Cosmic Microwave Background: Fossil of the Fireball Universe

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Landeskunde Japan, January 14, 2016

Basic Research in Germany

- I feel very fortunate to be in Germany for doing my research because both State of Bavaria and Federal government *strongly support* basic research
    - **Basic research = Research usually useless for daily life**

- Max-Planck-Institute, which is funded almost entirely by public funding (~50% from State and ~50% from Federal), enjoyed the budget **increase** of ~4-5% over the last five years

    - The other counties, such as USA and Japan, had either budget **decrease** or flat budget in the same period in basic research

Max Planck Institute

- There are 76 Max Planck Institutes throughout Germany, and 5 in foreign countries
- World-class achievements in basic research
- Total annual budget ~ 1.5 Milliarde Euro
    - About the same as the budget of University of Tokyo

Max-Planck-Institut für Astrophysik (MPA)

- Located in Garching [U6 Garching Forschungszentrum]
- Specialised in theoretical and computational astrophysics
    - MPA has about 90 scientists
- I came to Germany to become one of four directors at MPA in 2012
    - I was a professor at the University of Texas at Austin before coming to Germany [lived in USA for 13 years]

Seeing the Early Universe

- Astronomers often talk about the early Universe as if they were there to see it…
    - The stories told by astronomers are remarkable, but aren't they just imaginations of astronomers?
- Although we cannot be there physically, **we can observe the phenomena in the early Universe using powerful telescopes**
    - We are not making stuff up!

Seeing the Early Universe

- The goal of my presentation is to show you how we are seeing and studying the early Universe directly using the **light from the epoch of the fireball Universe**

- For the next 20 minutes, you will be hearing the well-established results from a series of observations and measurements made over the last half century

  - So, please sit back and enjoy learning about what it is like to ***see the early Universe***

Fireball Universe

Time

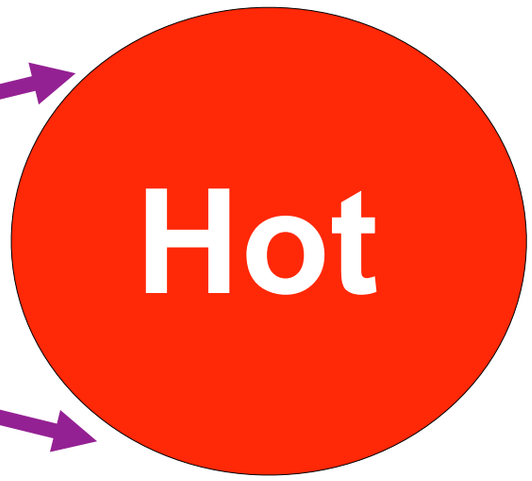
Hot and
Dense

Space

Fireball Universe

Time

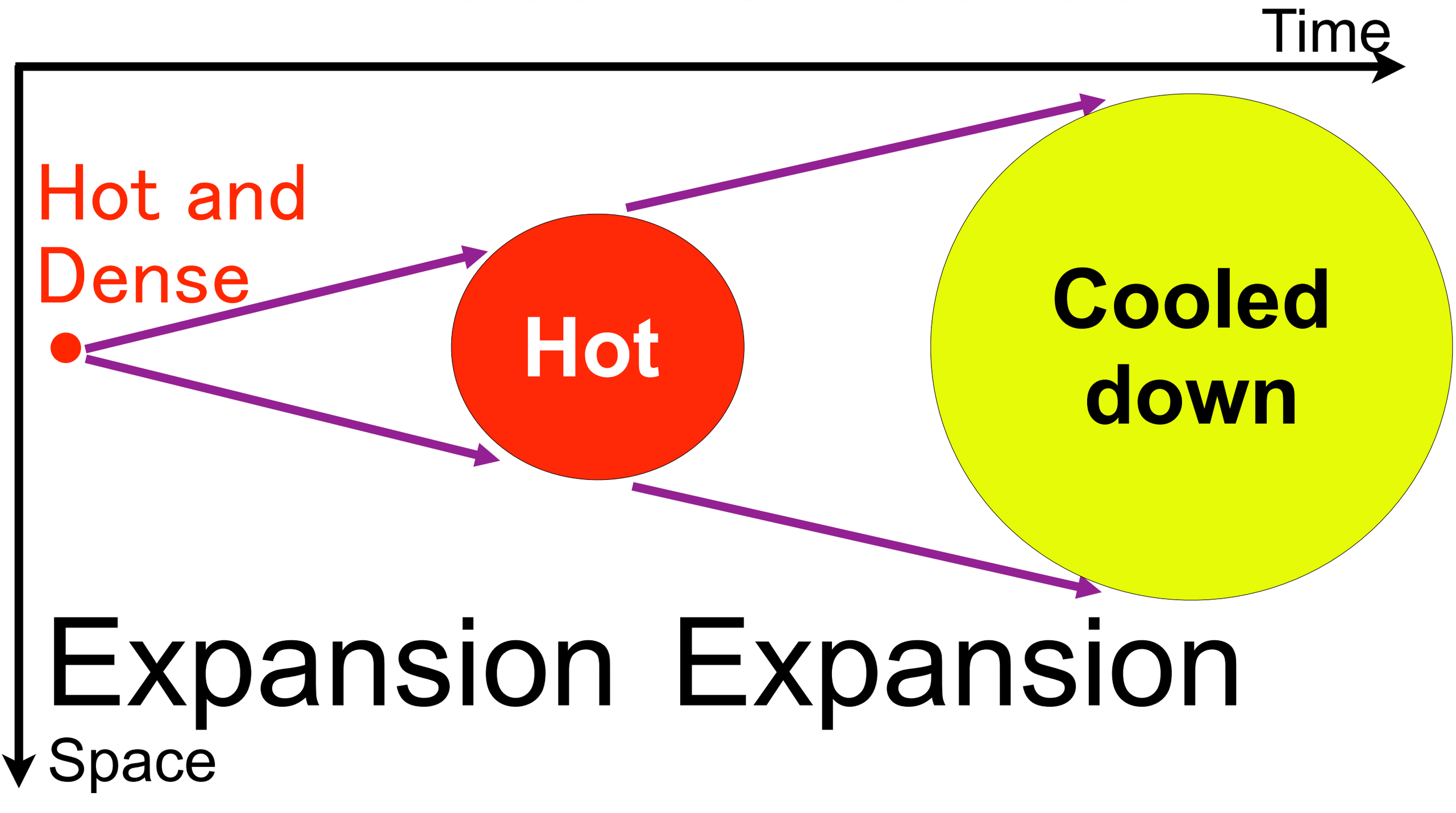
Hot and
Dense



Expansion

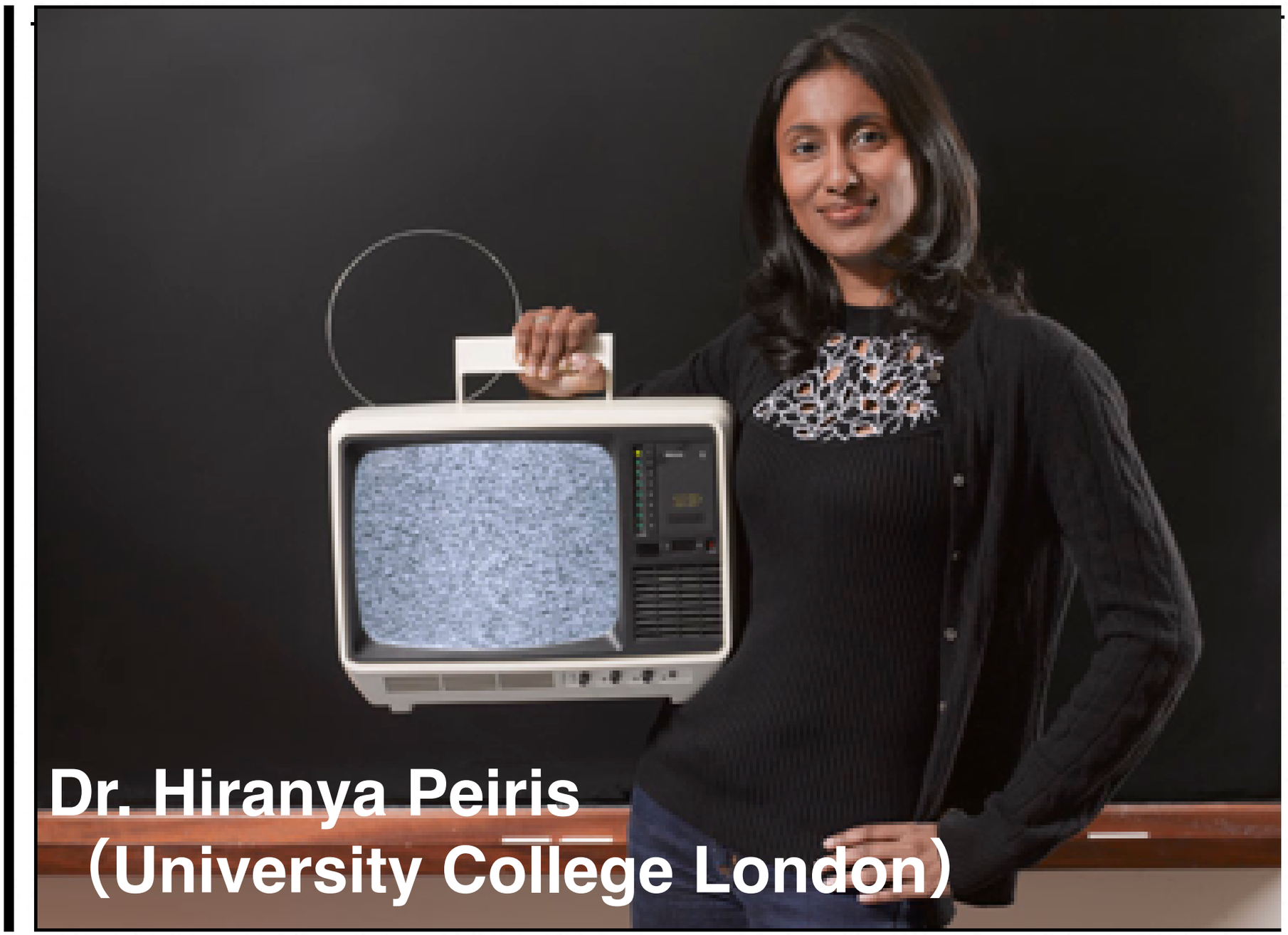
Space

Fireball Universe



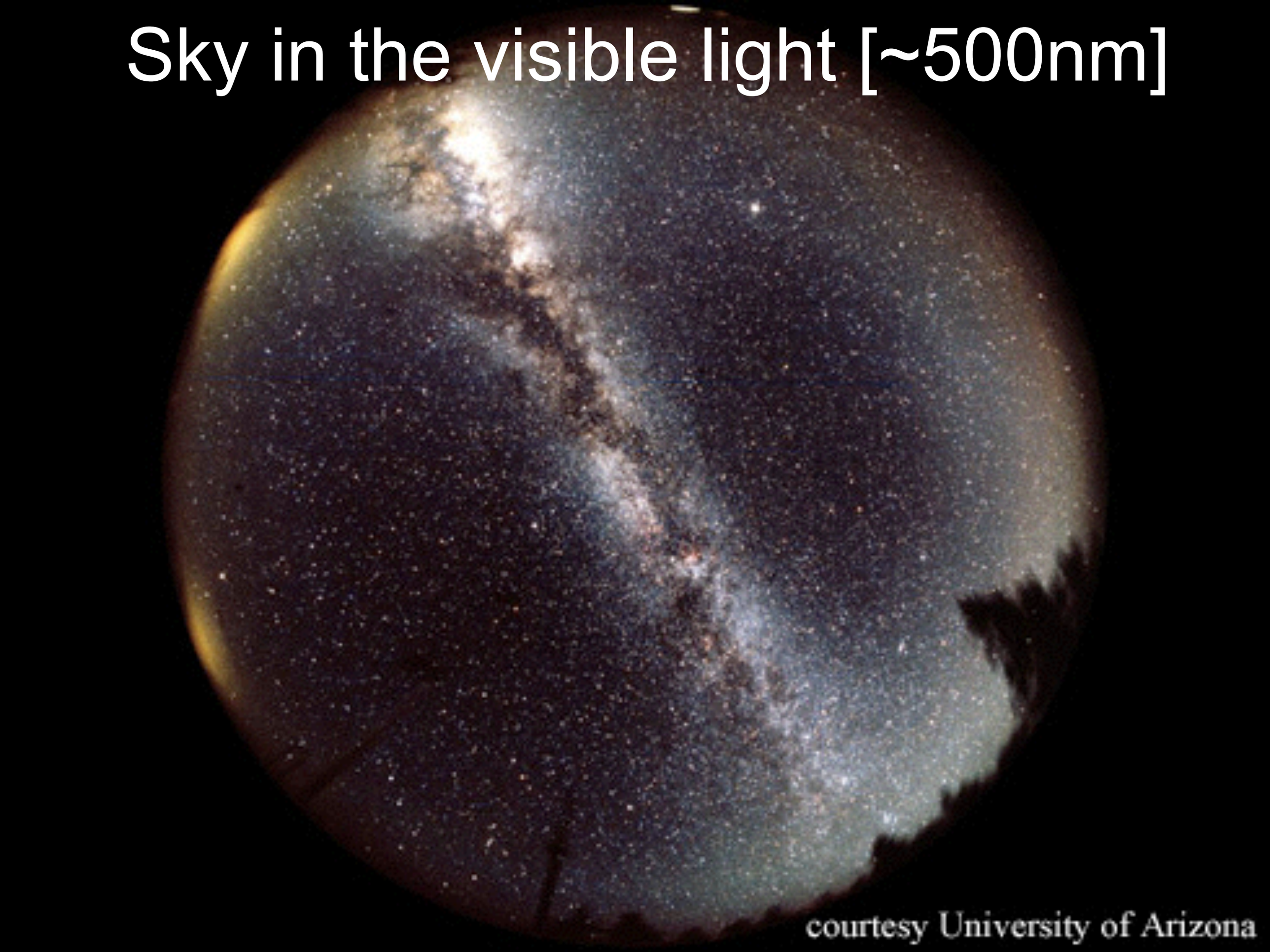
Definitive Result

- Those photons which filled the fireball Universe are still with us
- There are **410 such photons per cubic centimetre**
- Due to the expansion of space and cooling down, these photons are cold, and their wavelength is in the radio/microwave region



All you need to do is to detect radio waves. For example, 1% of noise on the TV is from the fireball Universe

Sky in the visible light [~500nm]



courtesy University of Arizona

Sky in the microwaves [~1mm]

courtesy University of Arizona

Sky in the microwaves [~1mm]

Light from the fireball Universe filling our sky

The Cosmic Microwave Background (CMB)

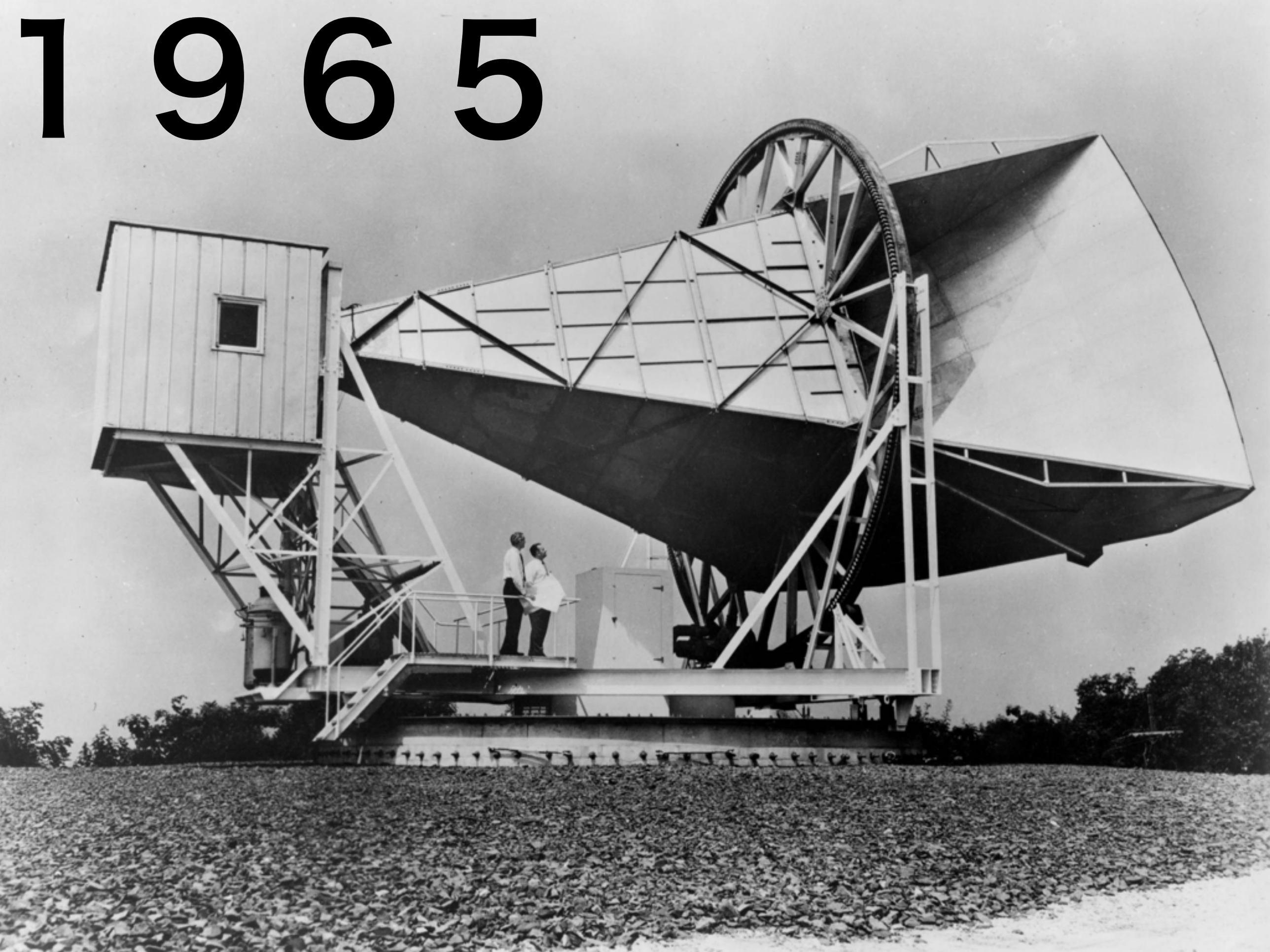
courtesy University of Arizona

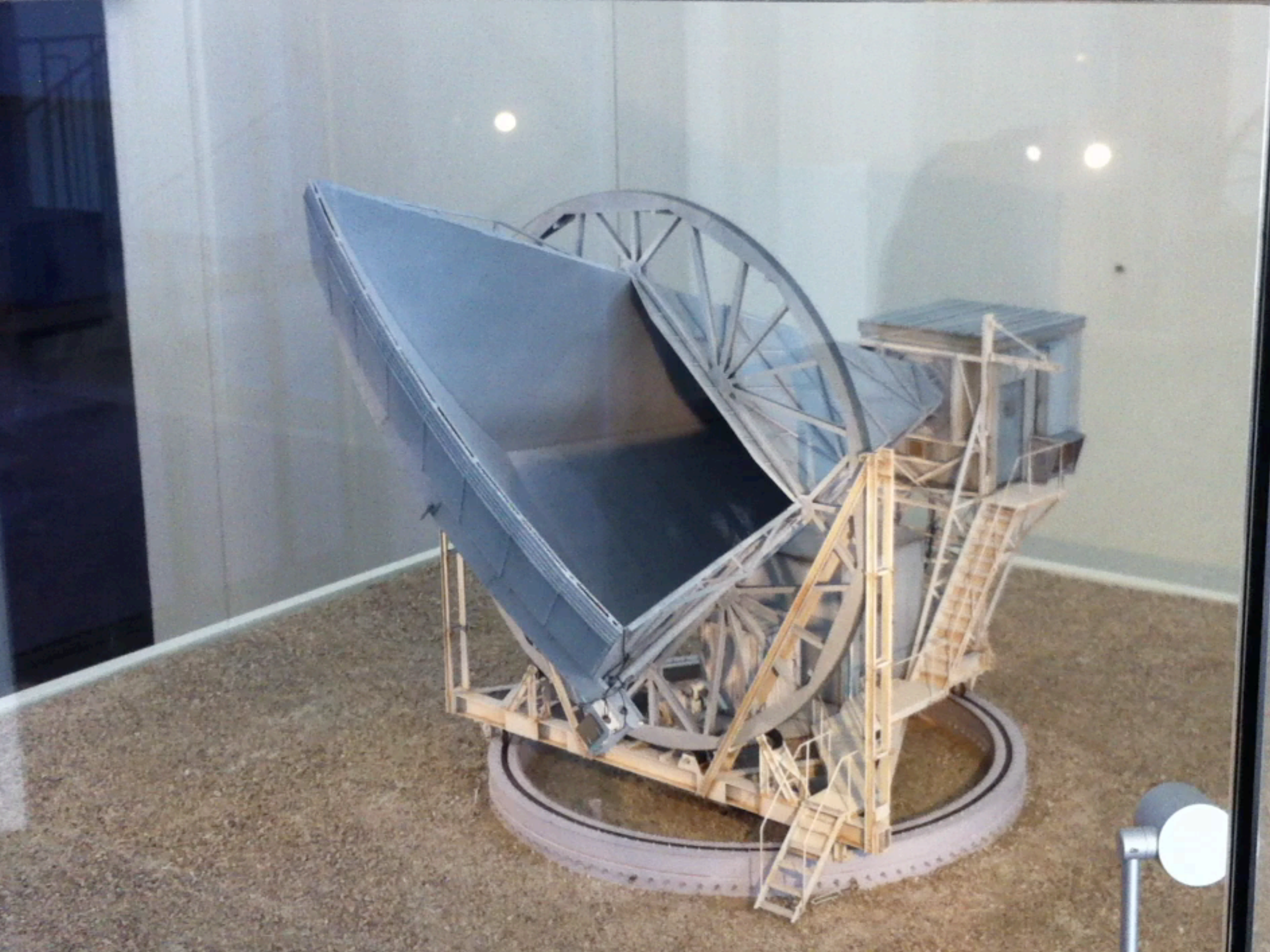
Temperature of CMB

−270.5°C

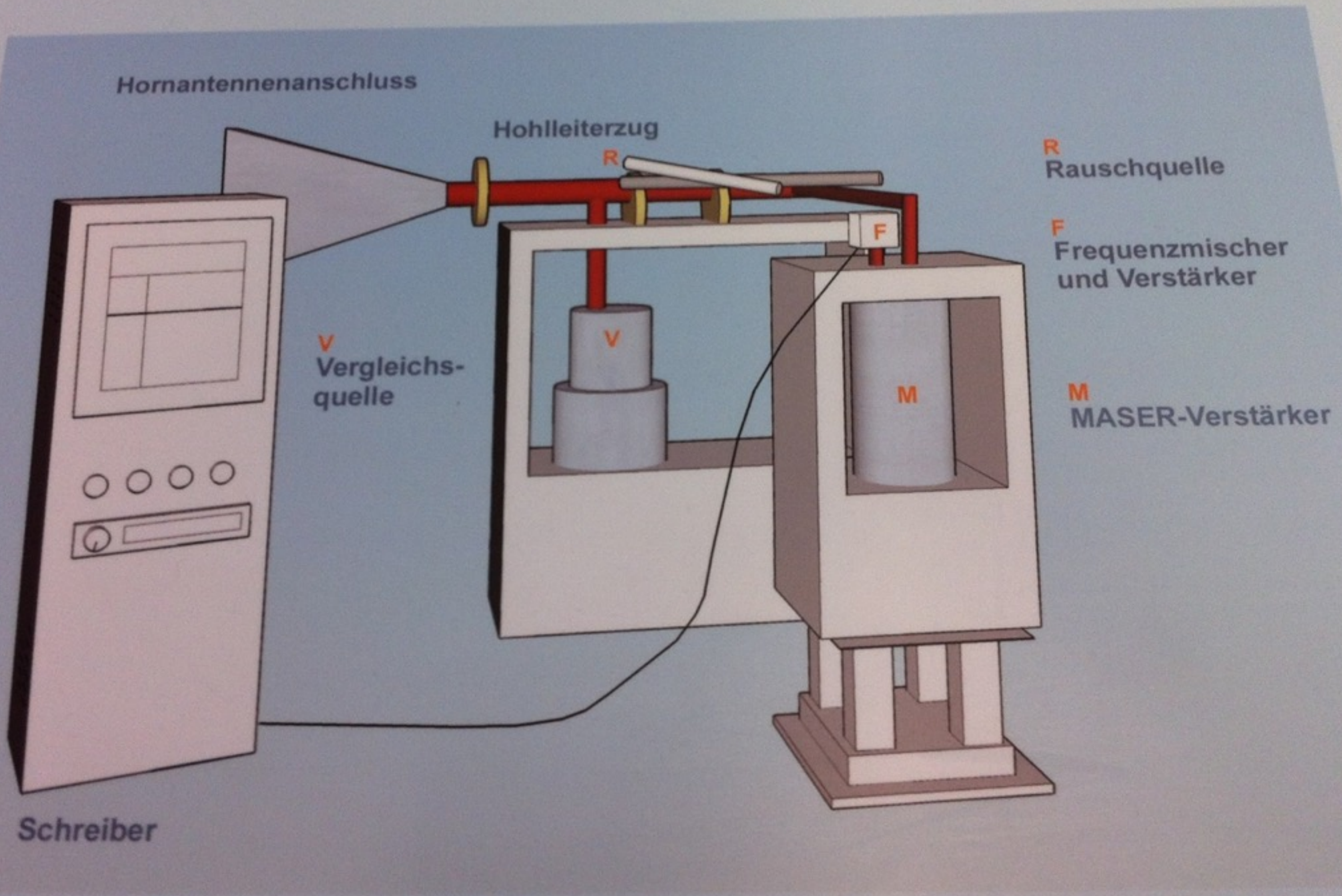
2.7K in absolute temperature

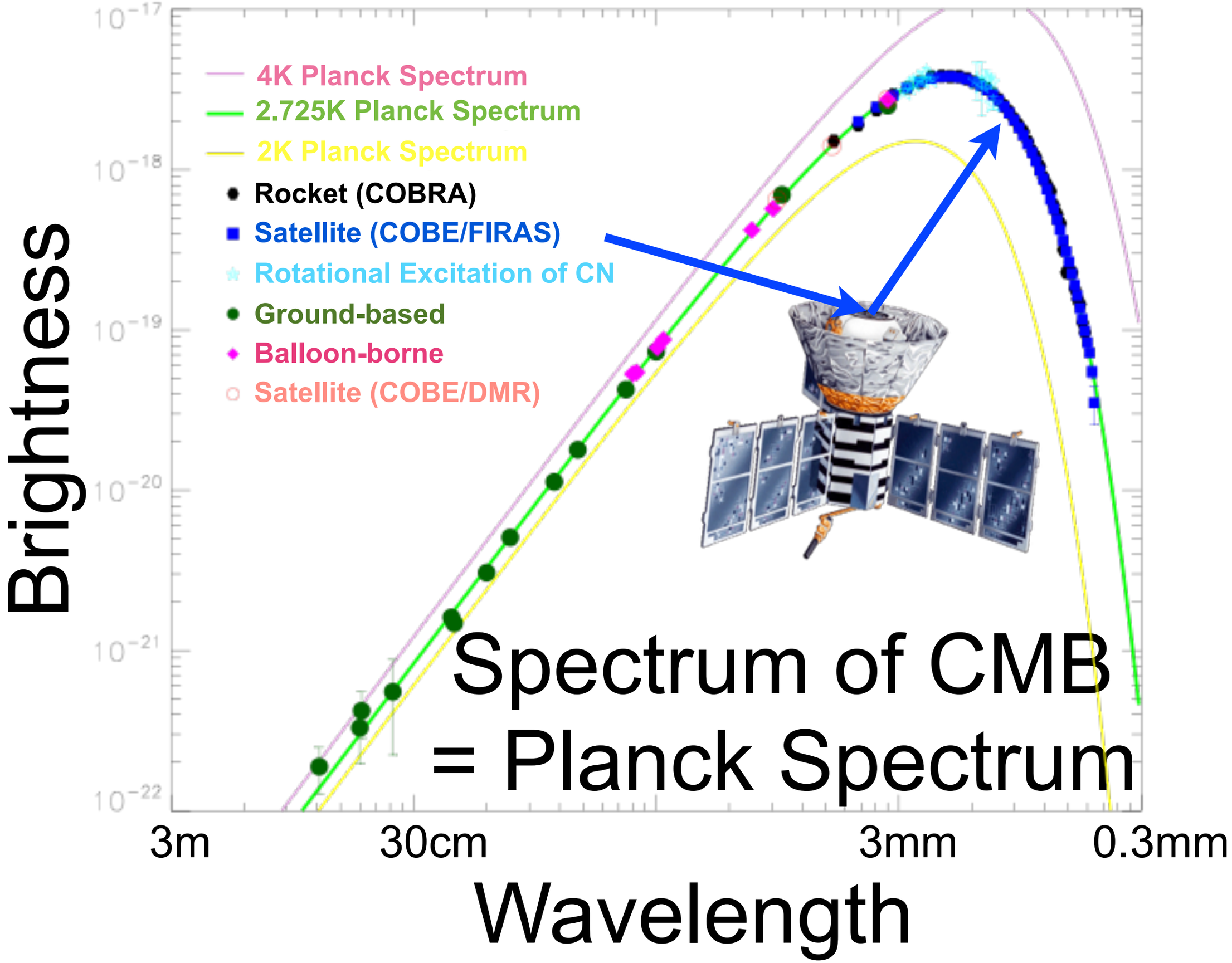
1965





The real detector system used by Penzias & Wilson
The 3rd floor of Deutsches Museum


Hornantennenanschluss
Hohlleiterzug
R
F
V
V
Vergleichs-
quelle
M
R
Rauschquelle
F
Frequenzmischer
und Verstärker
M
MASER-Verstärker
Schreiber


4K Planck Spectrum
2.725K Planck Spectrum
2K Planck Spectrum
Rocket (COBRA)
Satellite (COBE/FIRAS)
Rotational Excitation of CN
Ground-based
Balloon-borne
Satellite (COBE/DMR)
Brightness
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
Spectrum of CMB
= Planck Spectrum
3m
30cm
3mm
0.3mm
Wavelength

Fireball Universe, Observed

- The **Planck spectrum** is achieved only when matter and radiation are exchanging energies frequently
  - Called “thermal equilibrium”
  - Imagine a blast furnace (Hochofen)

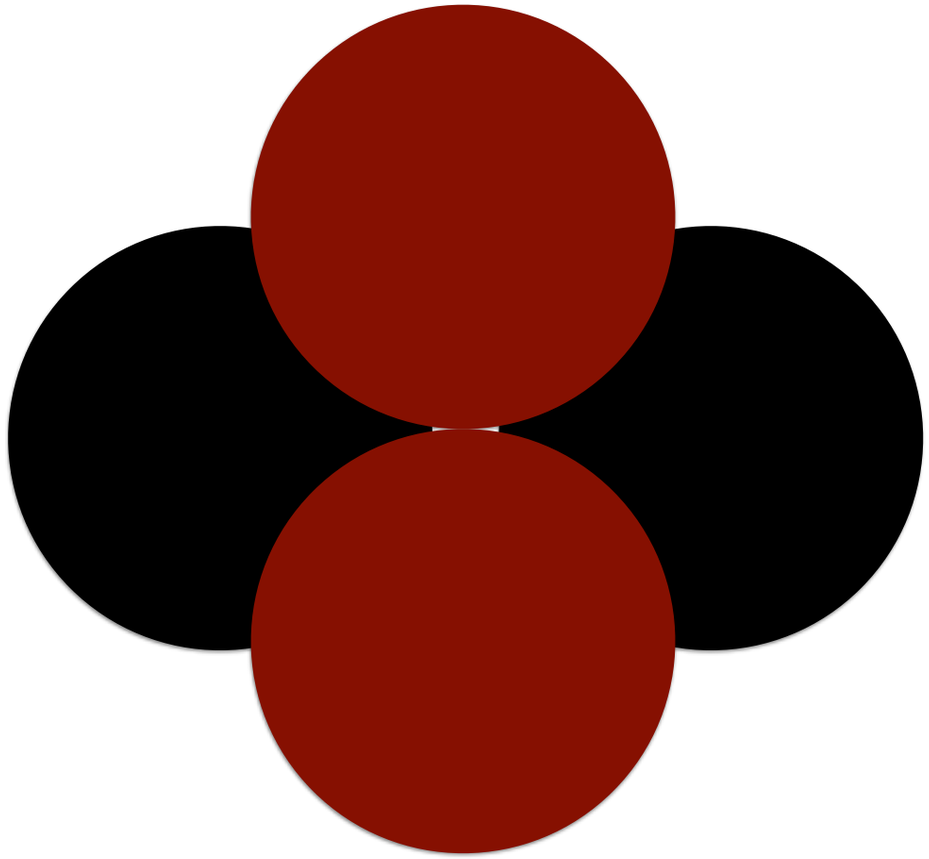
Max Planck (1858-1947)

- Today’s Universe is not in thermal equilibrium (we die otherwise), which means that **the Universe was in thermal equilibrium in the past - fireball Universe** [Urknalls]

Origin of CMB

- When matter and radiation were hotter than 3000 K, matter was completely ionised. The Universe was filled with plasma, which behaves just like a soup
- The main ingredients of this soup include:
  - Photons, Protons, electrons, and helium nuclei

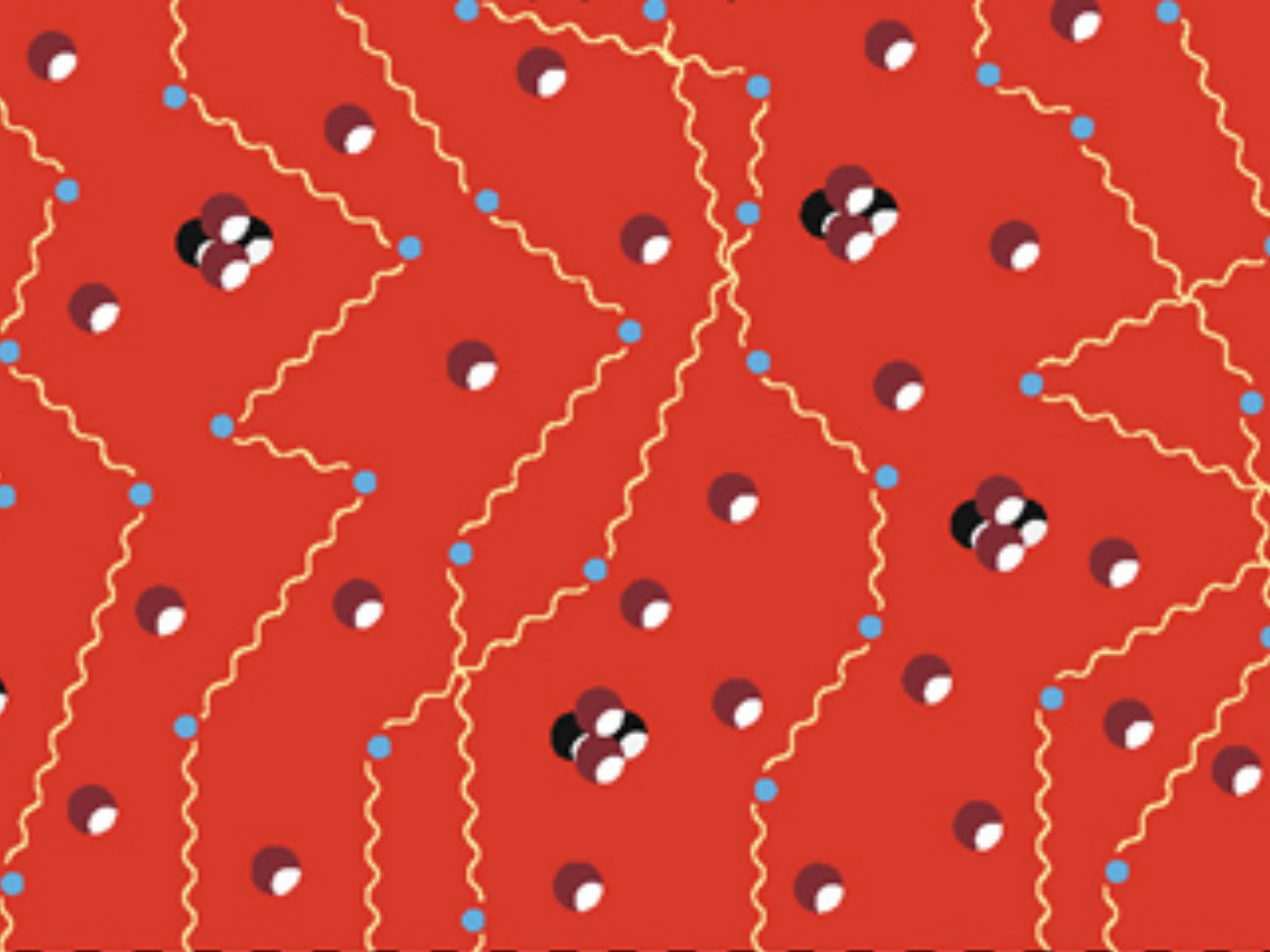
Protons



Helium Nuclei

Electrons

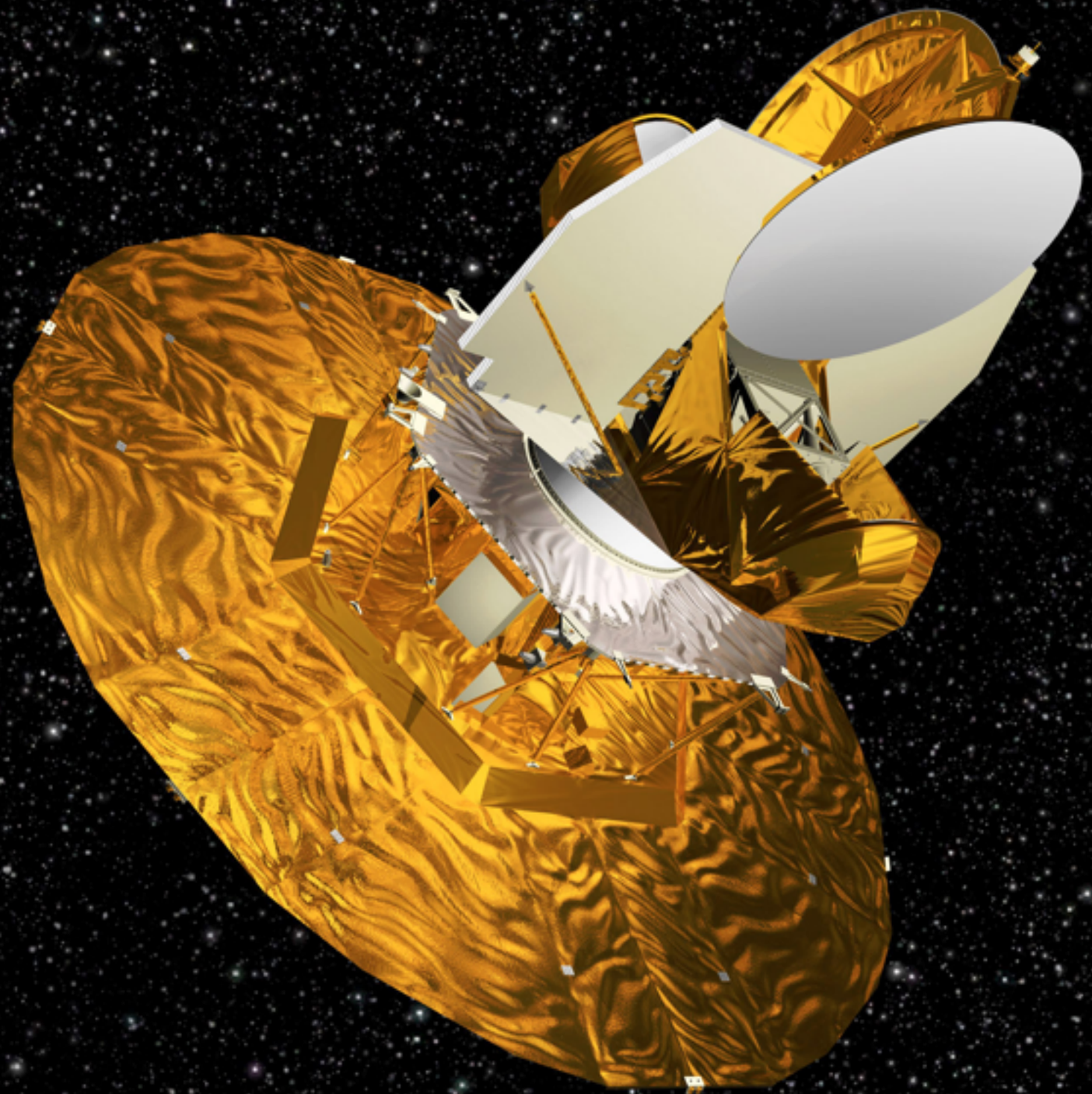
Photons



Time

380,000 years (temperature is 3000K)

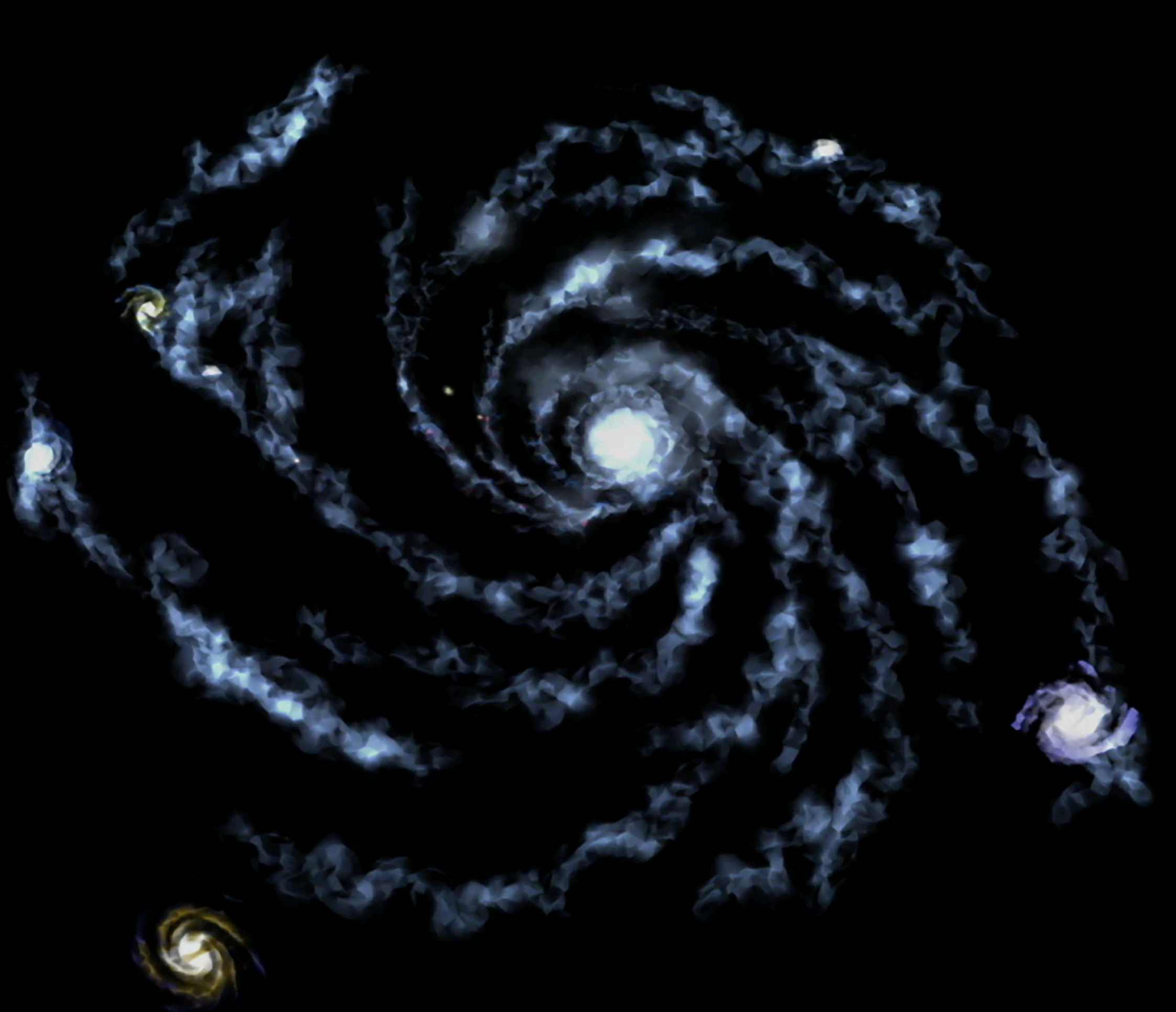
2001



WMAP Science Team

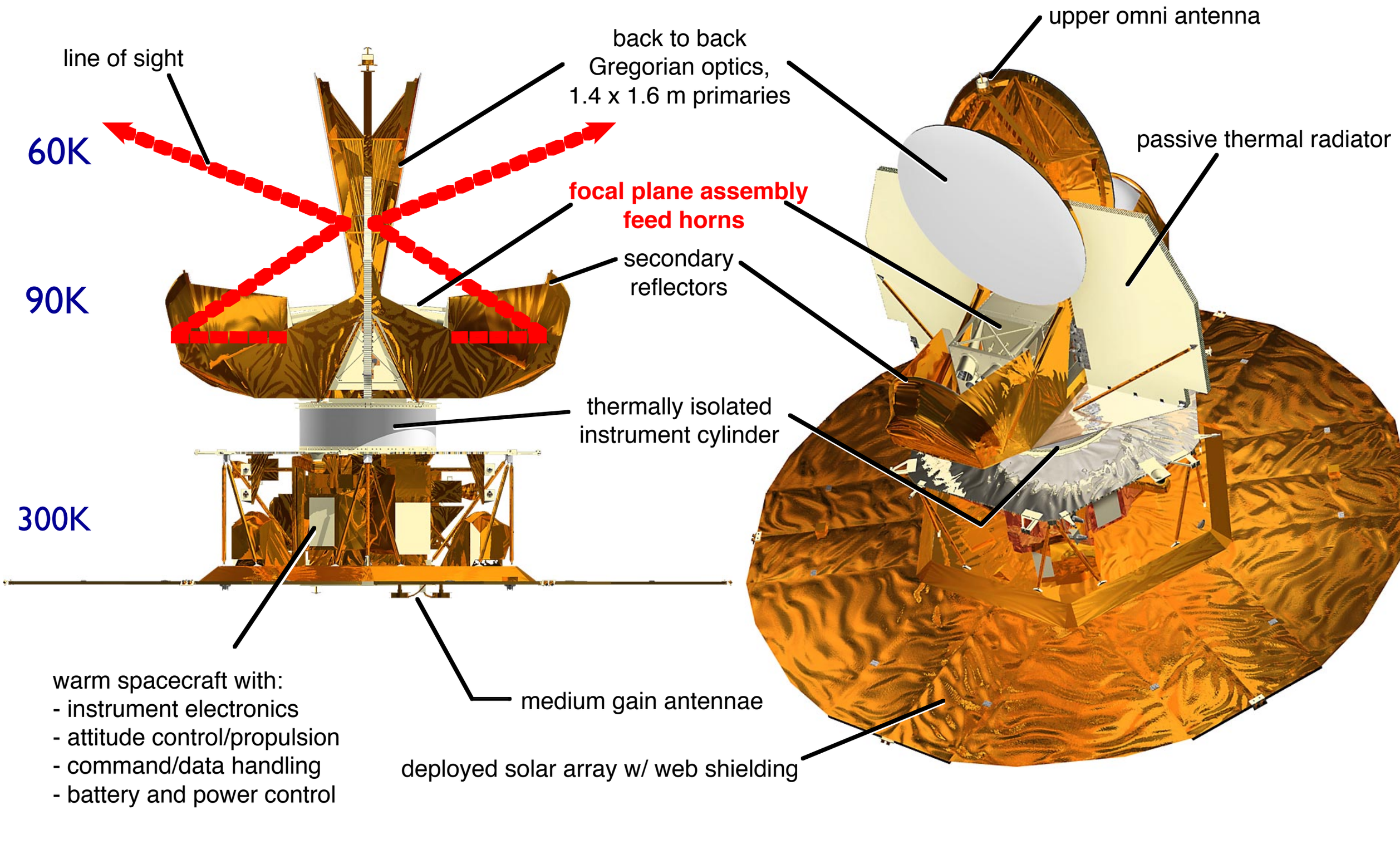
July 19, 2002

- WMAP was launched on June 30, 2001
- The WMAP mission ended after 9 years of operation



WMAP Spacecraft

No cryogenic components



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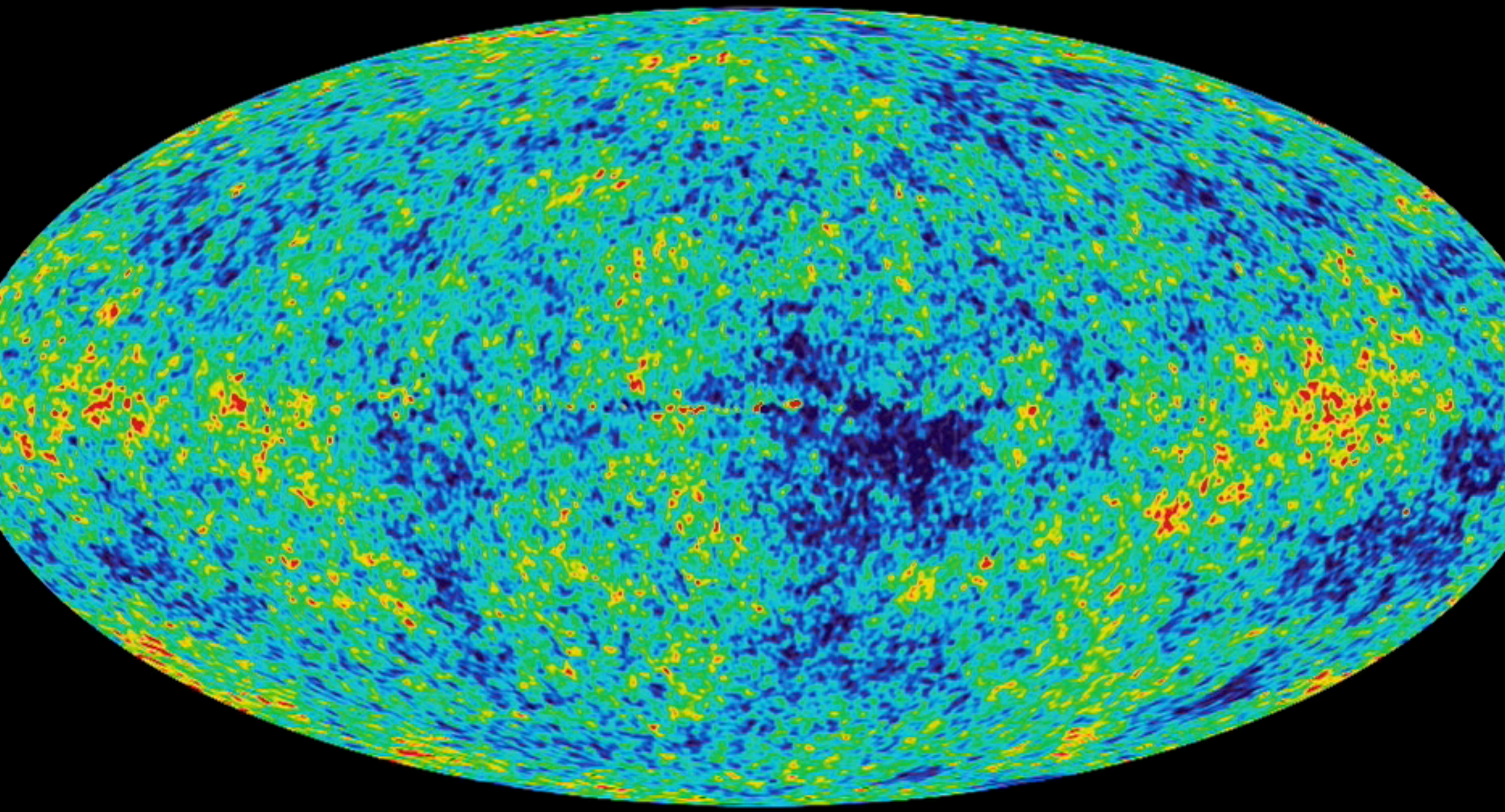
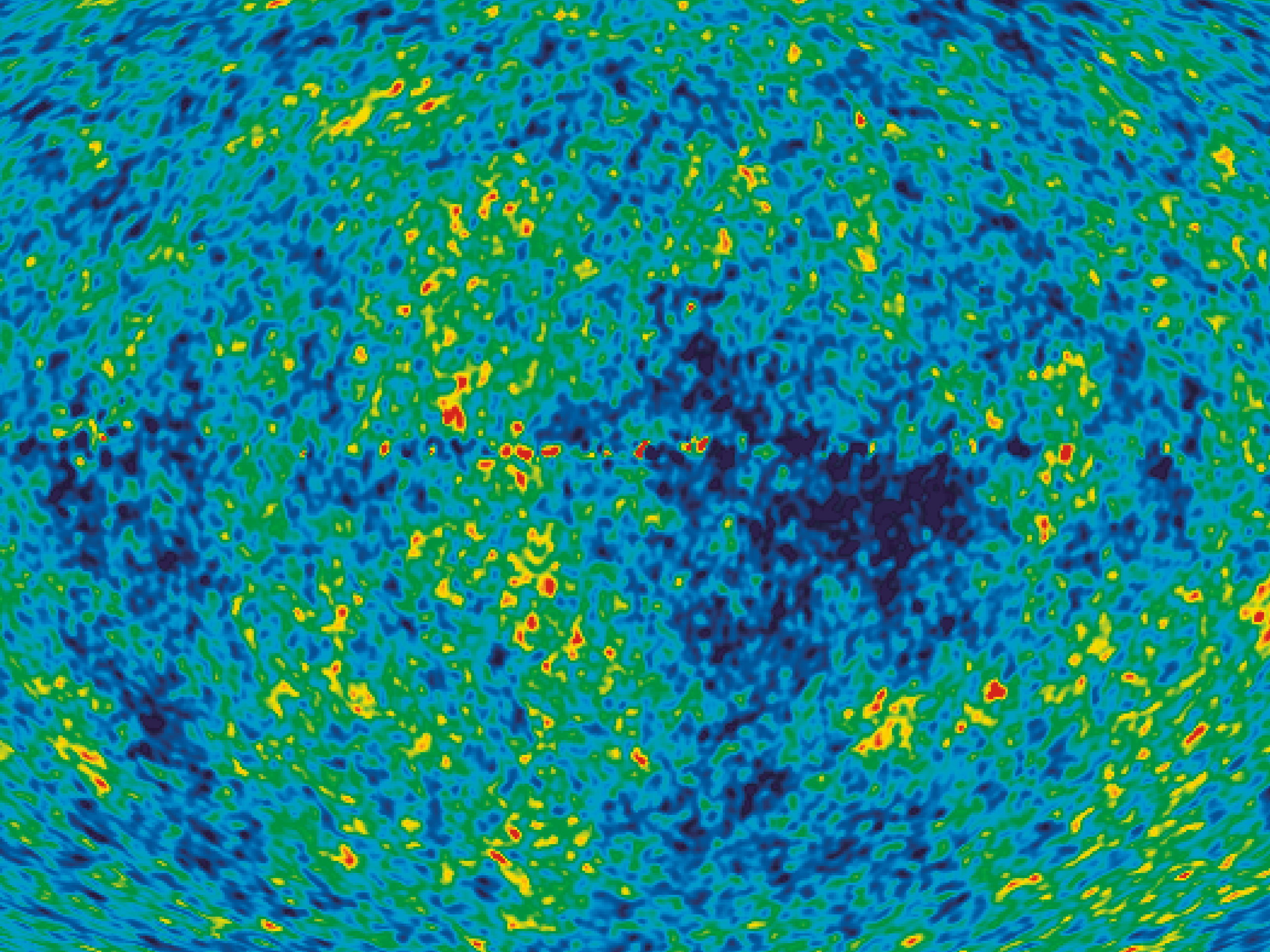




Our Origin

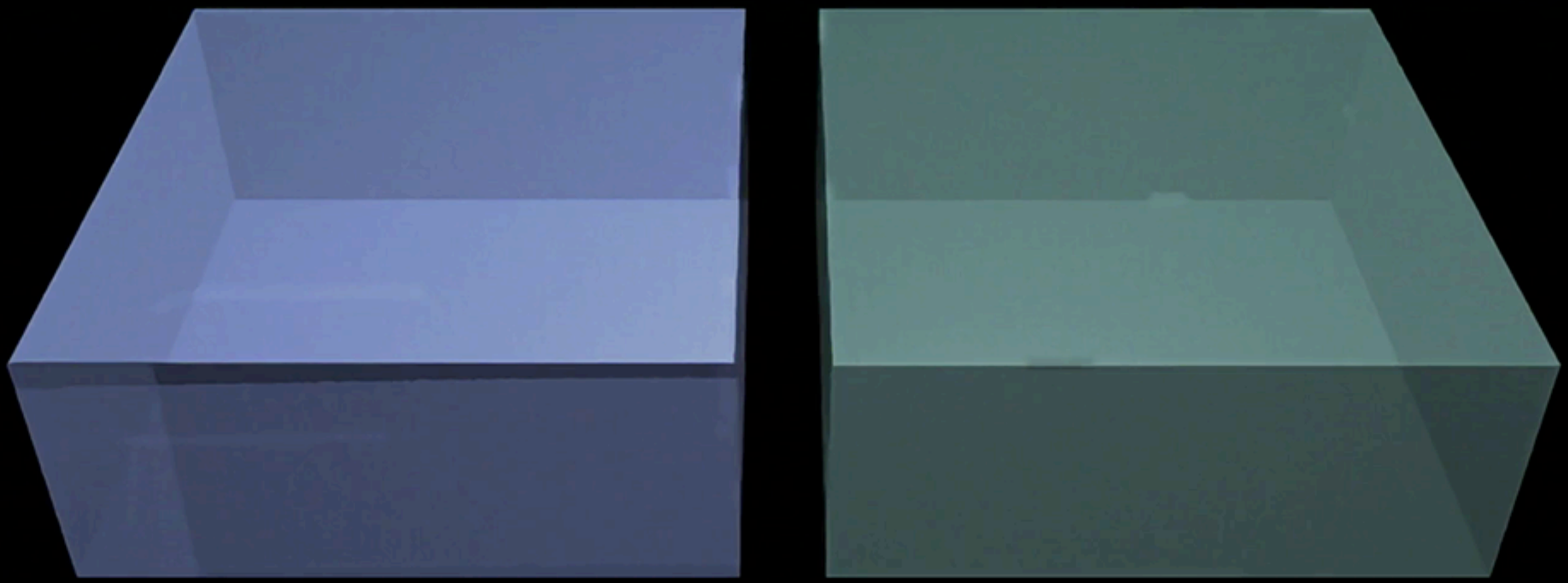
- WMAP taught us that **galaxies, stars, planets, and ourselves originated from tiny fluctuations in the early Universe**

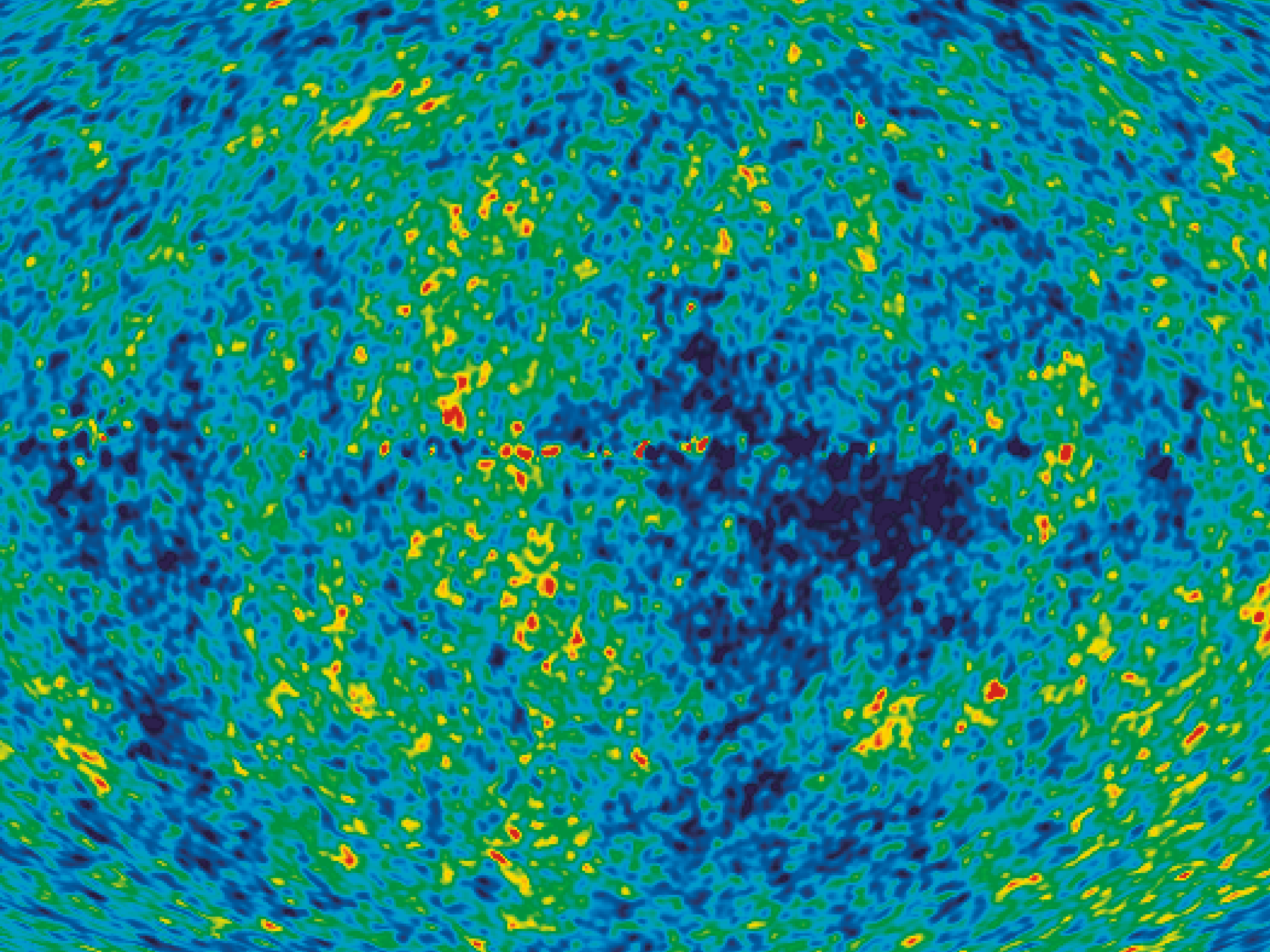
Kosmische Miso Suppe

- When matter and radiation were hotter than 3000 K, matter was completely ionised. The Universe was filled with plasma, which behaves just like a soup

- Think about a Miso soup (if you know what it is). Imagine throwing Tofus into a Miso soup, while changing the density of Miso

- And imagine watching how rippes are created and propagate throughout the soup





Data Analysis

- Decompose temperature fluctuations in the sky into a set of waves with various wavelengths
- Make a diagram showing the strength of each wavelength

Long Wavelength

Short Wavelength

TT

Amplitude of Waves [μK²]

6000

5000

4000

3000

2000

1000

0

10

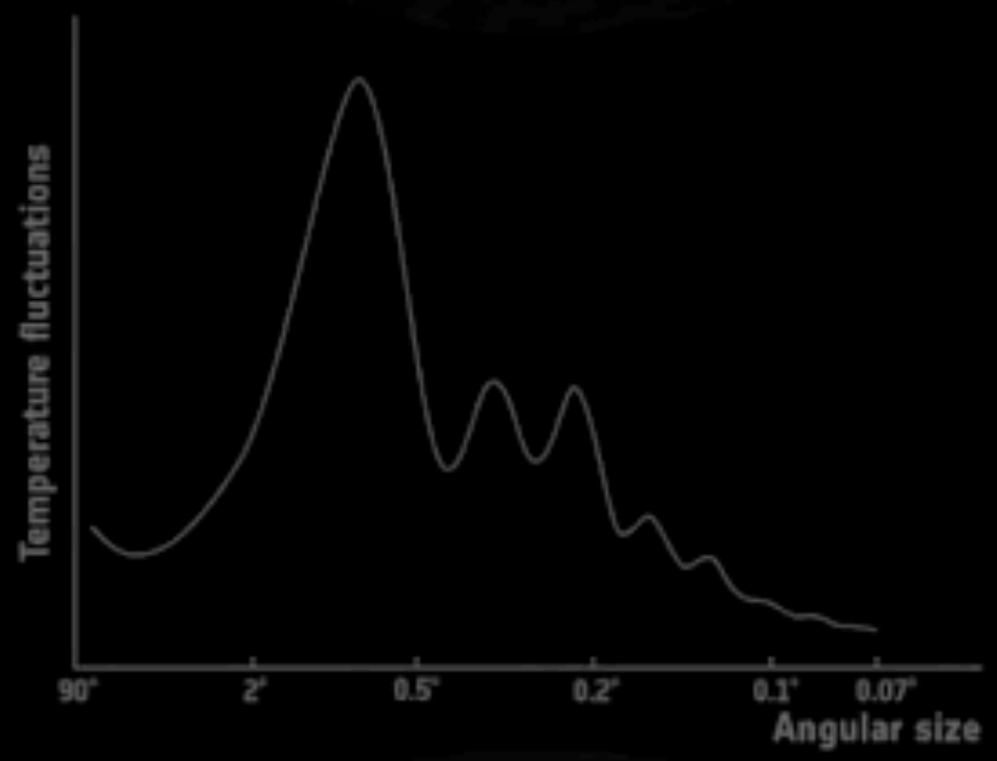
100

500

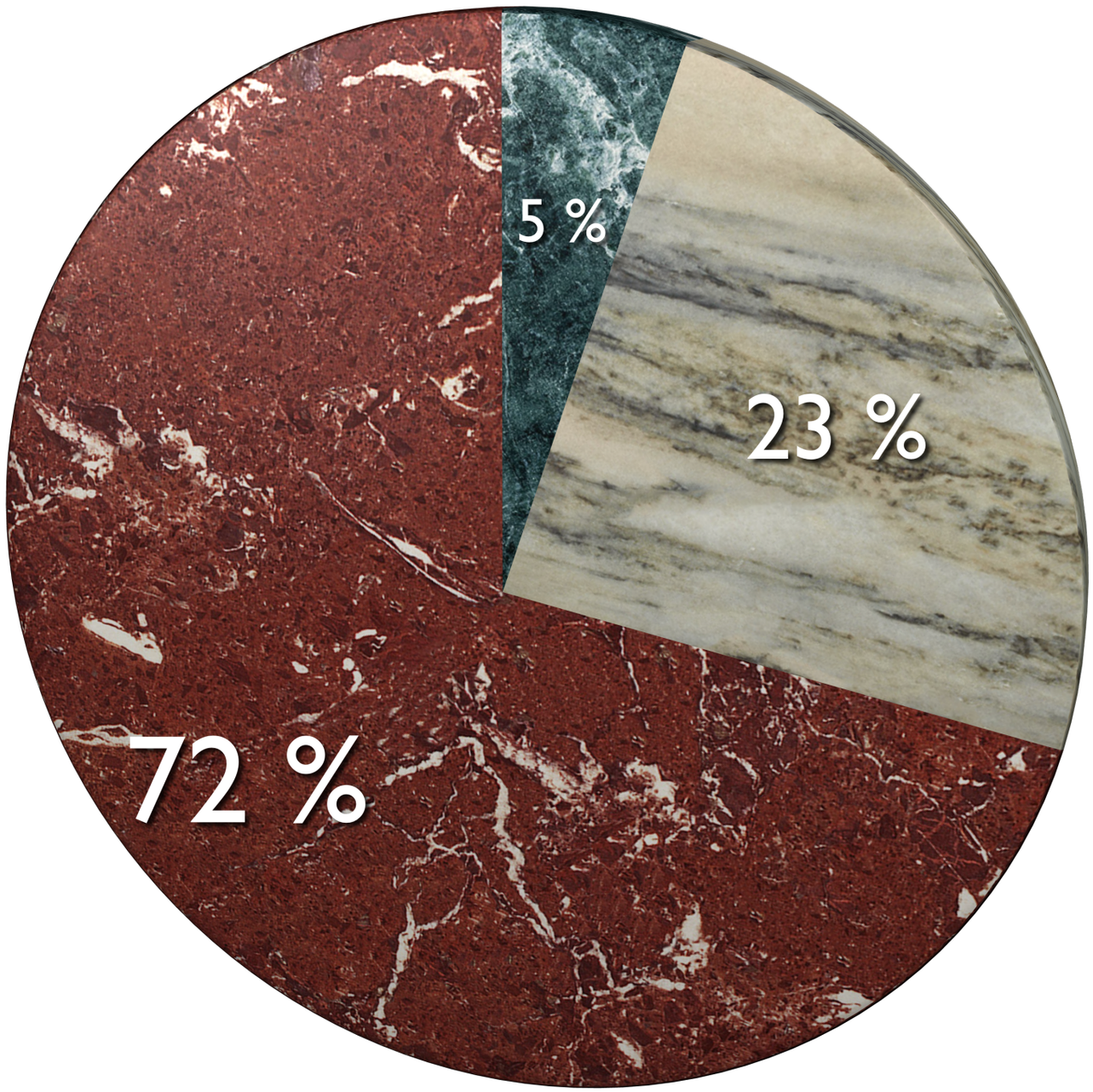
1000

180 degrees/(angle in the sky)

esa



Cosmic Pie Chart



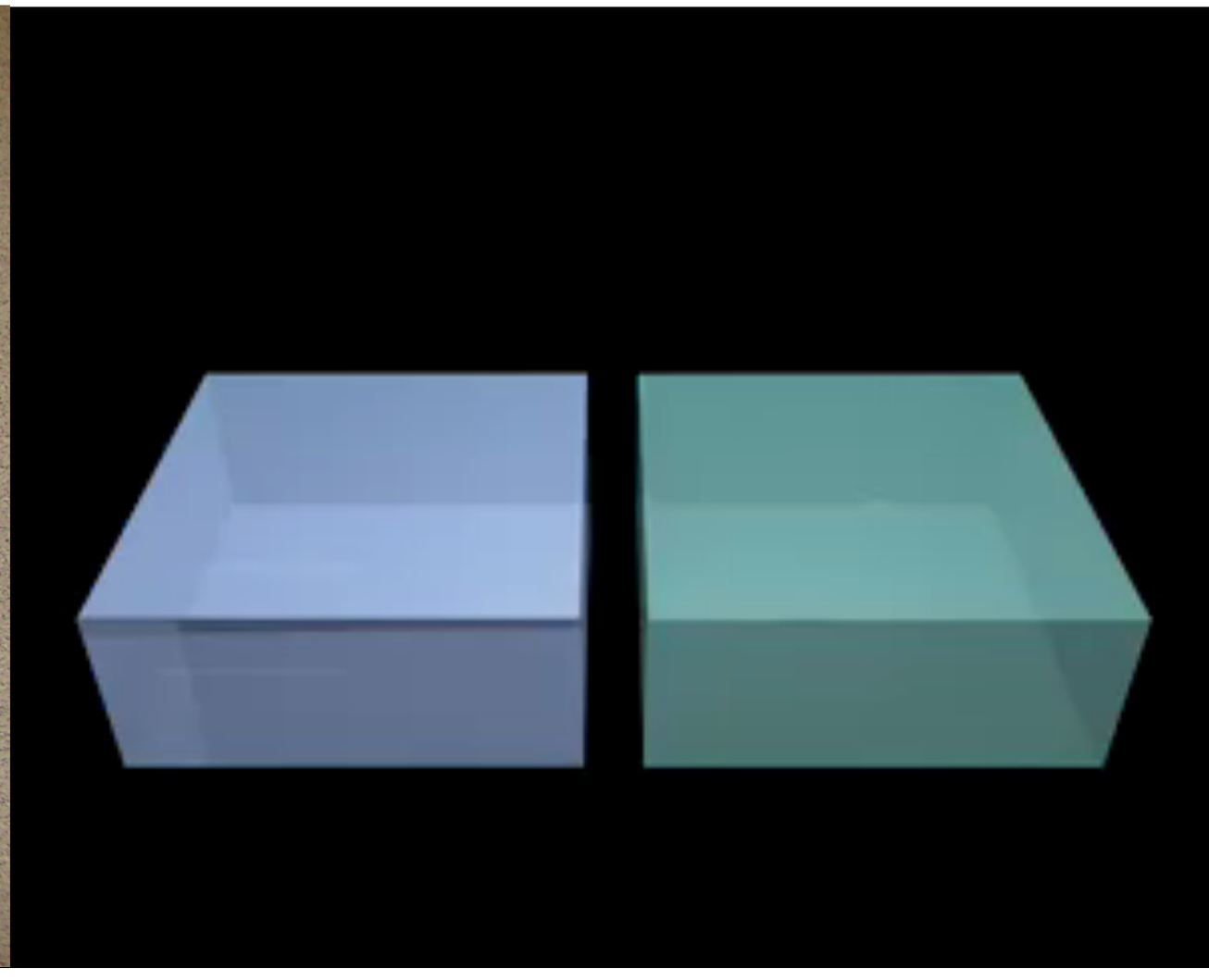
- WMAP determined the abundance of various components in the Universe

- As a result, **we came to realise that we do not understand 95% of our Universe…**

H&He
Dunkle Materie
Dunkle Energie

Current Question: Origin of Fluctuations

- Who dropped those Tofus into the cosmic Miso soup?



Summary

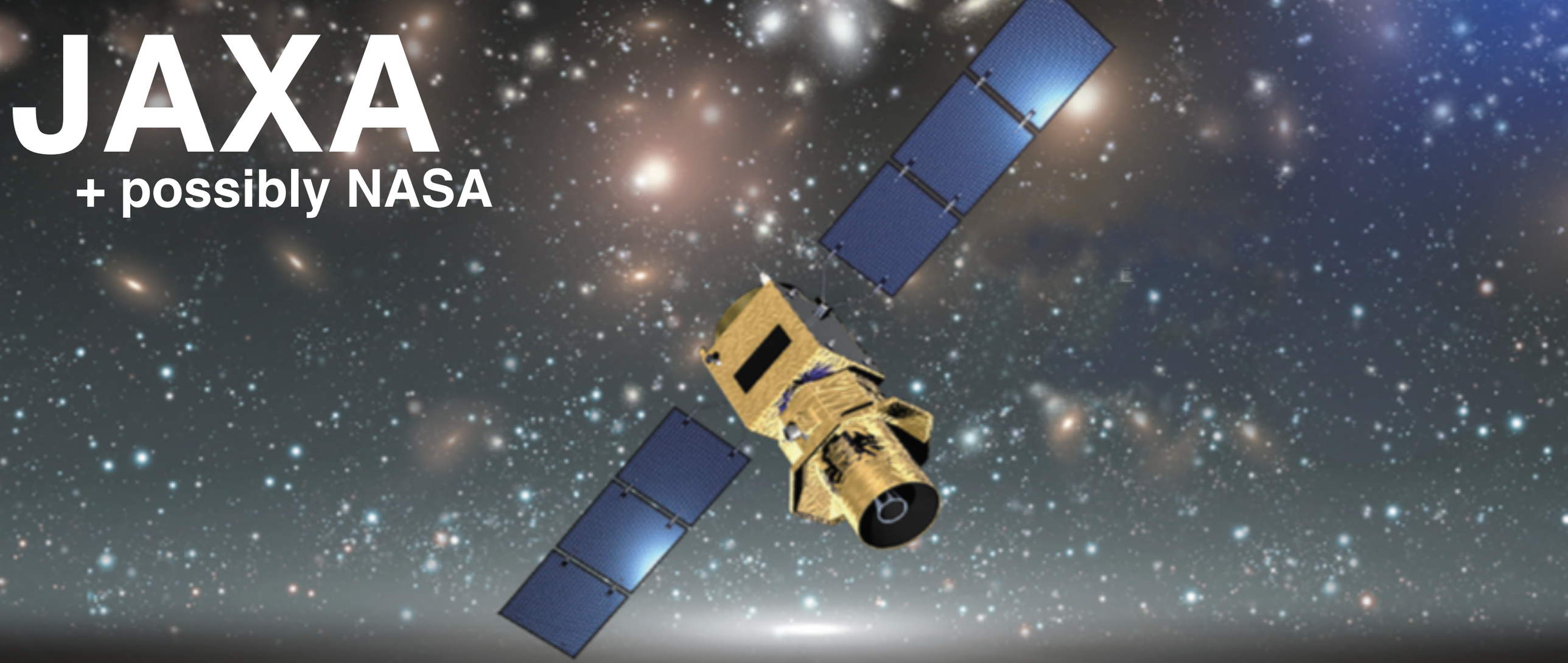
- We are seeing physical conditions of the early Universe using CMB

- Our origin goes back to tiny fluctuations that existed in the early Universe

- **Origin of fluctuations?**

  - To understand the origin of fluctuations? We are trying to launch another CMB satellite with colleagues in Japan: **LiteBIRD**

JAXA
+ possibly NASA



LiteBIRD
2025– [proposed]