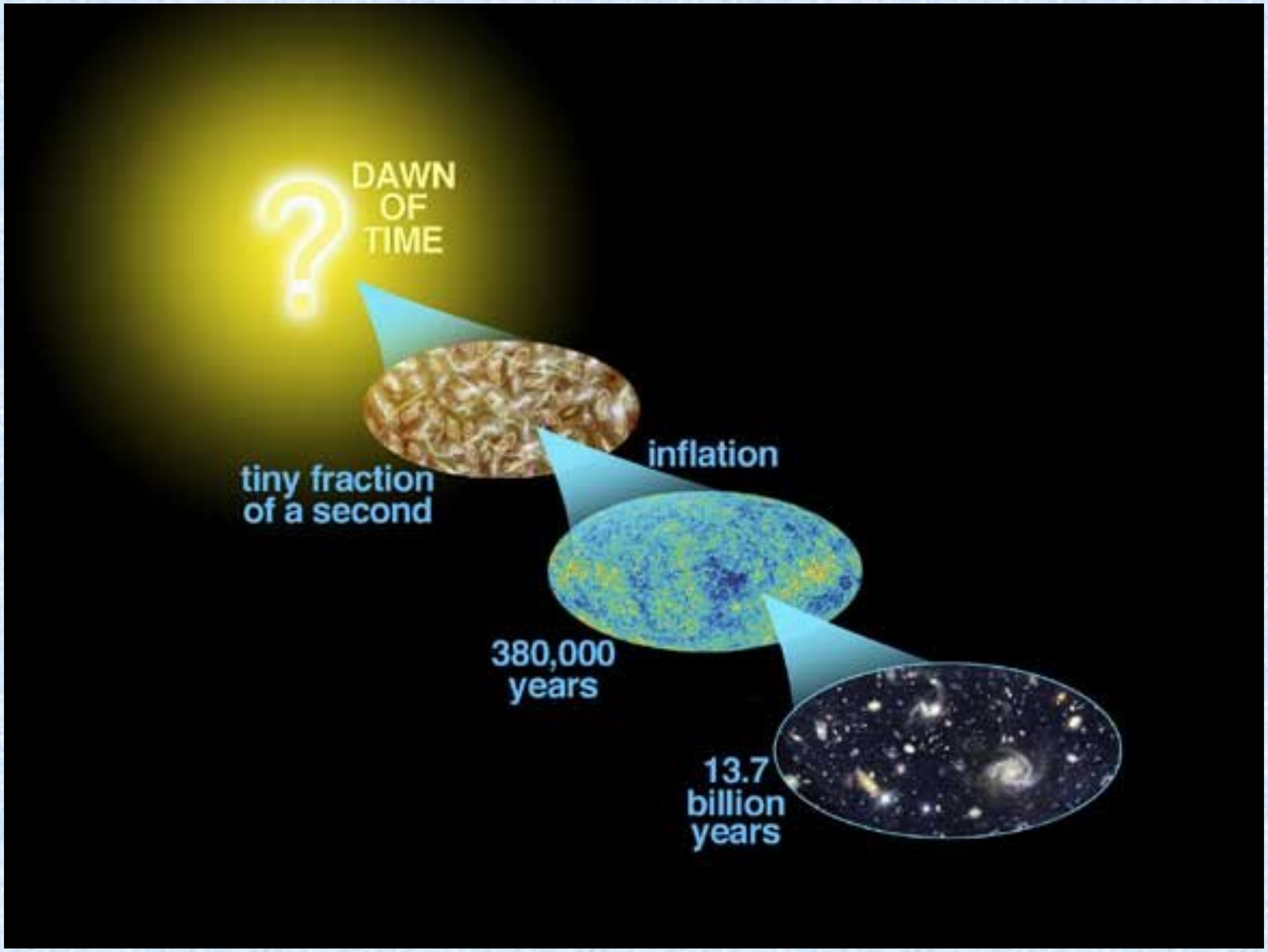
# Astro-2: History of the Universe




Lecture 7; May 2 2013

# Previously… on astro-2

- A scientific theory is a logically self-consistent model or framework for describing the behavior of a related set of natural or social phenomena.
- It originates from and/or is supported by experimental evidence.
- In this sense, a theory is a systematic and formalized expression of all previous observations that is **predictive, logical and testable**.
- Scientific theories are always tentative, and subject to corrections or inclusion in a yet wider theory.
- Good scientific theories should be “simple”. Ockham’s razor

# Previously… on Astro-2

- Olbers' s paradox: the night sky is dark
- This implies that the emission of starlight in the universe must be finite, in space, time or both.
- The Big-bang explains Olbers' s paradox with the finiteness of the lifetime of the Universe and hence of its stars:
- The universe is NOT eternal in the past! The universe evolves! Other evidence for evolution is given for example by the cosmic star formation rate

# Previously… on Astro-2

- Hubble's law is interpreted as evidence that the universe is expanding
- In the Big Bang model any two points in space were arbitrarily close to each other a finite amount of time ago.

# Previously… on astro-2

- $1/H_0$ is approximately equal to 14 Gyr
- The life of the universe is of order of 14Gyr.
- the age of the oldest stars in the Universe are remarkably consistent with the age of the universe itself, at any redshift where we can measure it.
- This does not prove that the model is right, but is a great triumph of the theories of the big bang and that of stellar evolution

# Assignments. Due Friday 5/09 4PM

1. To TA: Universe 26.36 - 26.37 – 26.40 -26.42 - 26.45
2. On your own: 26.2-4-5-8-11-12-14-19-24-28-29-31

# Extra credit opportunities

1. "Booms, burps, and bangs: the dynamic universe" by Dr Shri Kulkarni, Santa Barbara Museum of Natural History, 7:30PM, May 9
2. Star parties. Check out the Santa Barbara Astronomical Unit website and calendar

# Today.. On Astro-2.
# Evidence for the big bang

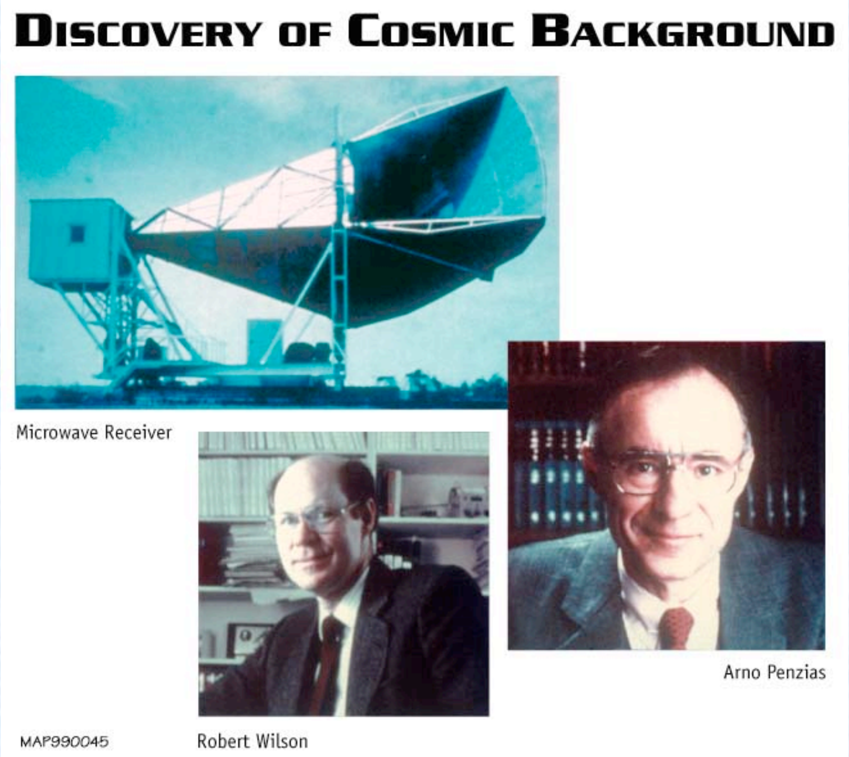
1. First, a few more words on the meaning of cosmic singularity..
2. Cosmic Microwave Background. The Universe is evolving from a "hot" state
3. Horizons and the horizon problem.

# A very good question… how can space reduce to a point?

- Space is at least 3D
- How can it reduce to a point?
- Well… we do not know… We do not even know if that is what happened..
- That is why I formulated the concept in terms of any two points getting very close at some point back in time.
- A fundamental limit is given by Plank time $t_p = \sqrt{Gh/c^5} = 1.35e\text{-}43s$
- In the Big Bang model, as we go back in time the universe becomes so dense and energetic that the laws of physics as we know them break down.
- From dimensional considerations we think that we cannot certainly tell anything about what happened between 0 and the Plank time…

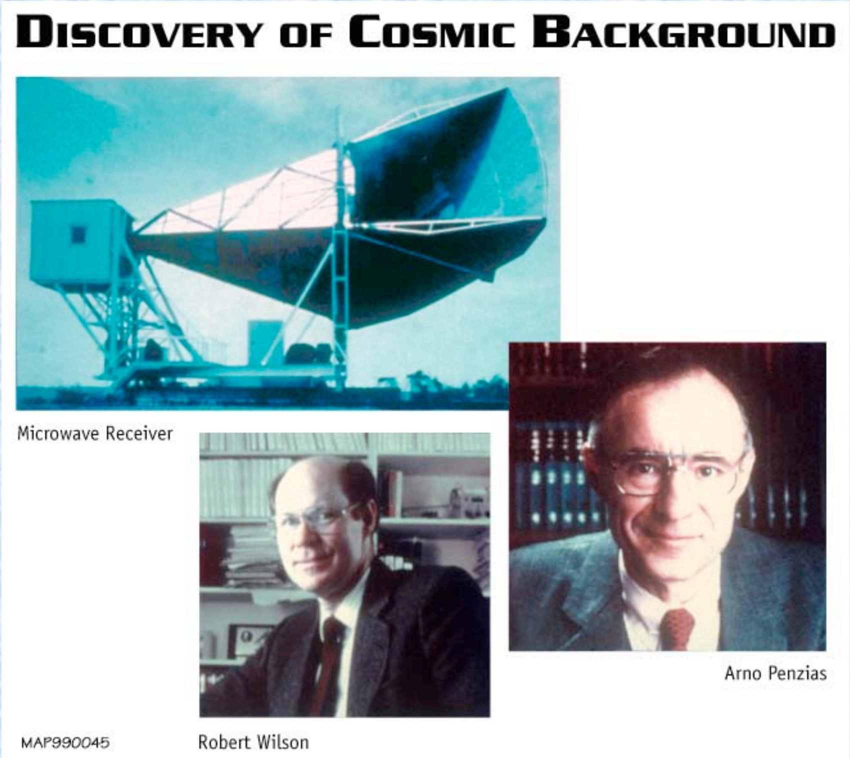
# Cosmic Microwave Background

- The cosmic microwave background was discovered as a background “noise” a real problem for telecommunication satellites
- Wherever Penzias and Wilson pointed their antenna they would detect a microwave signal, very uniform across the sky
- This signal is now called the cosmic microwave background…



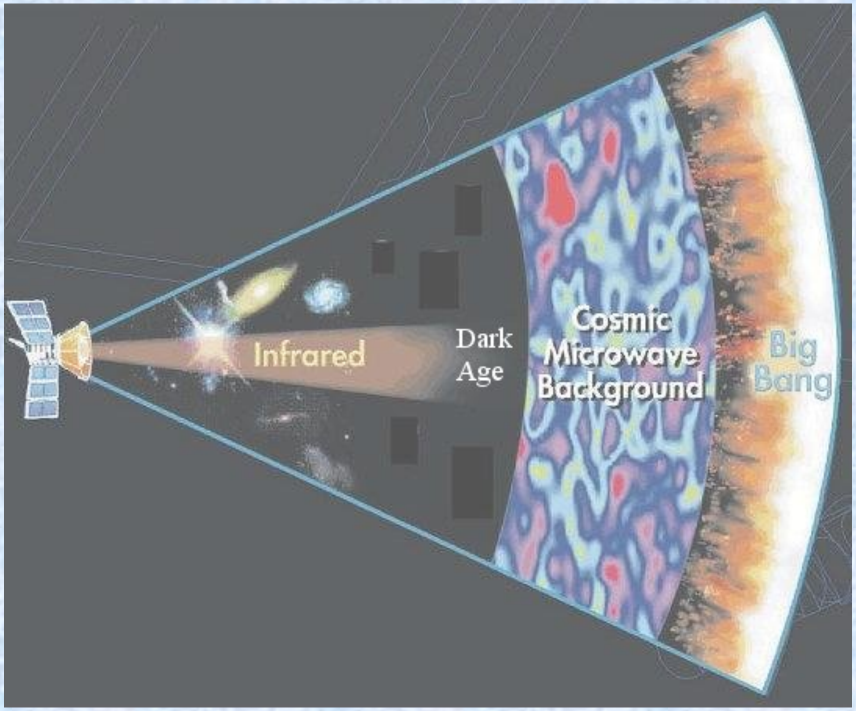
# Cosmic Microwave Background

- The CMB was already visible in the data taken by Dunham and Adams of the properties of CN in the interstellar medium …back in 1937
- The saw that CN was excited as if it was immersed in a thermal bath of radiation of temperature T~3K…
- But nobody realized it.. So the Nobel Prize went to Penzias & Wilson… and not to Dunham and Adams.. Such is life..



# Cosmic Microwave Background

- A group of physicist (initially Alpher and Hermann and then Dicke and his group at Princeton) had predicted such radiation, from the so-called big bang nucleosynthesis theory (later in the class..)
- The CMB was predicted to be:
  - Thermal
  - At a temperature of about 5K
  - Isotropic



# Cosmic Microwave Background. Thermal "Blackbody" Radiation

- We know Penzias and Wilson detected isotropic radiation, so that was consistent with the Big Bang model and the copernican principle
- The theory predicted it to be thermal, i.e. a blackbody.
- But what is a blackbody?
- A blackbody is a very specific spectral energy distribution

**Plank's Equation**

$$B_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{\exp\frac{hc}{\lambda kT} - 1}$$

Where:

$B_\lambda$ = *Magnitude of Radiation per Wavelength.*

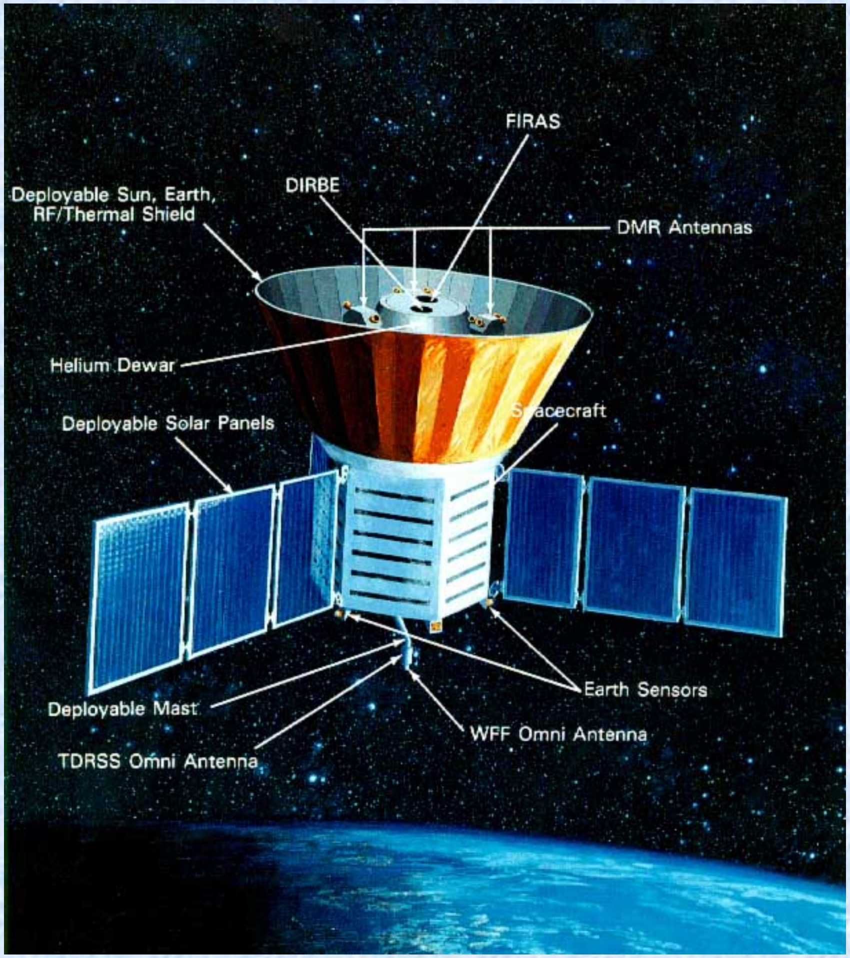
$\lambda$ = *Wavelength.*

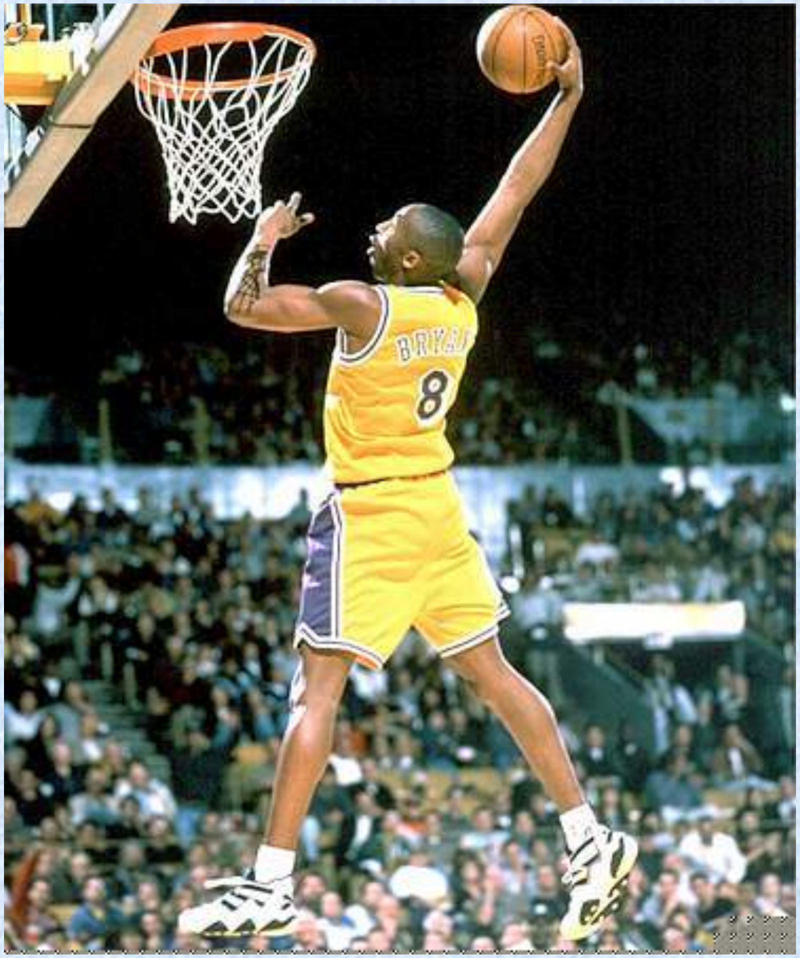
$h$ = *Plank's Constant* $(6.6238 * 10^{-34}\ Js)$.

$c$ = *Speed of Light* $(3.0 * 10^{8}\ m/s)$.

$k$ = *Boltzmann Constant* $(1.3807 * 10^{-23}\ J/K)$.

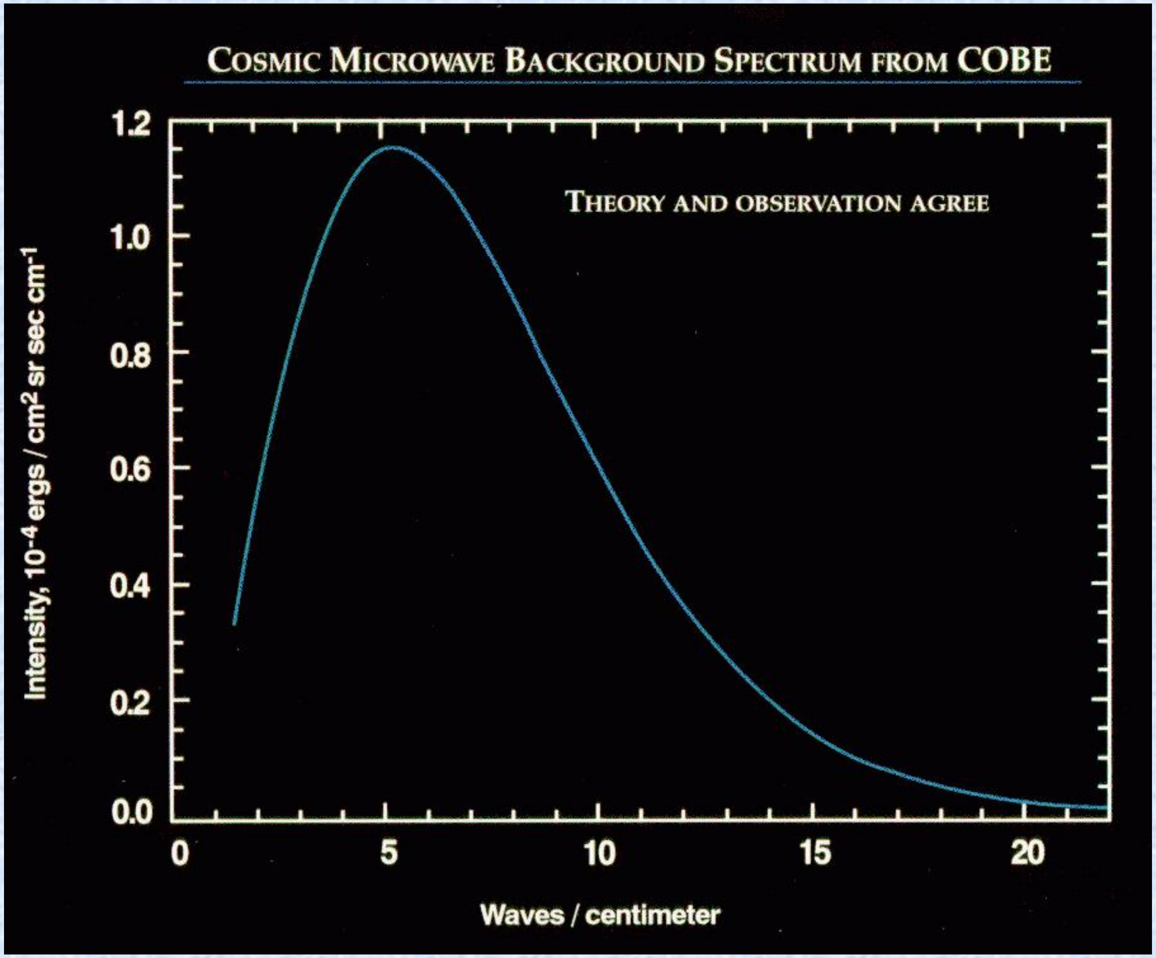
# Is the CMB a Blackbody?
# COBE got the answer



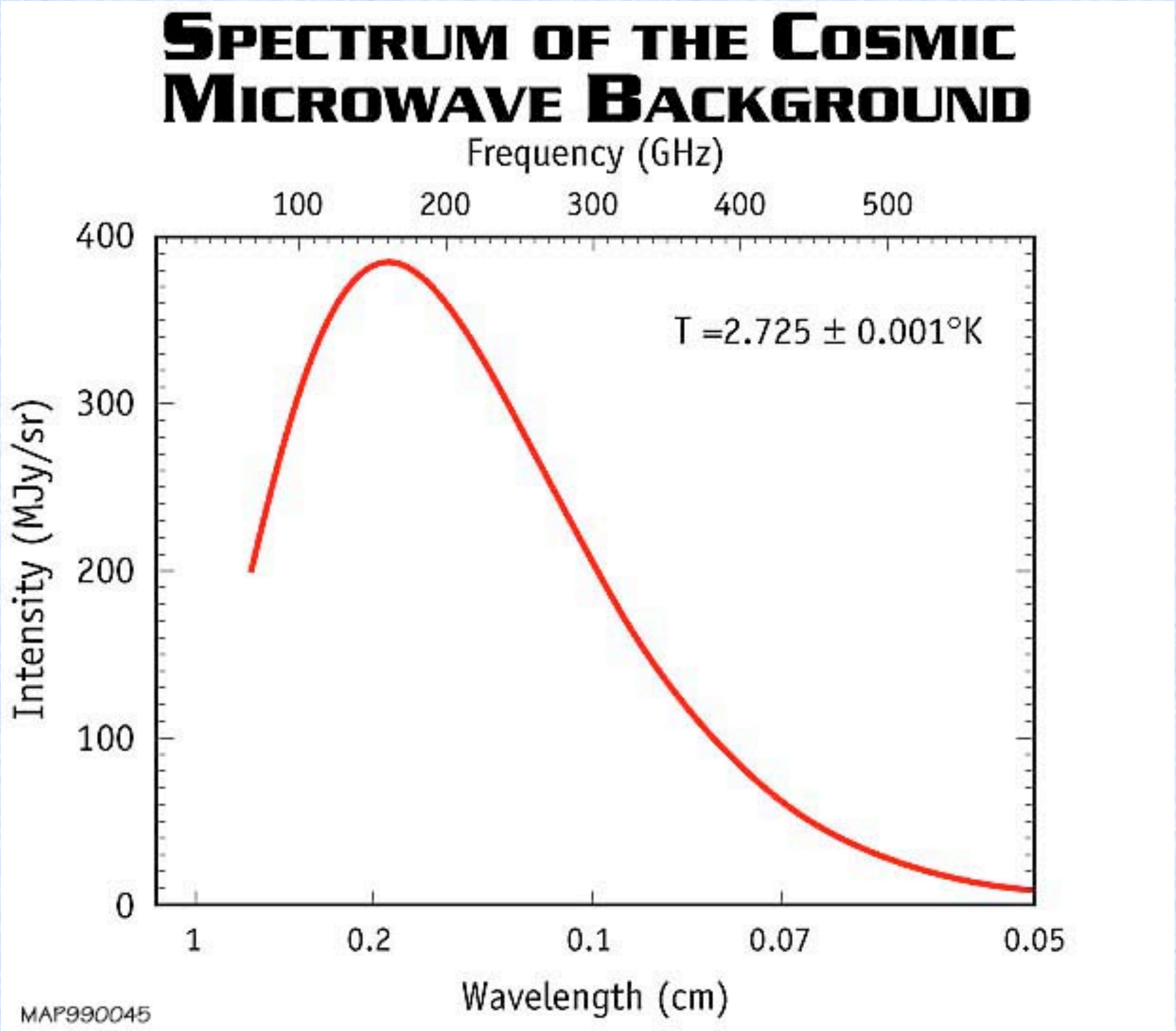

COBE…………………………….NOT KOBE!

# Cosmic Microwave Background.
# The CMB is a "perfect" Blackbody




COBE FIRAS 1989

# Cosmic Microwave Background. The temperature is 2.725 K..



# Isotropy and homogeneity of the Universe. What's the connection? DISCUSSION.

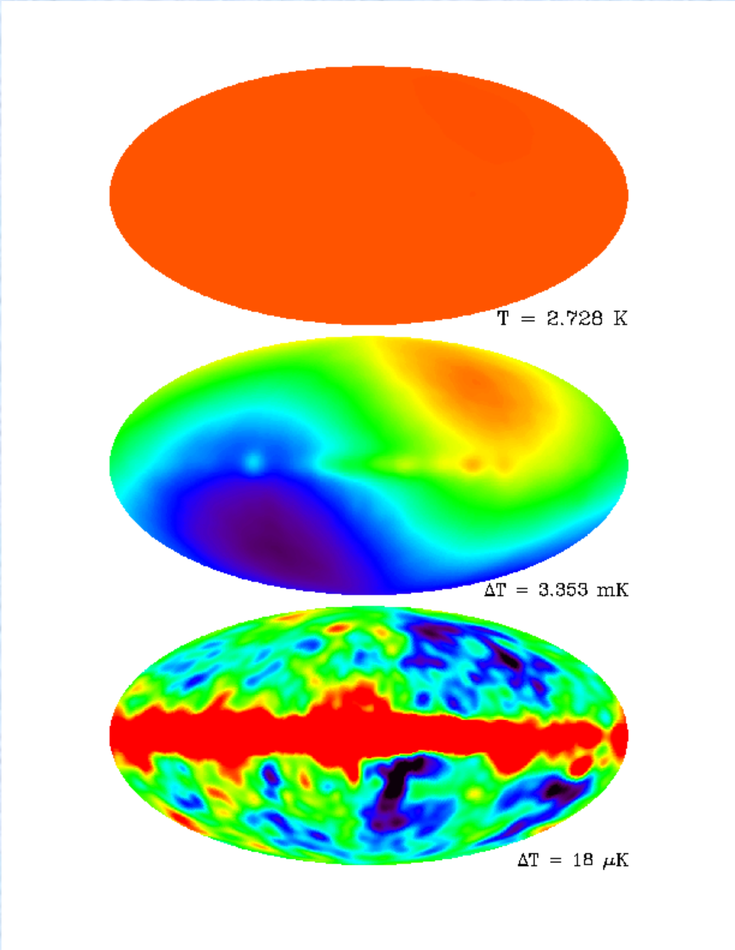
- What we measure directly is the isotropy of the CMB (and other extragalactic sources)
- That is consistent both with a homogeneous universe and with an inhomogeneous universe, if we are located at the exact center!
- However, based on the copernican principle we reject the second alternative and therefore we interpret the CMB as evidence that the Universe is HOMOGENEOUS and ISOTROPIC

# Cosmic Microwave Background. Is it really isotropic?

- Penzias and Wilson knew the radiation was isotropic within their limited sensitivity, but is it really isotropic?
- We know that some small scale structure is present in the Universe (galaxies, clusters..) so, according to the Big Bang theory, the CMB cannot be exactly isotropic.

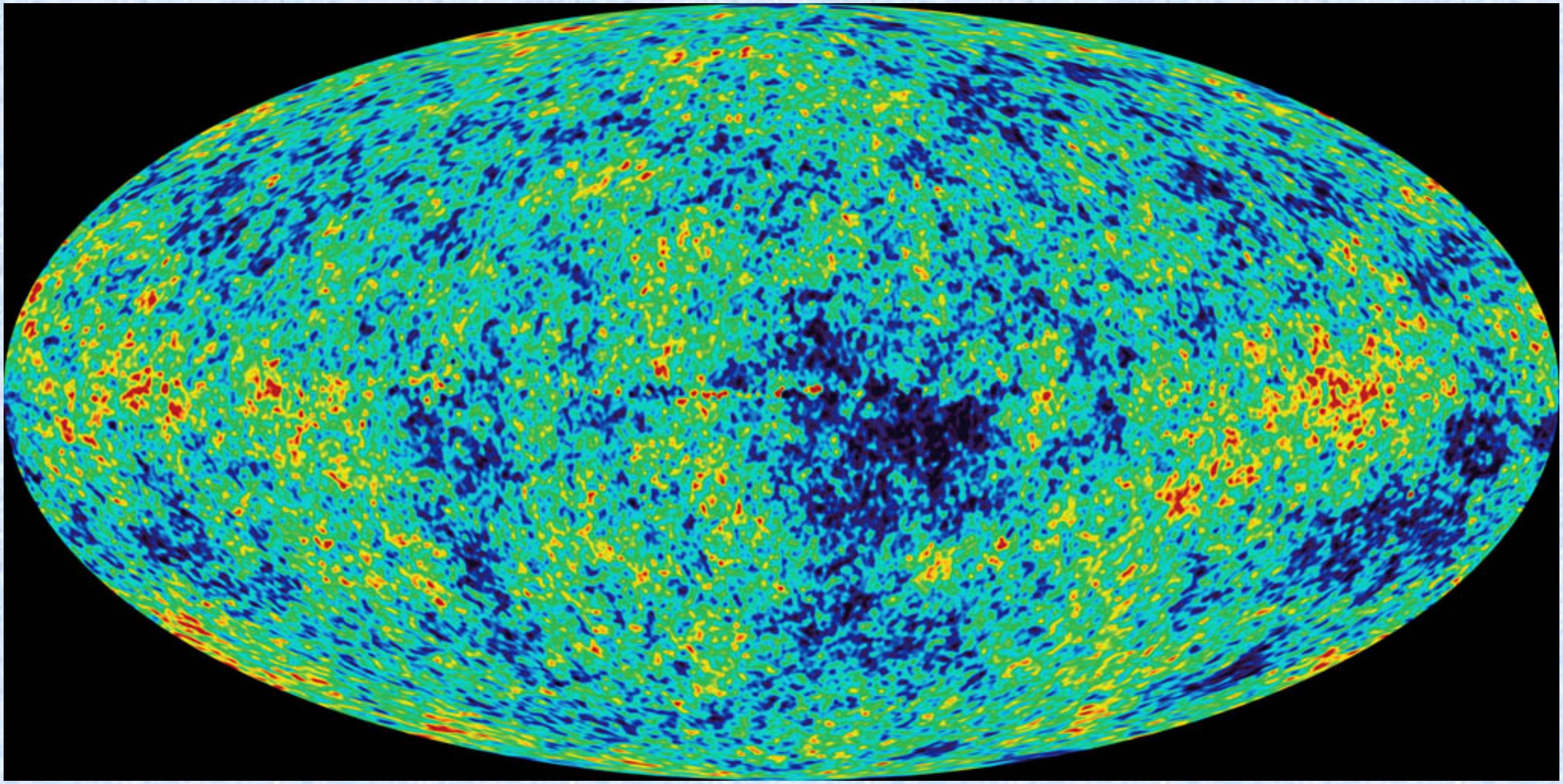
# Cosmic Microwave Background. Is it perfectly isotropic?

- The first anisotropy is the so called “dipole”
- This is the result of the motion of the galaxy with respect to the rest frame of the Universe (about 600 km/s), towards the “Great Attractor”
- After removing the dipole there is residual anisotropy at the 0.00001 level… first detected by COBE some 25 years after the initial discovery!




COBE

# Cosmic Microwave Background. Anisotropies from WMAP



The CMB sky, circa 2002…

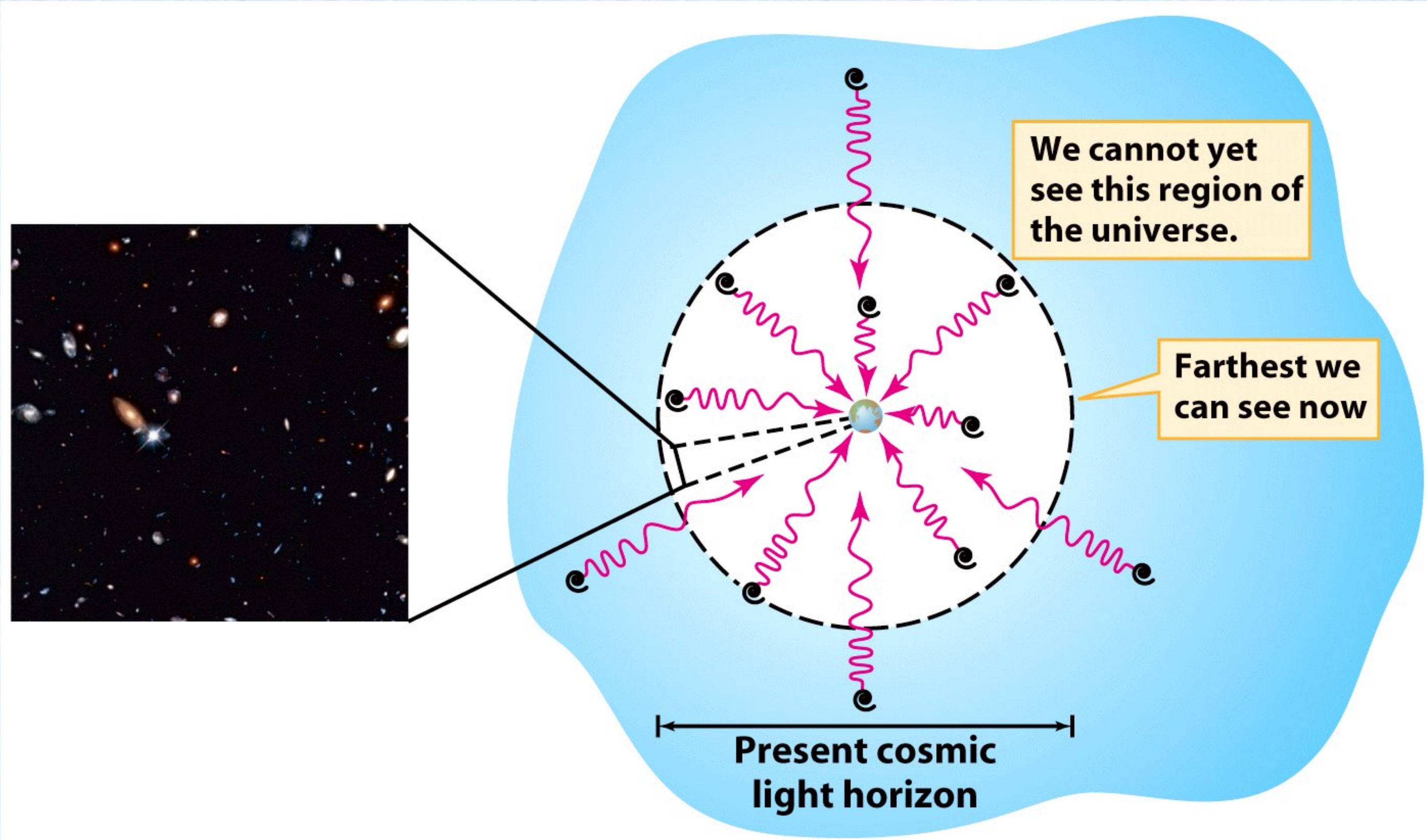
# Anisotropy of the CMB? What can we learn from it?

- The small fluctuations in the temperature of the CMB are interpreted in the Big Bang model as the result of initial density fluctuations
- A precise measurement of the CMB anisotropy contains information on the matter content of the universe, on its "clumpiness" but also on other properties such as the geometry of the Universe (we will see this later on..)

# Cosmic Microwave Background 1. Summary

- Wherever we look in the sky there is a background of microwaves, the CMB.
- The CMB is very close to isotropic better than 0.001%
- The spectrum of the CMB is indistinguishable from a that of Blackbody at 2.725 K.
- In the Big Bang model the CMB is interpreted as the fossil record of an epoch close to the beginning of time, when the Universe was extremely dense and hot and filled with radiation in thermal equilibrium

# Horizons



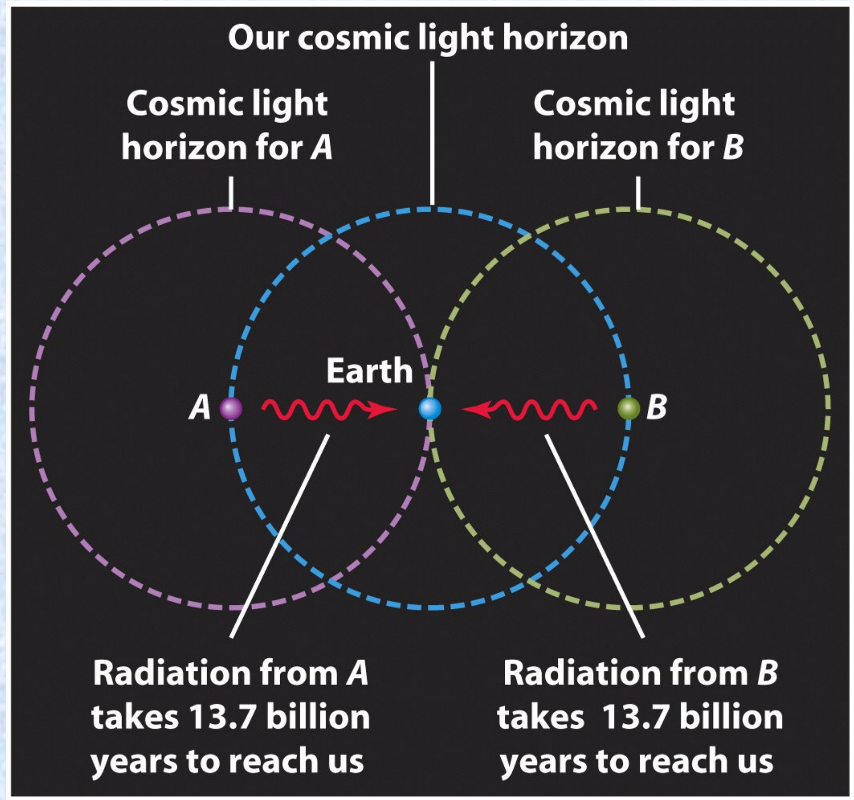

Light travels at finite speed so we can only see to a finite distance

# Horizons evolve

- As time goes by our horizon increases, because light had more time to travel and so we can reach further.
- In any case, even if the universe is infinite we can only see the finite part within the horizon.
- If we go back in time the horizons were smaller and smaller and as we approach the cosmic singularity the horizon goes to zero:
- ALL OBSERVABLE SPACE SHRINKS TO A POINT AT THE BIG BANG

# The isotropic CMB and the horizons problem

- The CMB is in thermal equilibrium at the same temperature everywhere
- This means that any two points must have been in "causal contact"
- Information can only travel at the speed of light.
- How can two points at the opposite parts of the sky be at the same temperature?
- This is know as the horizons problem and it is not explained by the classic big bang theory



# Horizons. Summary

- The region of space that we can see is limited by the finite speed of light
- We can only see as far as light has had time to travel, this is called our “horizon”.
- We can only see inside our horizon, which is finite even if the universe is infinite
- Horizons grow as time goes by.
- Two points can be causally connected only if they are inside each other’s horizons
- How is it possible that the CMB has the same temperature everywhere? This is known as the horizon problem?

# The End

See you Tuesday!