Misc

1. Second midterm solutions posted on the class website.

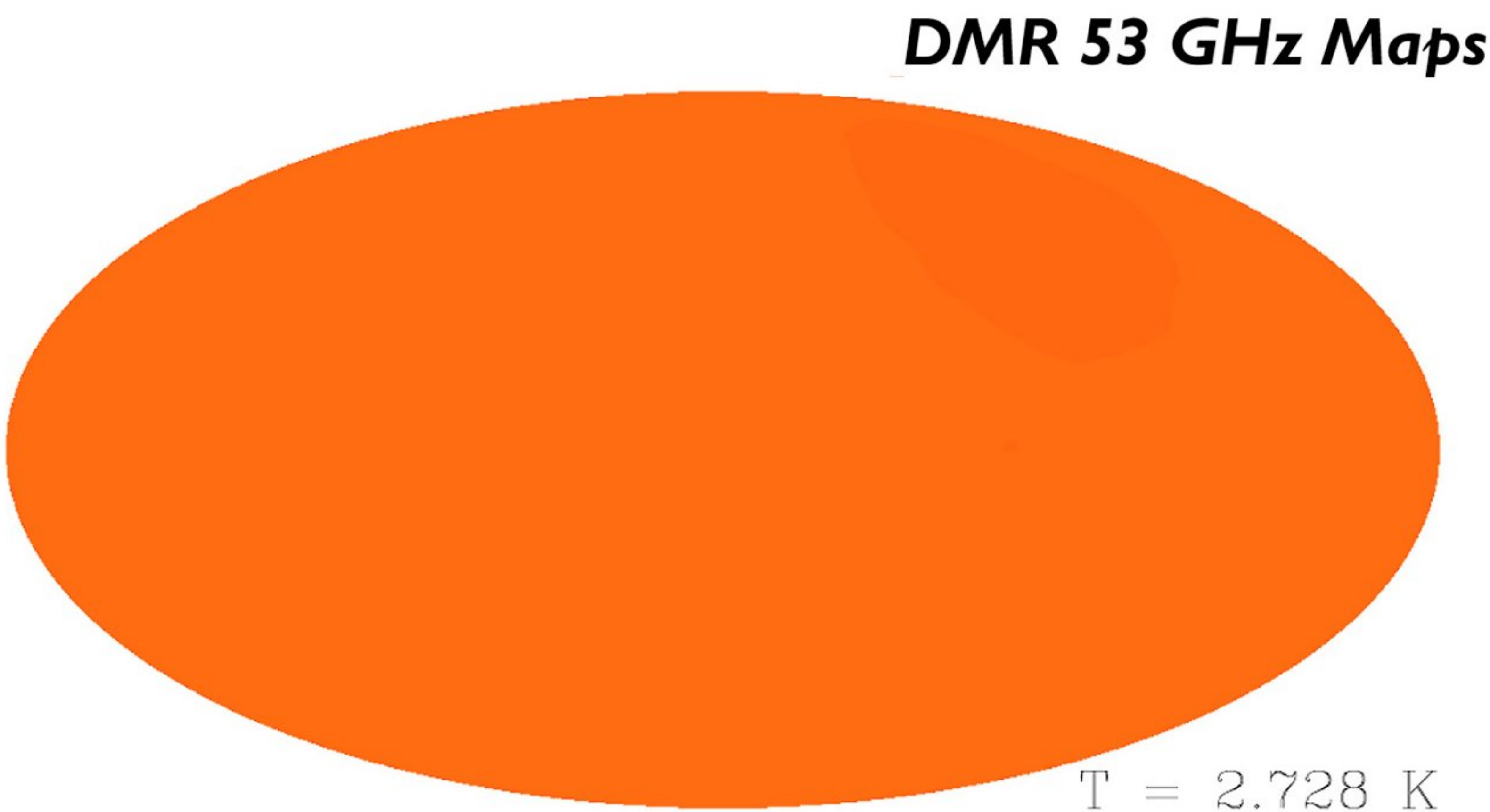
2. Homework 5 will be distributed on Friday (it will be due next Friday in class)

3. Homework 4 solutions and answers will be posted on the class website shortly.

4. Today, we are covering material of S 26-4, 26-5 (Ch. 26)

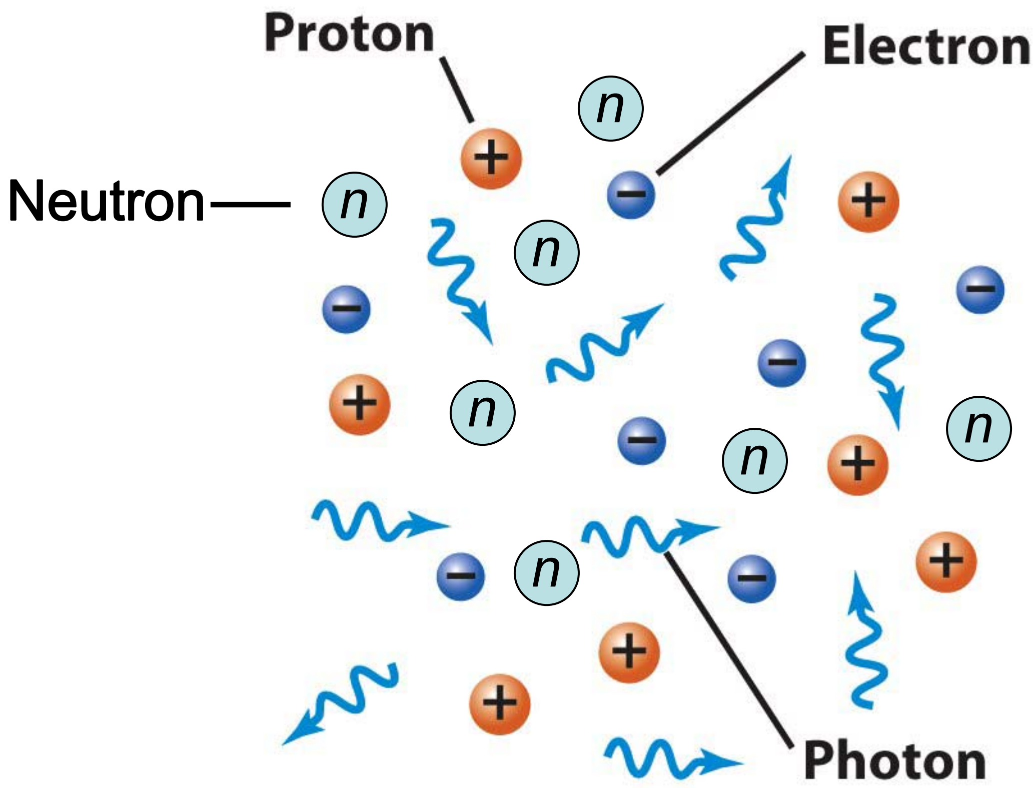
Consequences of the hot Big Bang:

Cosmic microwave background



The first 3 minutes

In the first three minutes the temperature of primordial plasma was hotter than the temperature in the center of the Sun, and conditions existed for hydrogen fusion similar to the thermonuclear fusion in the centers of stars.

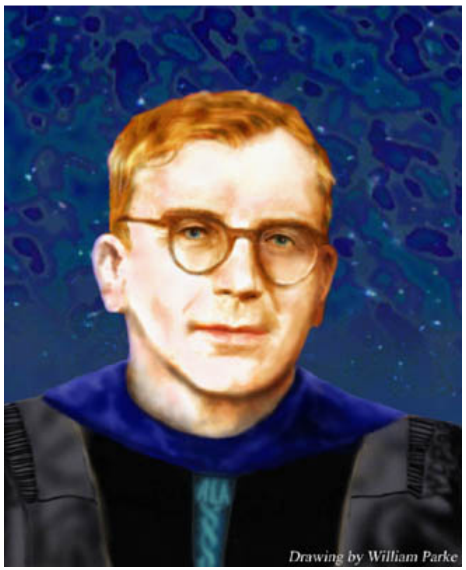


The relic sea of photons: Cosmic Microwave Background (or CMB)

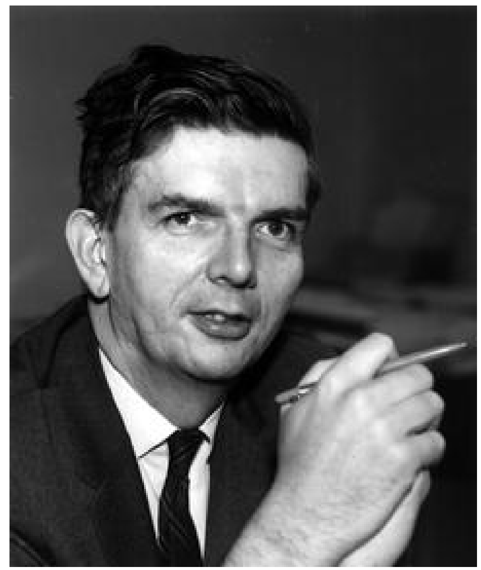
- When matter is hot and dense, it radiates energy with the *black body spectrum,* this is the basic and general prediction of quantum mechanics.

- At some point Universe becomes sufficiently cold and not as dense, so that light does not interact with matter (atoms) and can propagate freely, just redshifting its wavelength due to expansion of space.

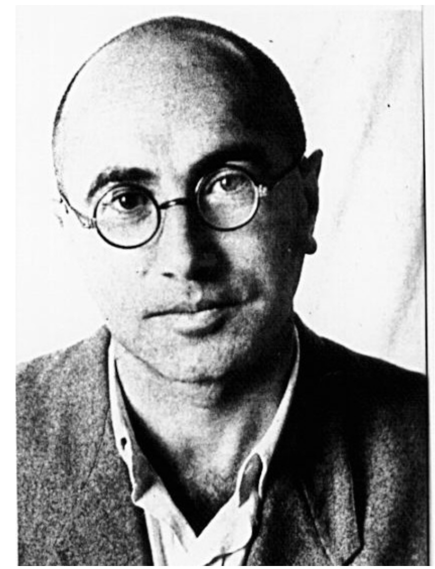
Existence of such relic radiation is a generic prediction of the Big Bang models, and IT EXISTS!



George Gamow



Robert Dicke



Yakov Zeldovich

Gamow, Alpher and Hermann predicted low-temperature (~10K) relic radiation from the Big Bang (the term coined by Gamow) in 1948. Prediction for the temperature was later refined by Alpher and Hermann to ~5K.

The prediction was rediscovered in early 1960s by Jim Peebles and Robert Dicke in Princeton, and by Yakov Zeldovich and colleagues in Moscow

The radiation was accidentally detected in 1964 by Arno Penzias and Robert Wilson

Penzias and Wilson and the antenna with which they discovered CMB in Holmdel, New Jersey energy could not be in the form of ordinary matter and may be presumed to be gravitational radiation (Wheeler 1958).

One other possibility for closing the universe, with matter providing the energy content of the universe, is the assumption that the universe contains a net electron-type neutrino abundance (in excess of antineutrinos) greatly larger than the nucleon abundance. In this case, if the neutrino abundance were so great that these neutrinos are degenerate, the degeneracy would have forced a negligible equilibrium neutron abundance in the early, highly contracted universe, thus removing the possibility of nuclear reactions leading to helium formation. However, the required ratio of lepton to baryon number must be $> 10^9$.

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

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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 wavelengths. This was expected on the basis of the non-peculiar $U-B$, $B-V$ colors. The spectrum of BSO 8 (called "BSO 105" by Sandage 1965 on an older numbering system) is continuous with no prominent absorption or emission lines. BSO 1 has a large redshift of $\Delta\lambda/\lambda_0 = 1.2410$, as described elsewhere (Sandage 1965).

Table 1 lists the precise optical positions of the first four interlopers, and estimated positions, accurate to perhaps $\pm 20''$, for the thirty-one survey objects. Where available, the colors and magnitudes determined photoelectrically at the 200-inch are also shown.

These blue objects are undoubtedly of the same class as the faint objects in the catalogues of Iriarte and Chavira (1957), Chavira (1958), and Haro and Luyten (1962). With the identification of most of these objects as intrinsically bright stellar-appearing galaxies, these catalogues provide a large finding list that can be surveyed by radio techniques to determine if the QSG's are weak radio emitters. It is expected that such study will shed light on the evolutionary process of radio decay after the intense QSS radio phase.

ALLAN SANDAGE
PHILIPPE VÉRON

May 21, 1965

MOUNT WILSON AND PALOMAR OBSERVATORIES
CARNEGIE INSTITUTION OF WASHINGTON
CALIFORNIA INSTITUTE OF TECHNOLOGY

REFERENCES

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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.

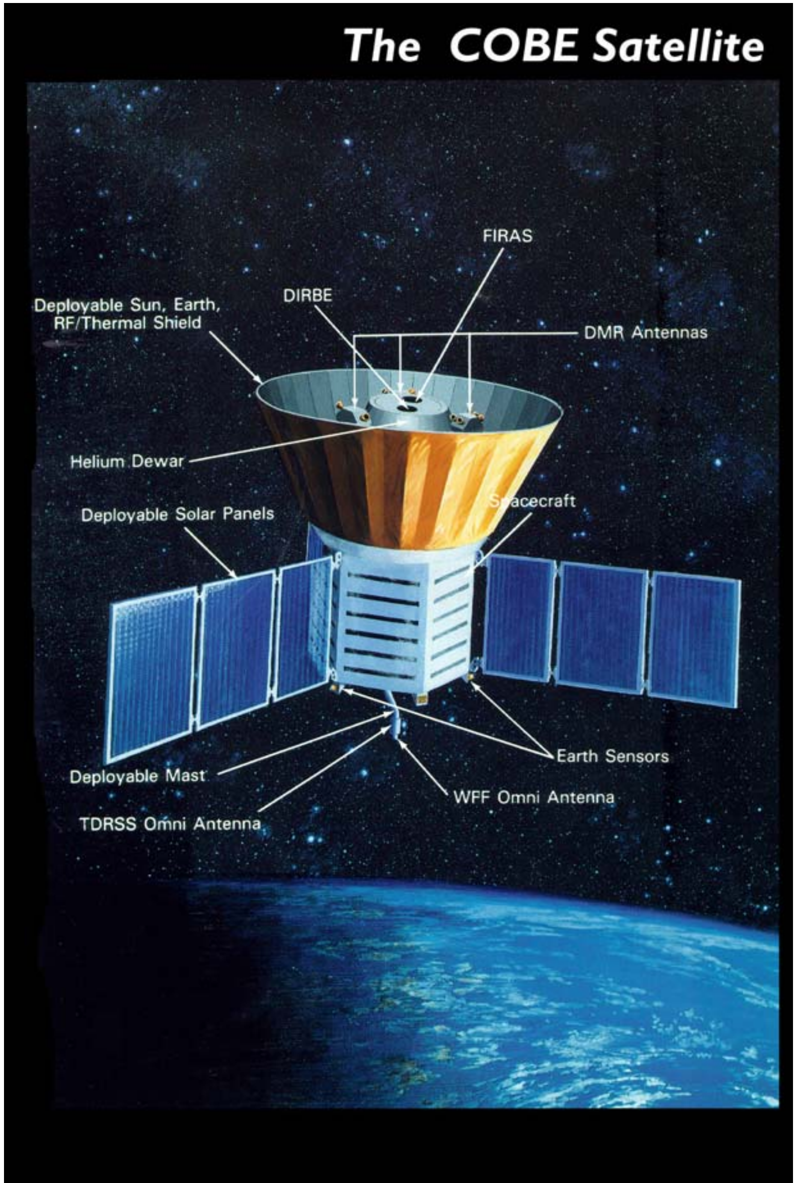
1. The assumption of continuous creation (Bondi and Gold 1948; Hoyle 1948), which avoids the singularity by postulating a universe expanding for all time and a continuous but slow creation of new matter in the universe.

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,

* This research was supported in part by the National Science Foundation and the Office of Naval Research of the U.S. Navy.

Is the CMB true black body radiation as predicted by the Bing Bang theory?

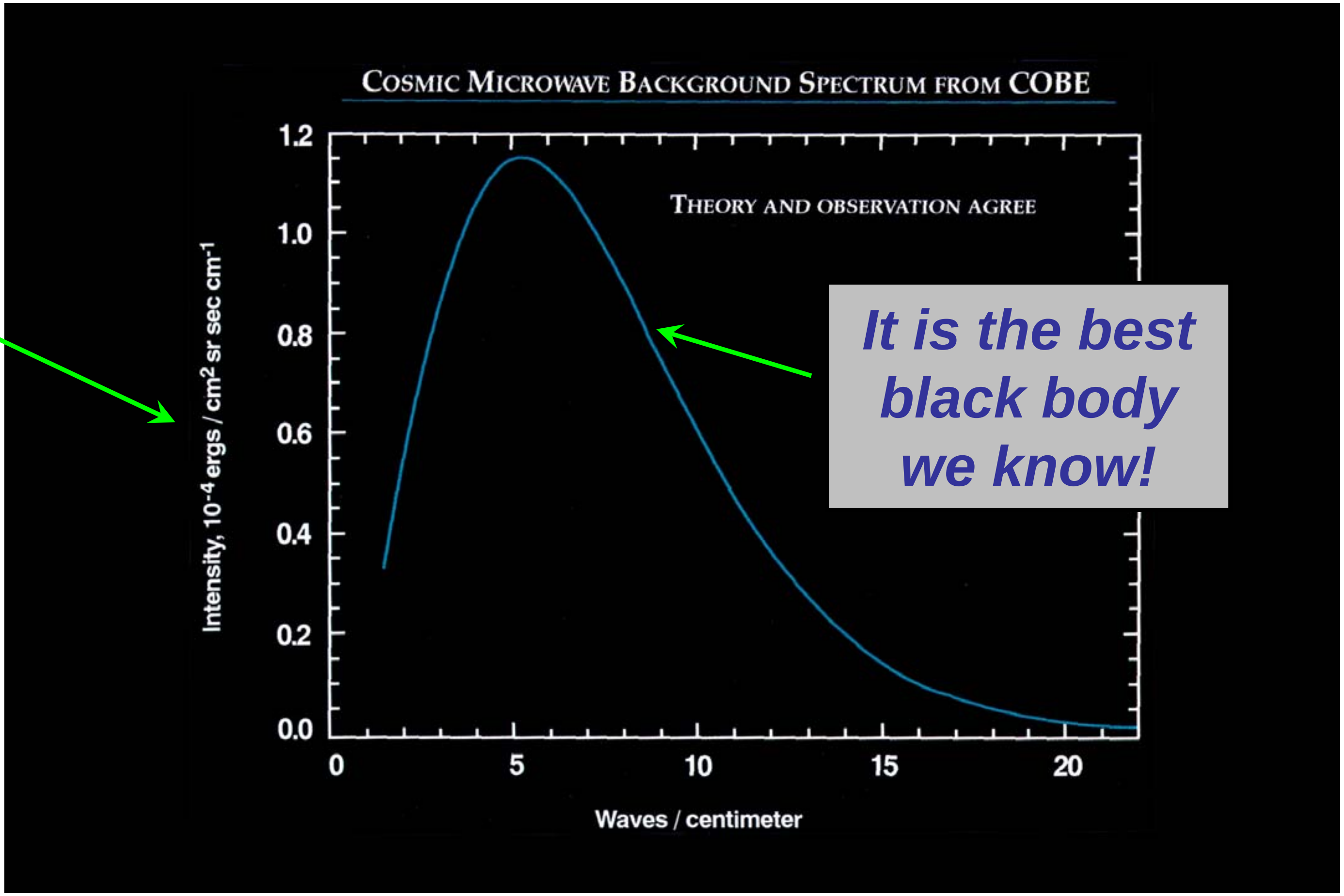


The situation was not entirely solid until early 1990s when the *Cosmic Microwave Background Explorer (COBE)* satellite was launched and operated

COBE satellite had a number of instruments and antennas onboard designed to observe at different frequencies to study infrared background, emission from our Galaxy, spectrum of the CMB, as well as its temperature in different parts of the sky

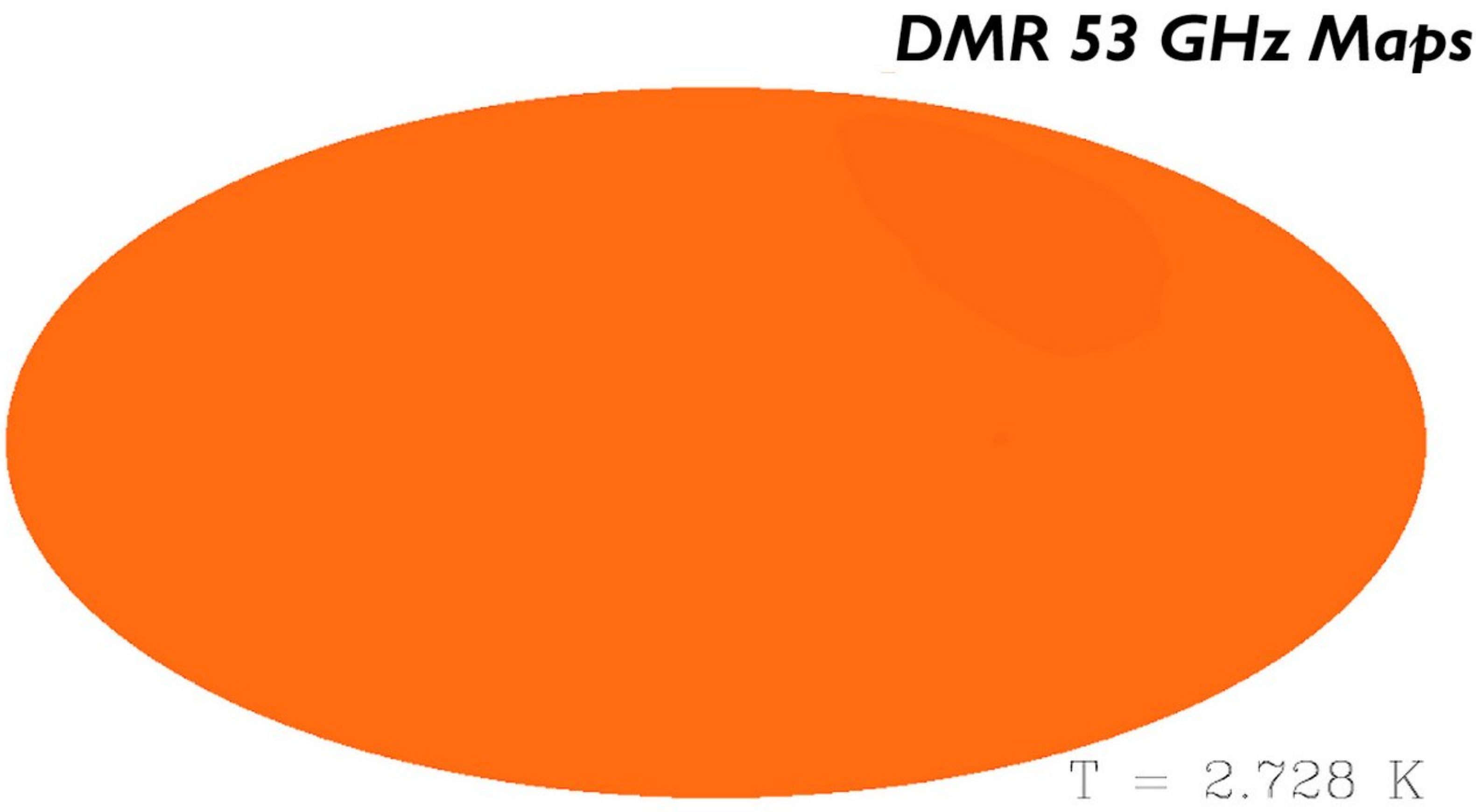
Is the CMB true black body radiation as predicted by the Bing Bang theory?

Spectrum of the CMB radiation (intensity as a function of frequency or wavelength)



Measured temperature of the CMB radiation: Tb = 2.728+-0.004 K

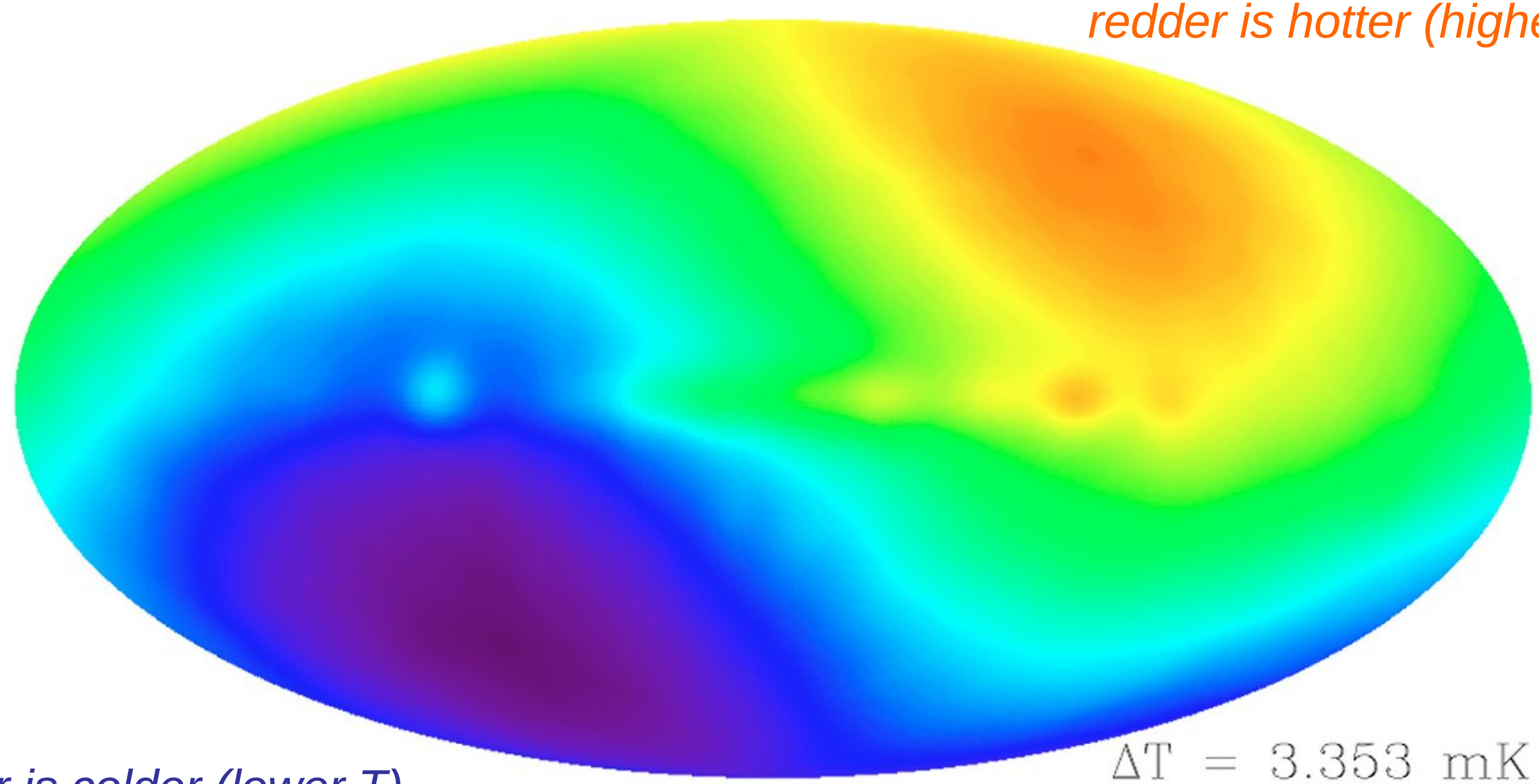
Is it isotropic as expected from the cosmological principle?



Yes! To an amazing degree…

But is it exactly isotropic?

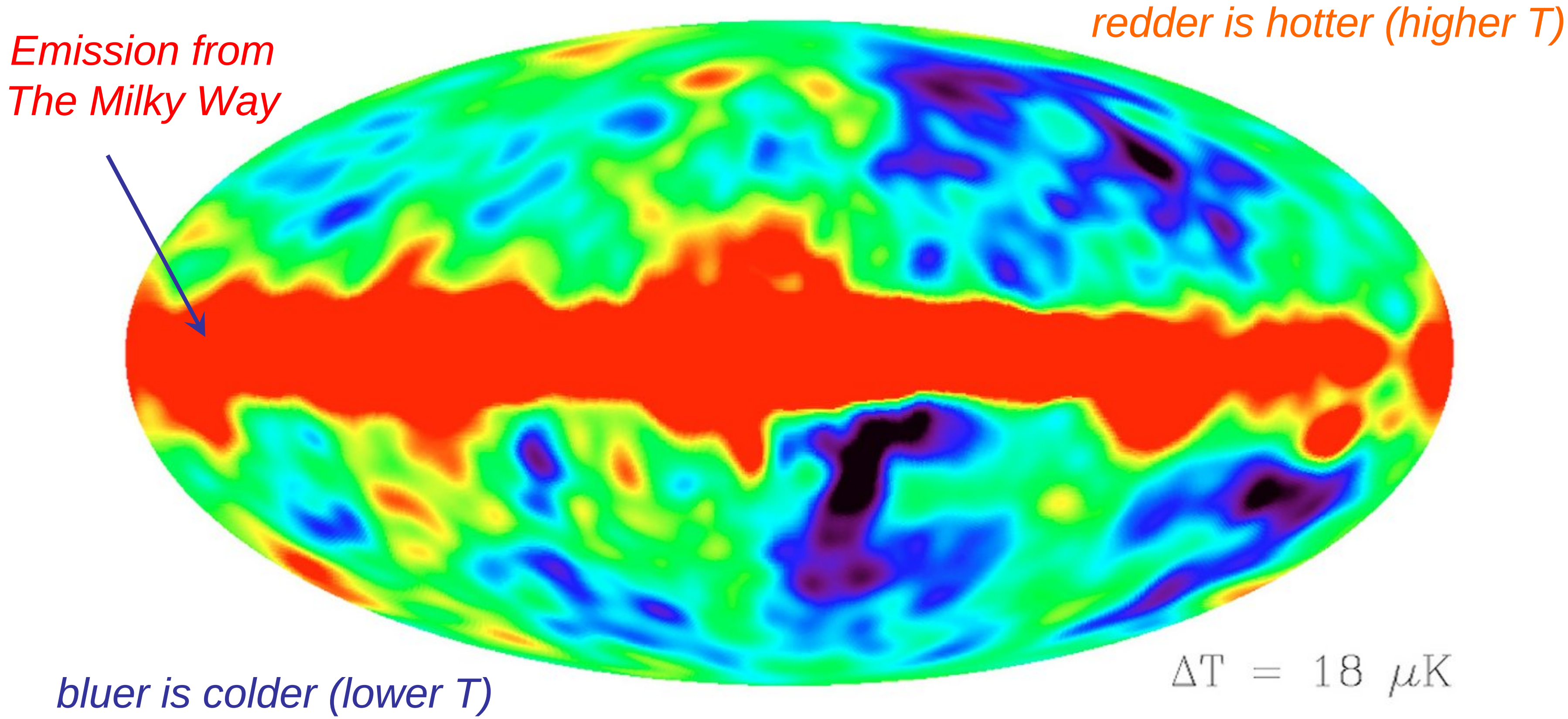
redder is hotter (higher T)



bluer is colder (lower T)

No. There are deviations. The largest ones are due to emission of our own Galaxy and due to its motion (so-called dipole anisotropy)

But is it exactly isotropic?



LUCKILY NOT! There are (expected) small anisotropies interpreted as primordial fluctuations which seeded formation of structures in the Universe (galaxies, clusters, etc… more on this later in the course)

Milky Way emission can be modeled and removed