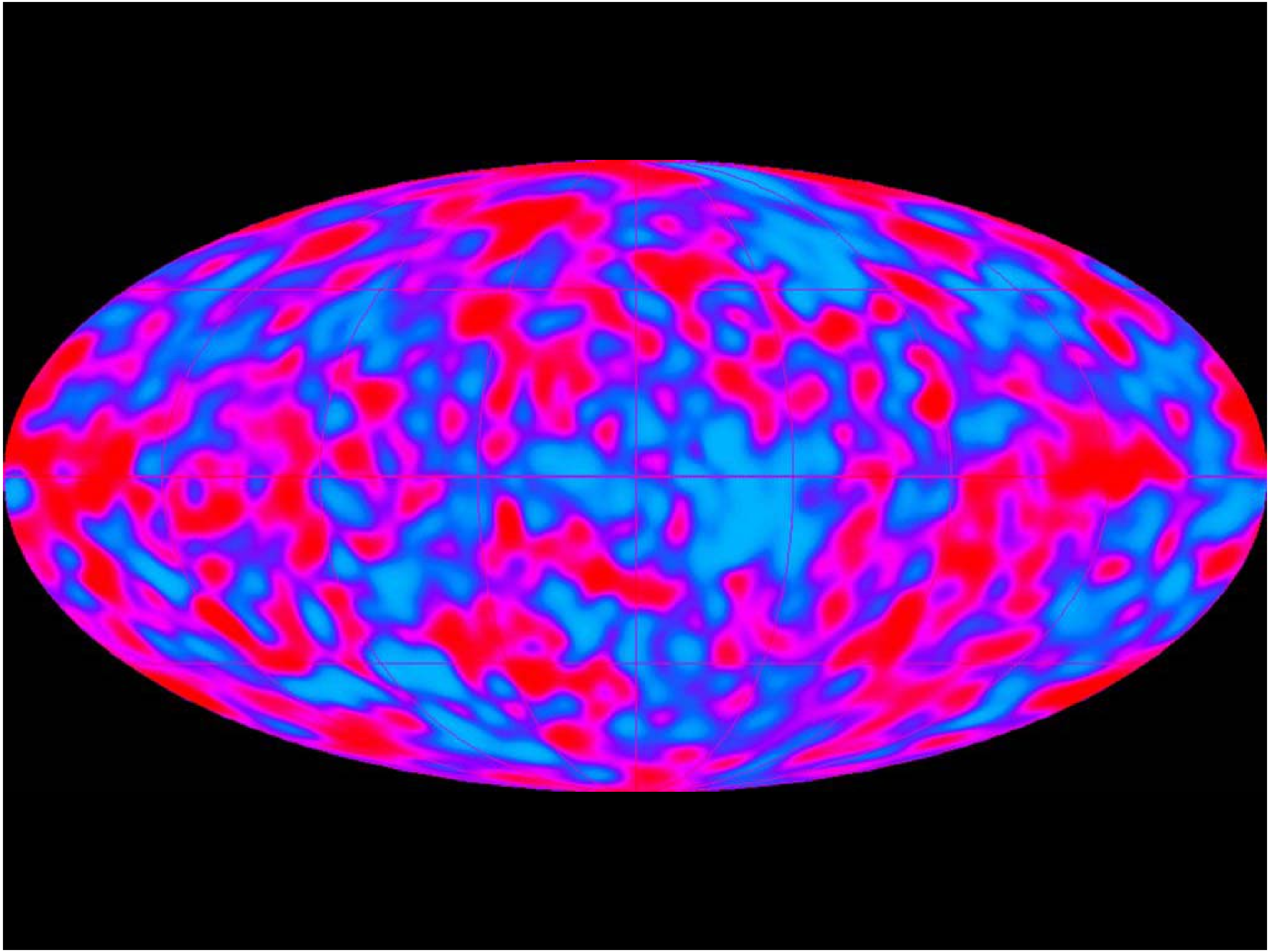


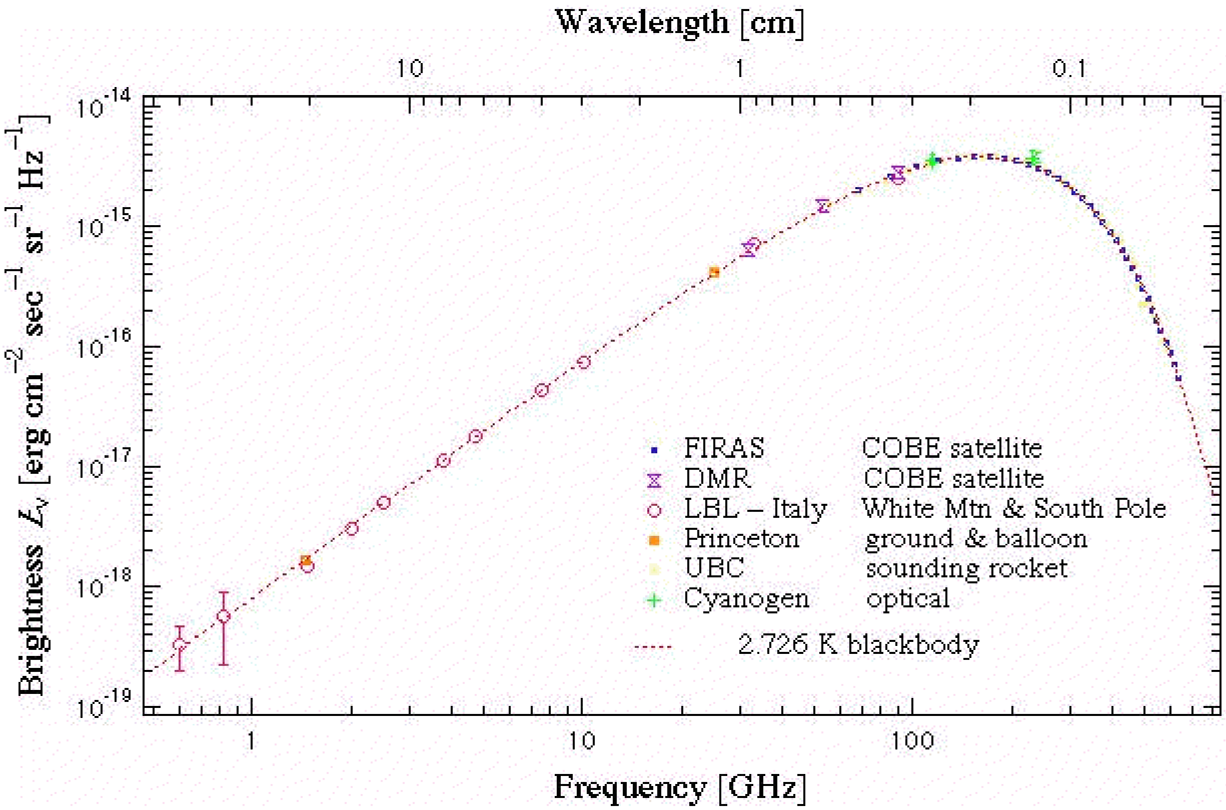
In order to make a blackbody spectrum, an object as to be opaque, non-reflective and isothermal. Thus a star, which is opaque, does not produce a blackbody spectrum because we can see both cooler outer layers and hotter deeper layers. But even though the temperature of the Universe changes as it evolves, with $T_{CMB} = T_o (1+z)$, the Universe looks isothermal because the redshifting of radiation makes the warmer but redshifted distant Universe appear to have exactly the same temperature as the Universe today.

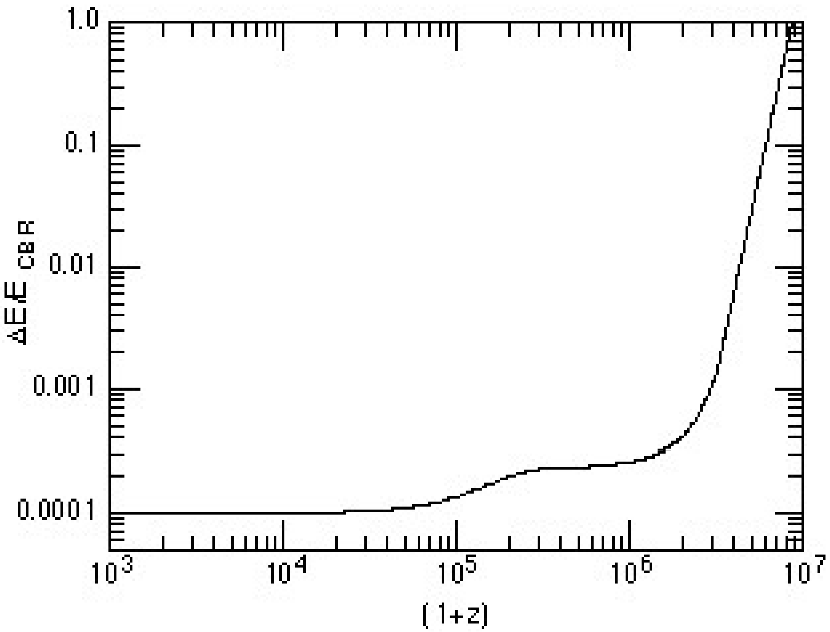




The first observations of the CMB were made by McKellar using interstellar molecules in 1940. The image at right shows a spectrum of the star zeta Oph taken in 1940 which shows the weak R(1) line from rotationally excited CN. The significance of these data was not realized at the time, and there is even a line in the 1950 book *Spectra of Diatomic Molecules* by the Nobel-prize winning physicist Gerhard Herzberg, noting the 2.3 K rotational temperature of the cyanogen molecule (*CN*) in interstellar space but stating that it had "only a very restricted meaning." We now know that this molecule is primarily excited by the CMB implying a brightness temperature of $T_o = 2.729 +/- 0.027$ *K* at a wavelength of 2.64 mm




Wavelength [cm]
10
1
0.1
Brightness I_ν [erg cm^{-2} sec^{-1} sr^{-1} Hz^{-1}]
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
FIRAS COBE satellite
DMR COBE satellite
LBL – Italy White Mtn & South Pole
Princeton ground & balloon
UBC sounding rocket
Cyanogen optical
2.726 K blackbody
1
10
100
Frequency [GHz]


1.0
0.1
0.01
0.001
0.0001
$\Delta E/E_{CBR}$
10^3
10^4
10^5
10^6
10^7
(1+z)

Steady-state hypothesis

Herman Bondi (1919-)

Thomas Gold (1920-2004)

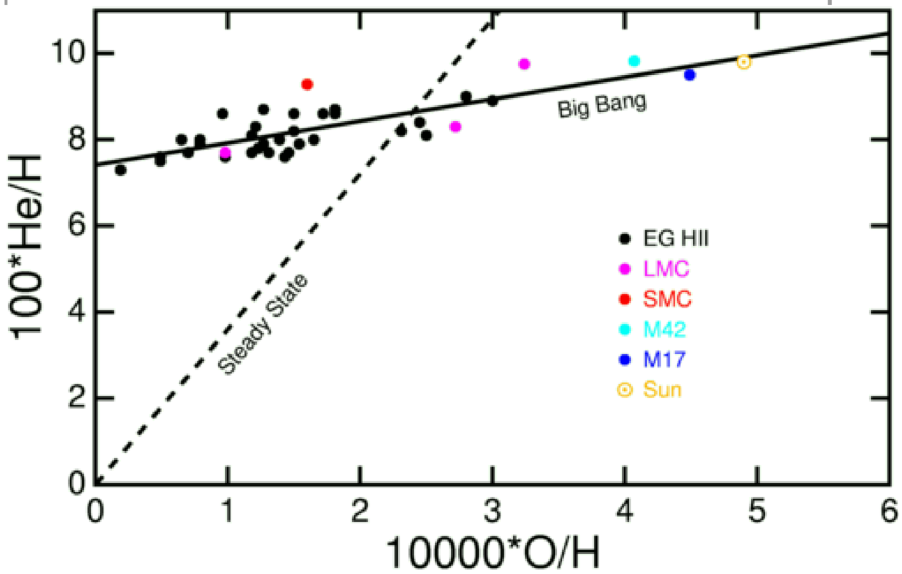
Fred Hoyle 1915-2001

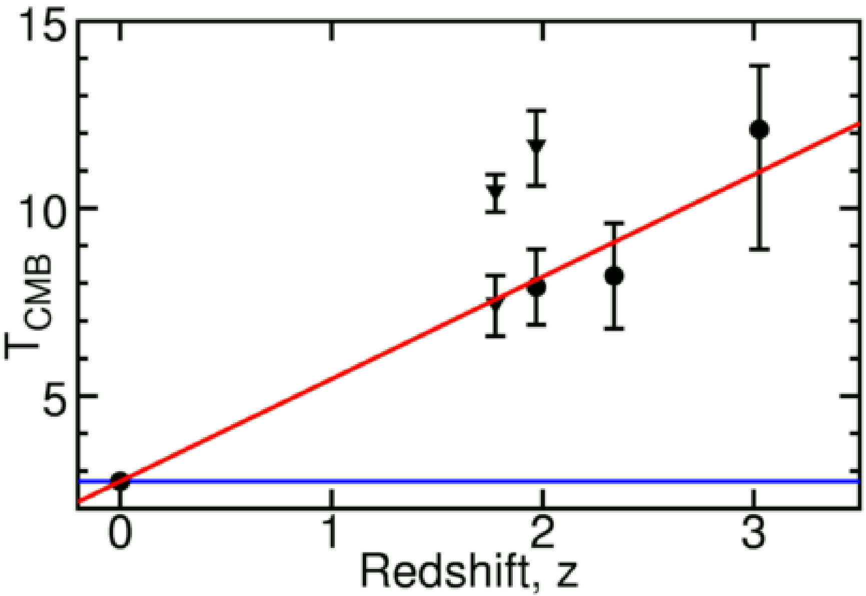
James Jeans

Born: **11 Sept 1877 in Ormskirk, Lancashir**

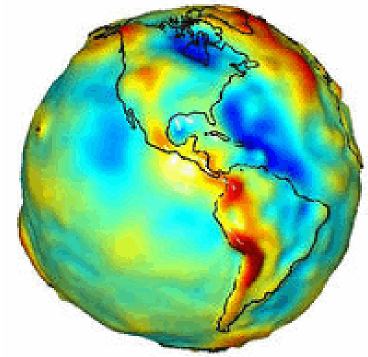
Died: **16 Sept 1946 in Dorking, Surrey**

Only a very little matter needs to be formed, roughly a few hundred atoms of hydrogen in the Milky Way Galaxy each year





KONTRAST GĘSTOŚCI $\delta\rho/\rho$



ZIEMIA $\delta\rho/\rho \approx 10^{29}$

SŁOŃCE $\delta\rho/\rho \approx 10^{28}$

UKŁAD SŁONECZNY

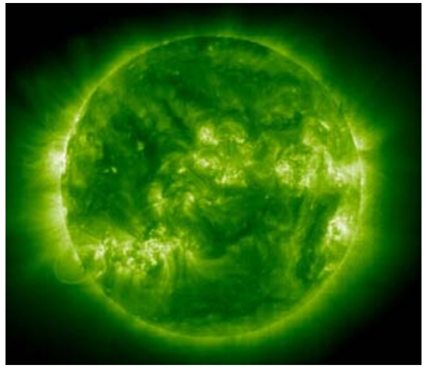
GROMADY KULISTE

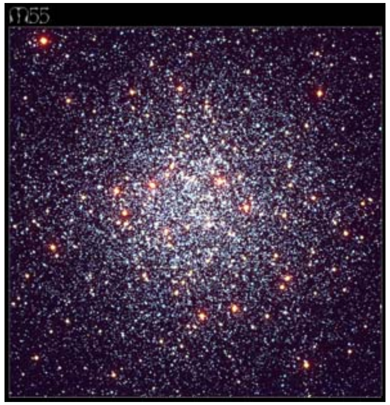
GALAKTYKA $\delta\rho/\rho \approx 10^{6}$

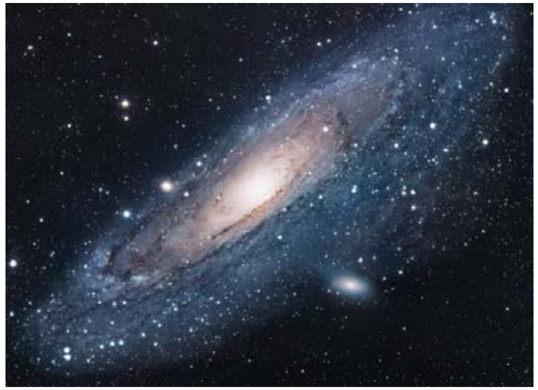
GRUPA LOKALNA

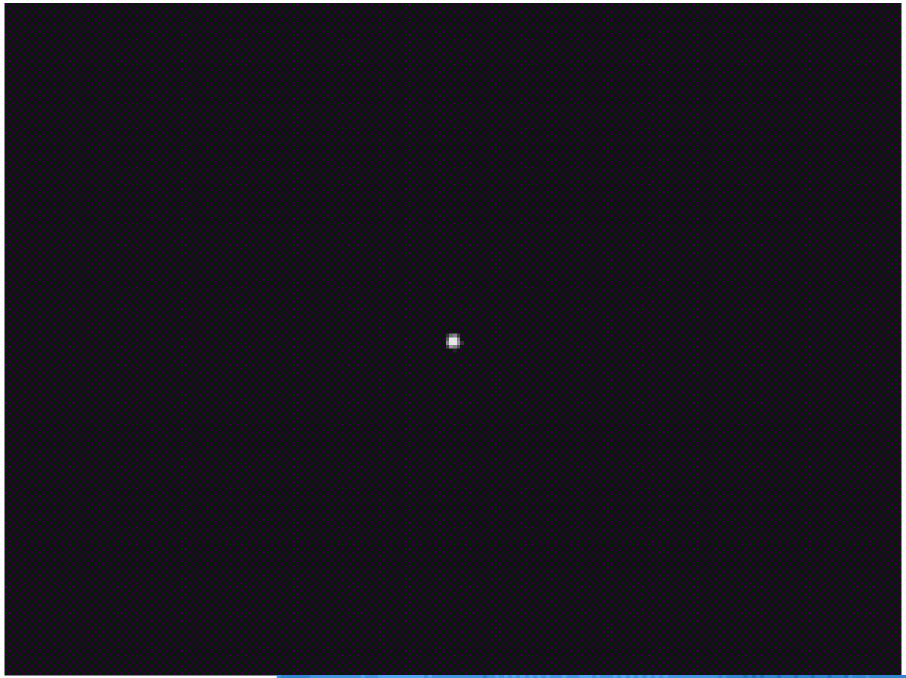
VIRGO $\delta\rho/\rho \approx 10^{3}$

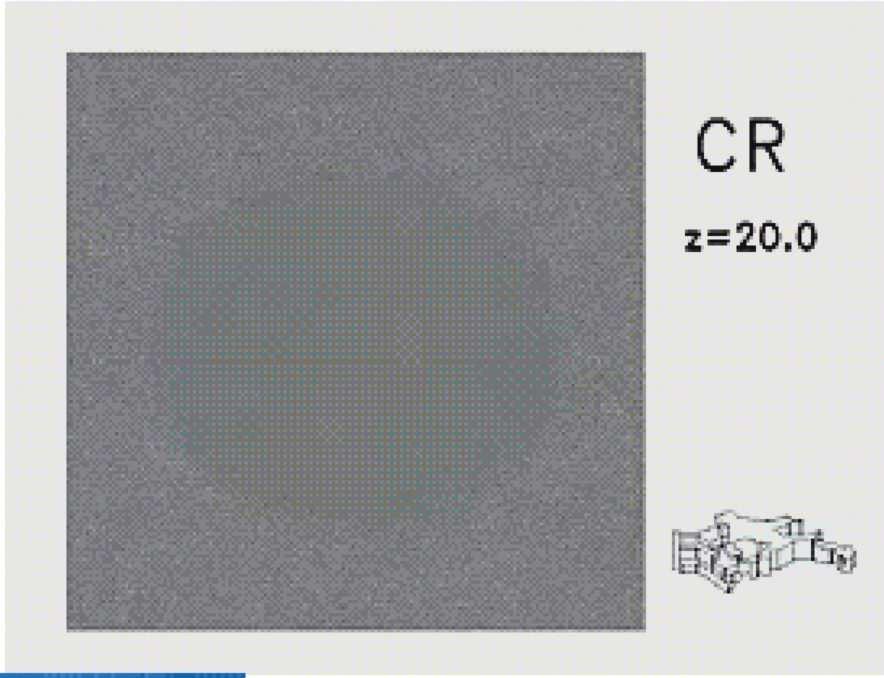
SUPERGROMADY $\delta\rho/\rho \approx 1 - 10$

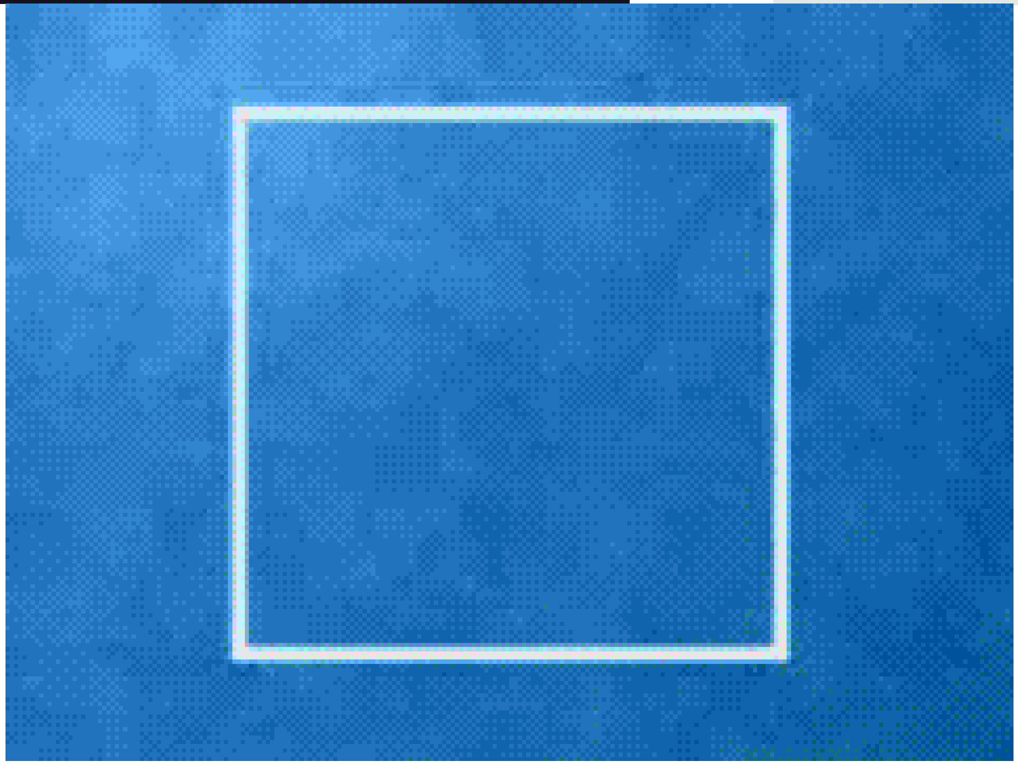




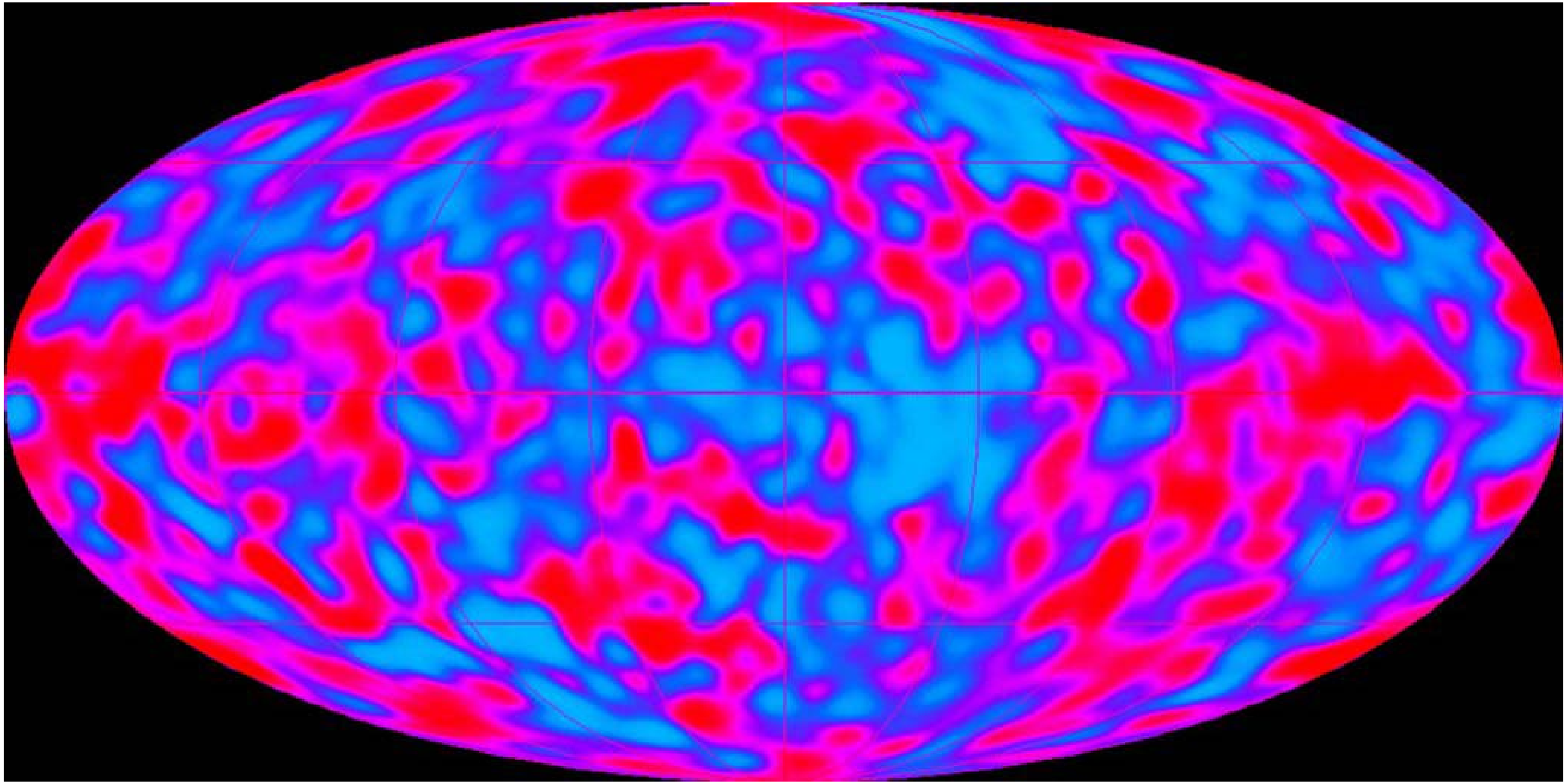








Virgo consortium

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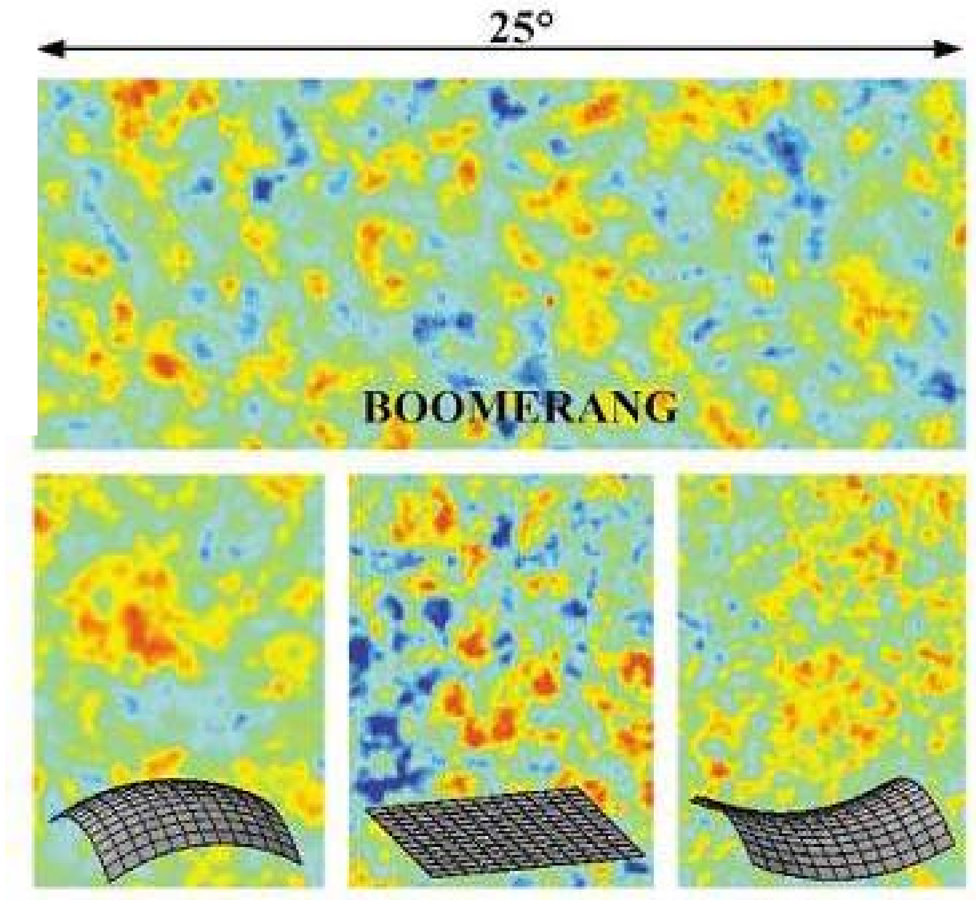
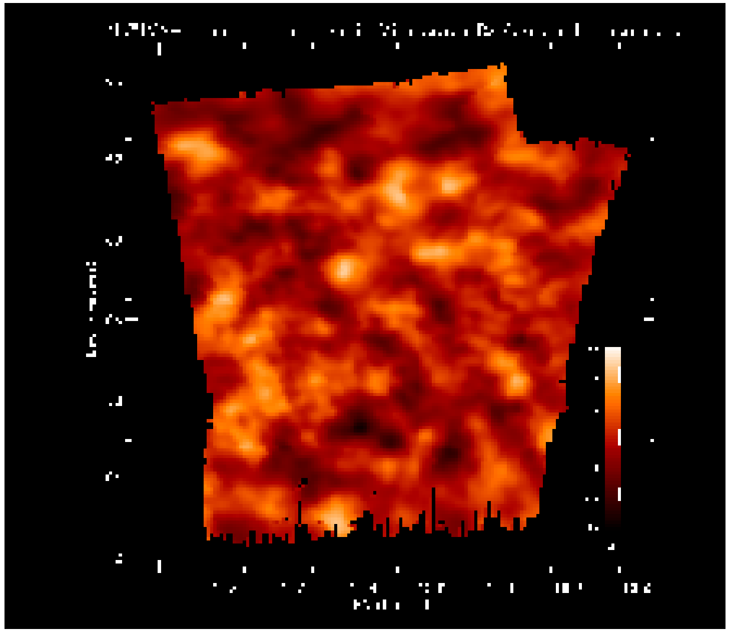
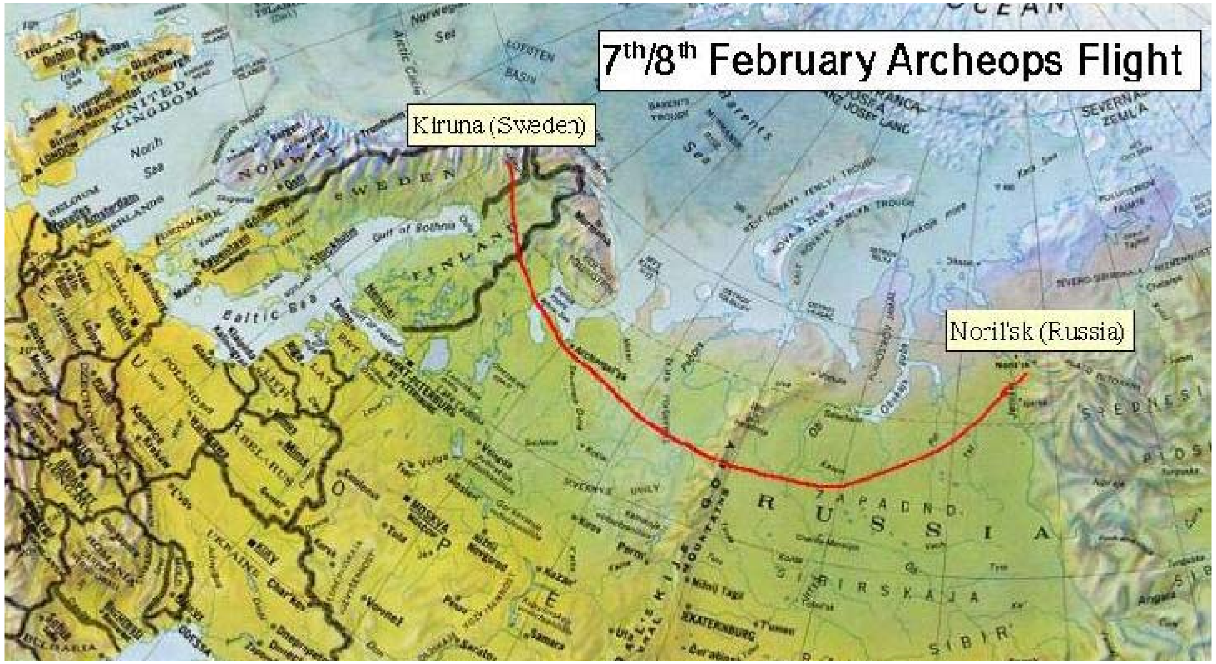


25°
BOOMERANG

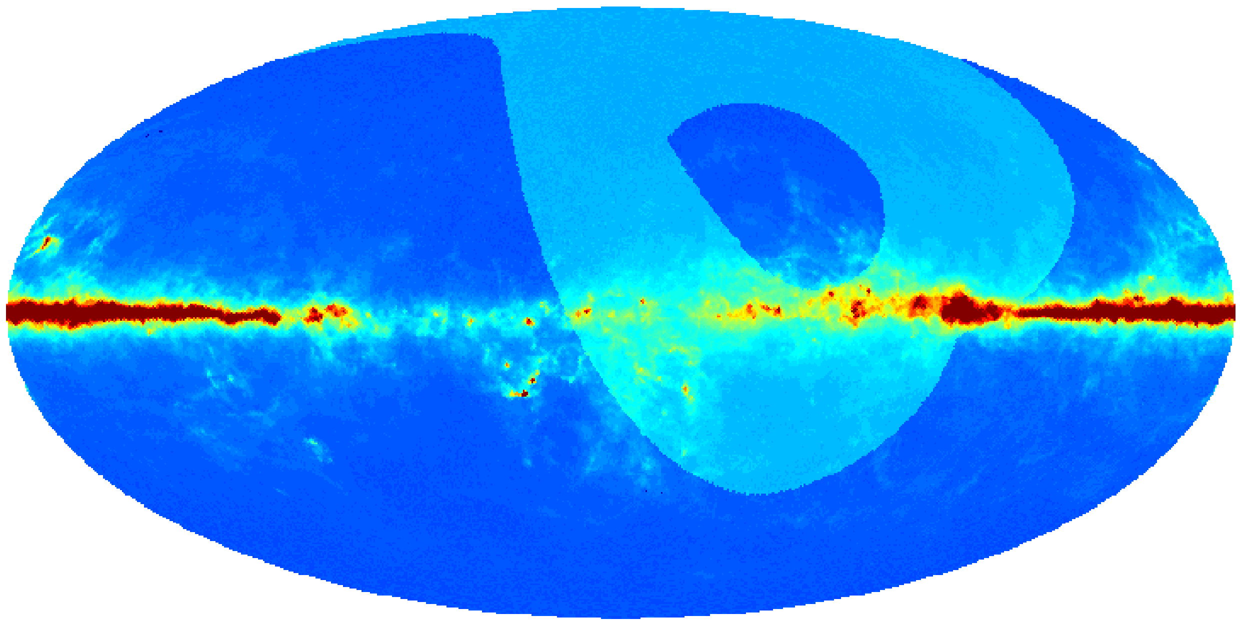
Maxima

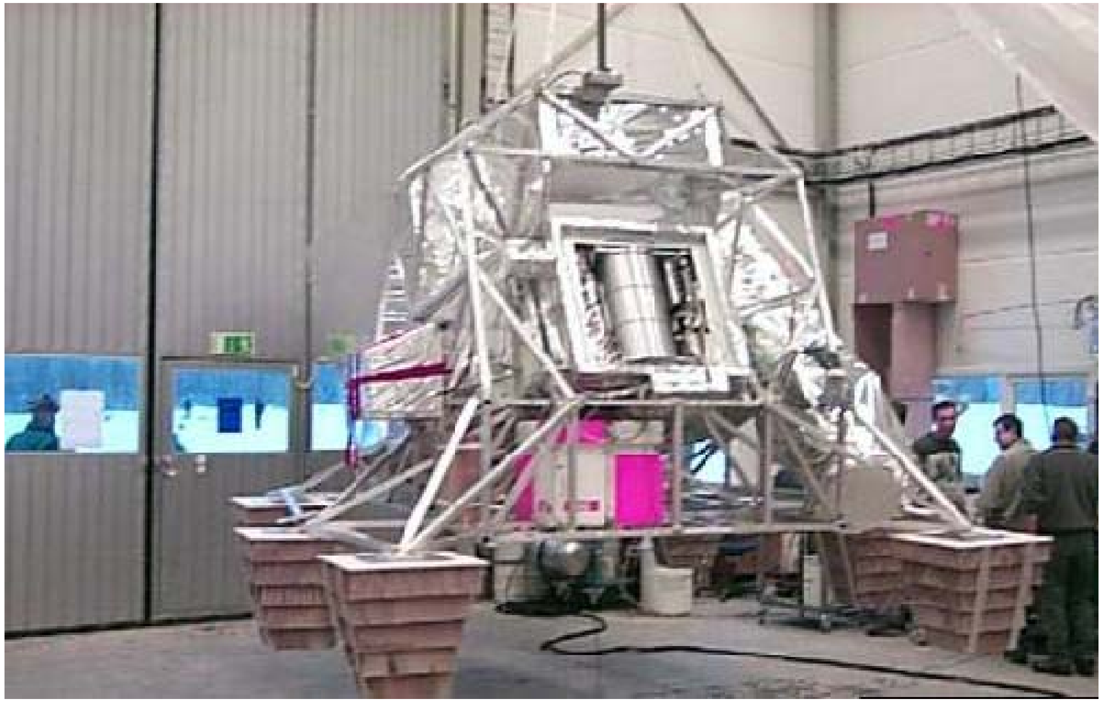


The Archeops Experiment



15.14 – 26.59 UT, Sky Coverage = 29.8%



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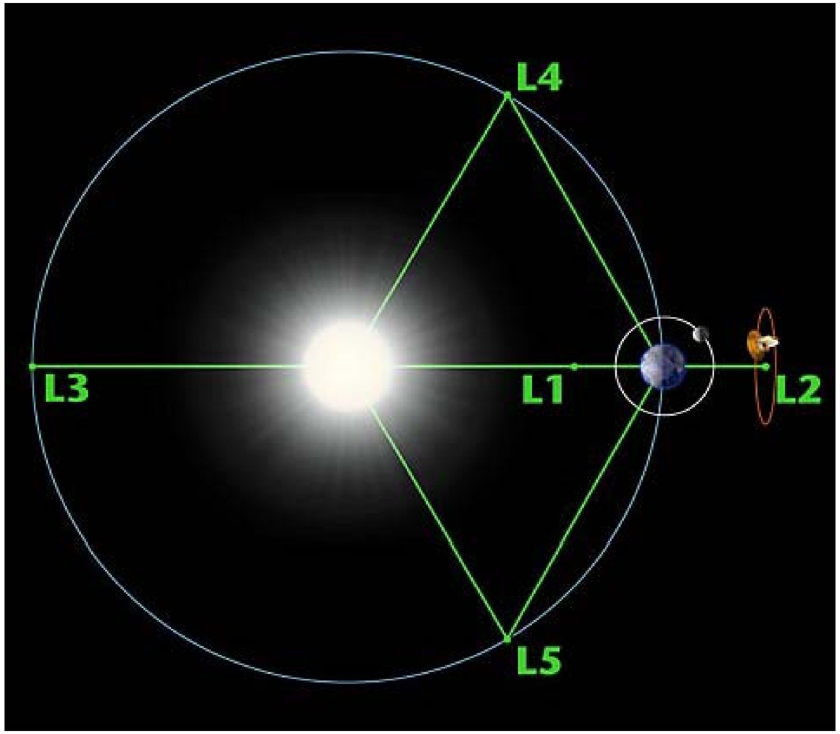
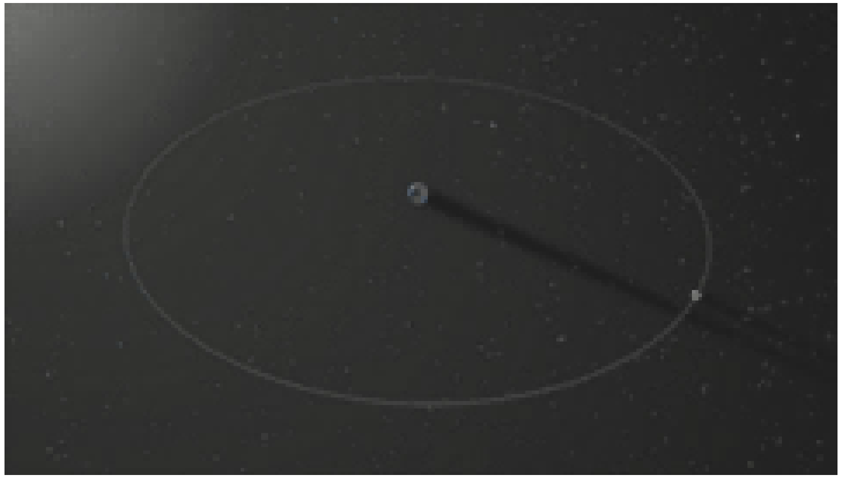
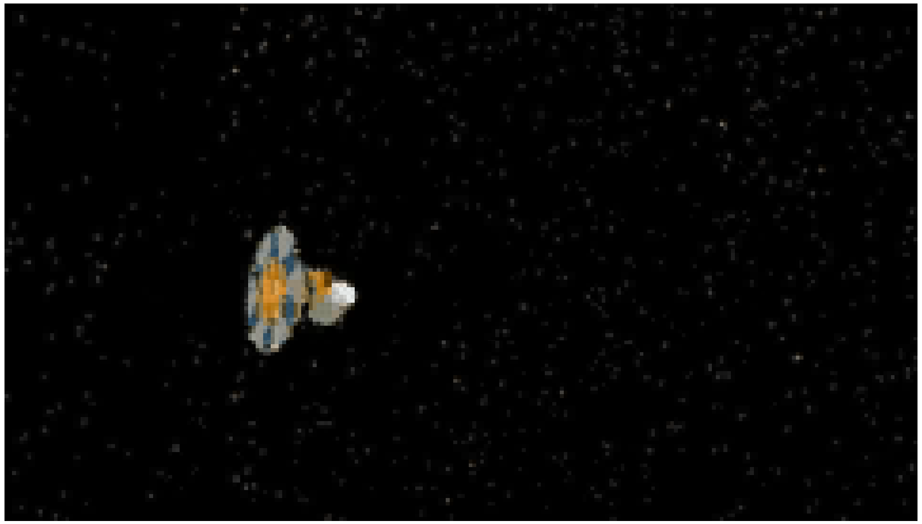
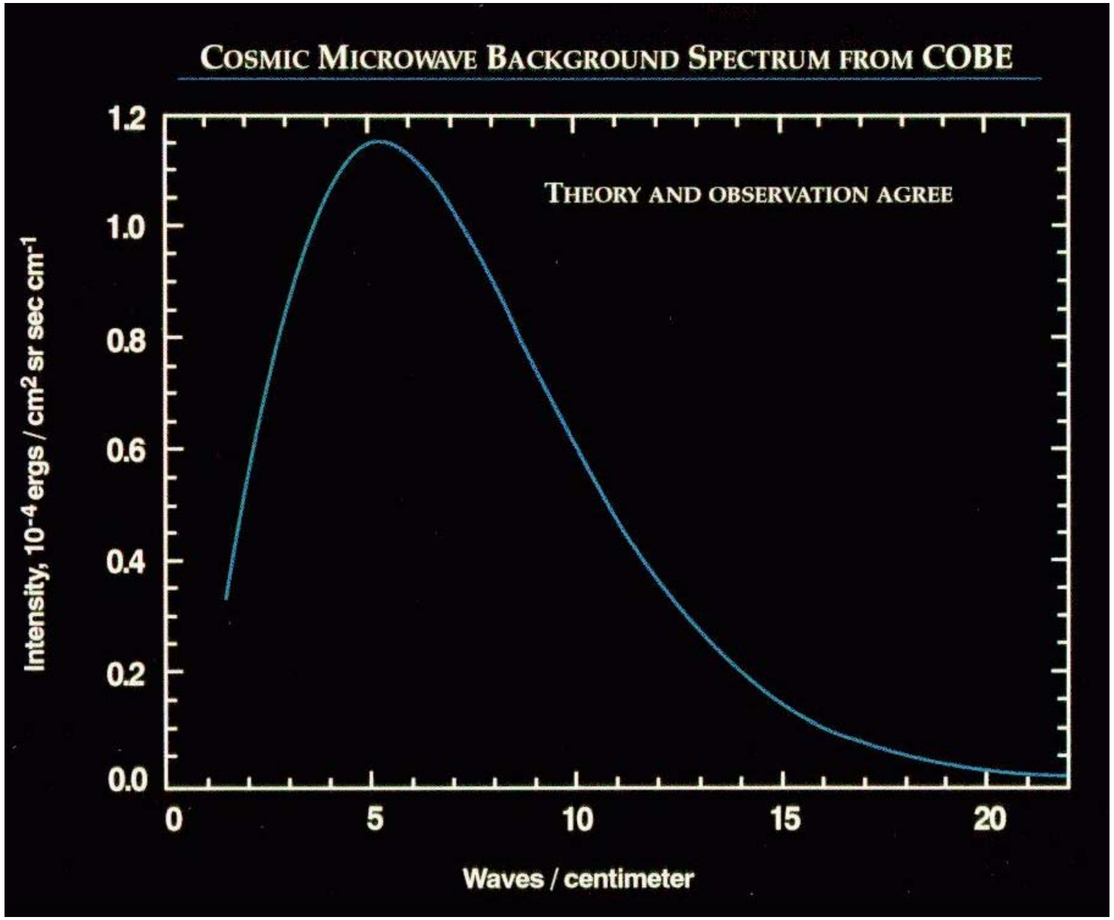
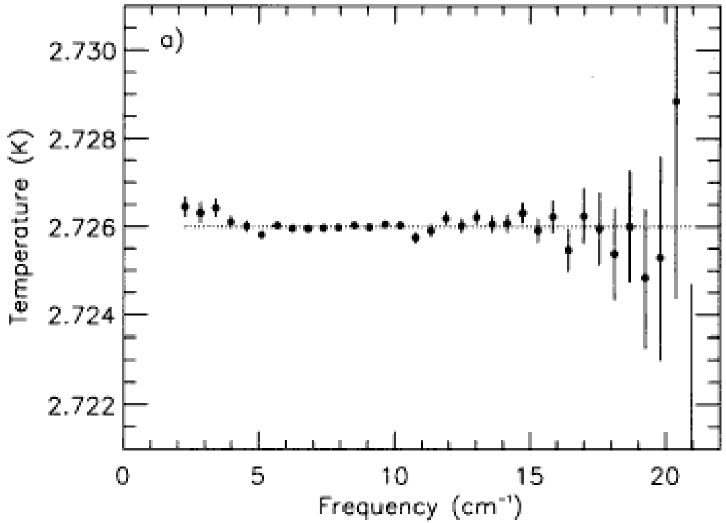

L4
L3
L1
L2
L5

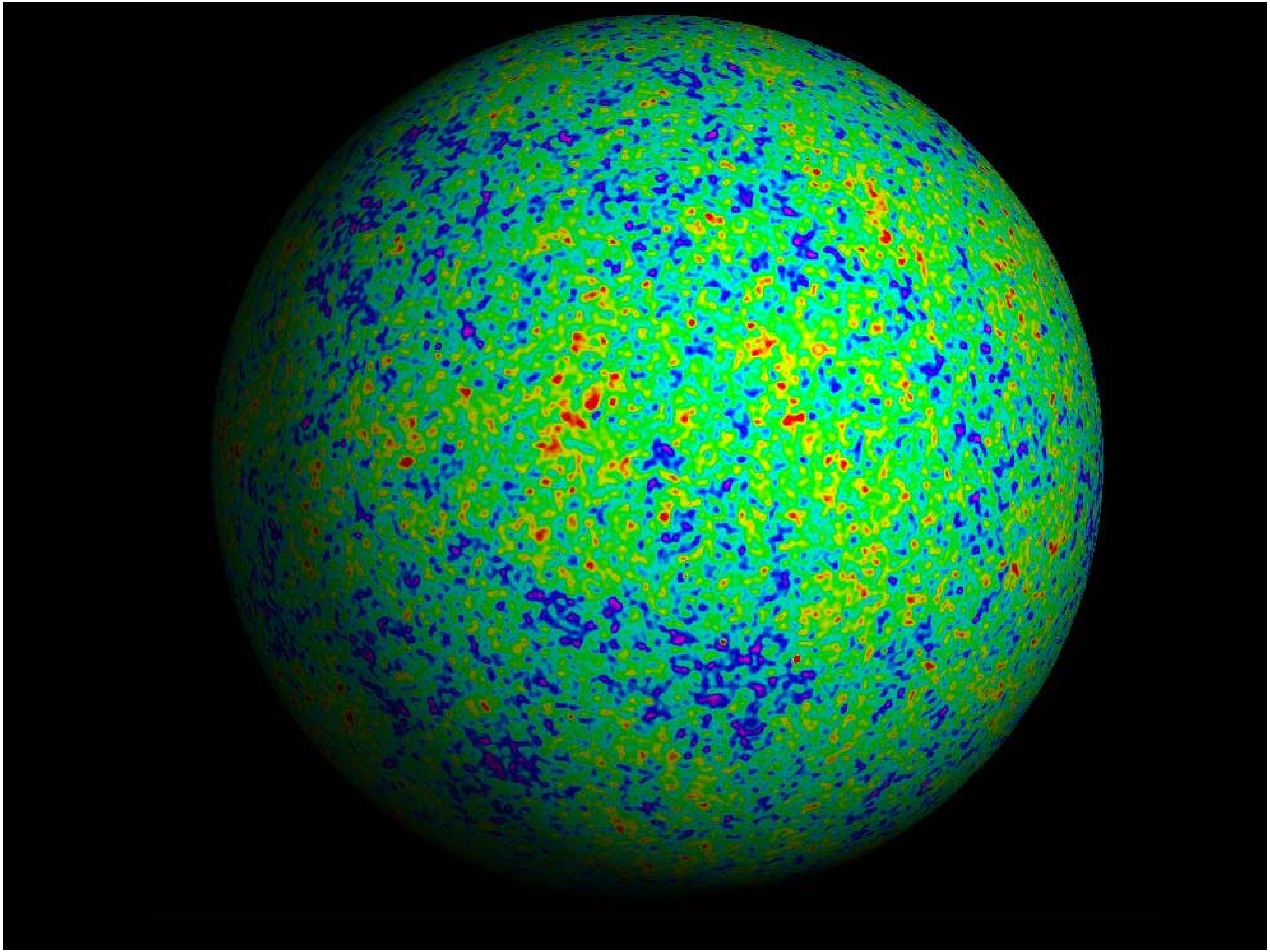


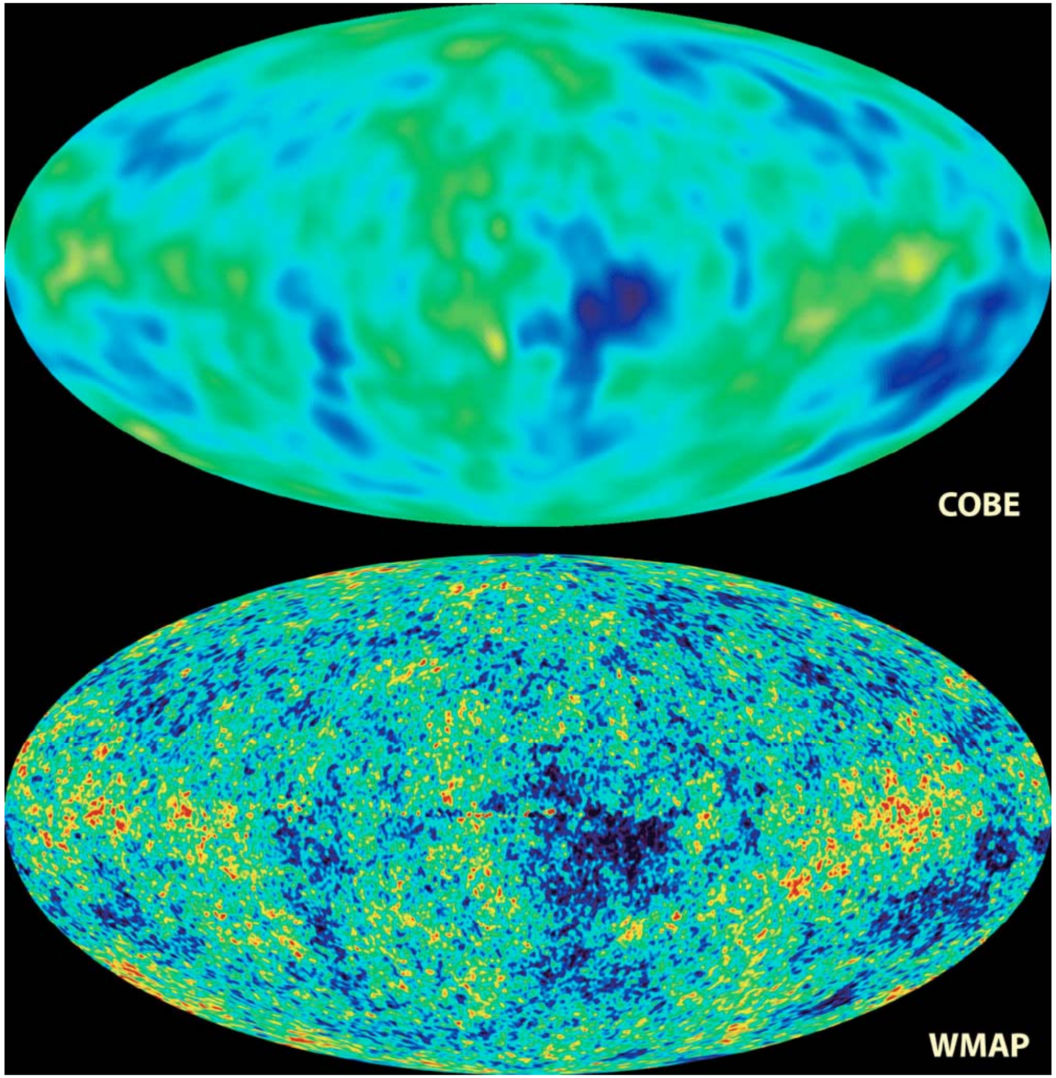






... **exactly** a blackbody spectrum, with a peak wavelength of 1.869 mm, corresponding to a temperature of **T = 2.725 +/- 0.010 K** .




COBE
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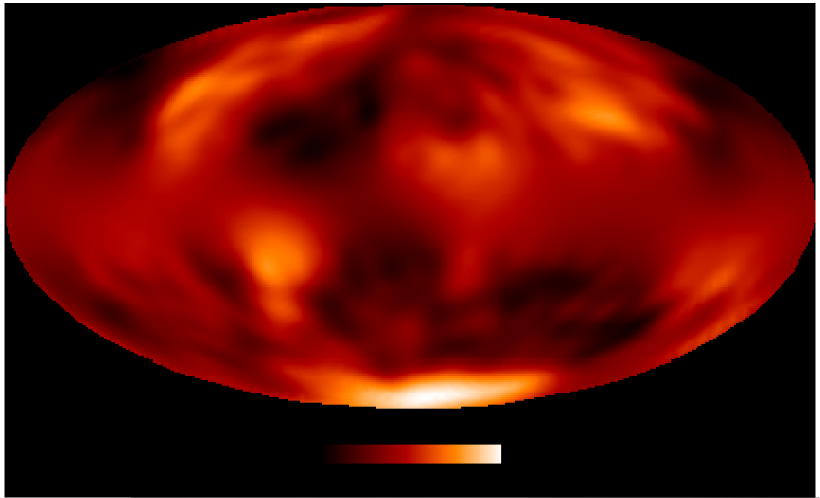

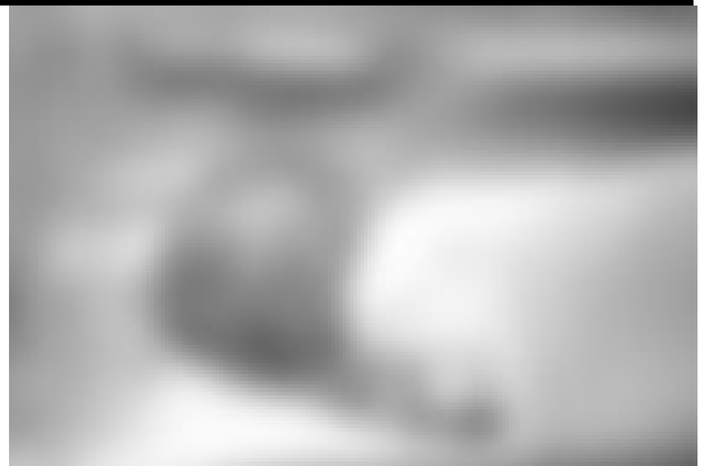


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