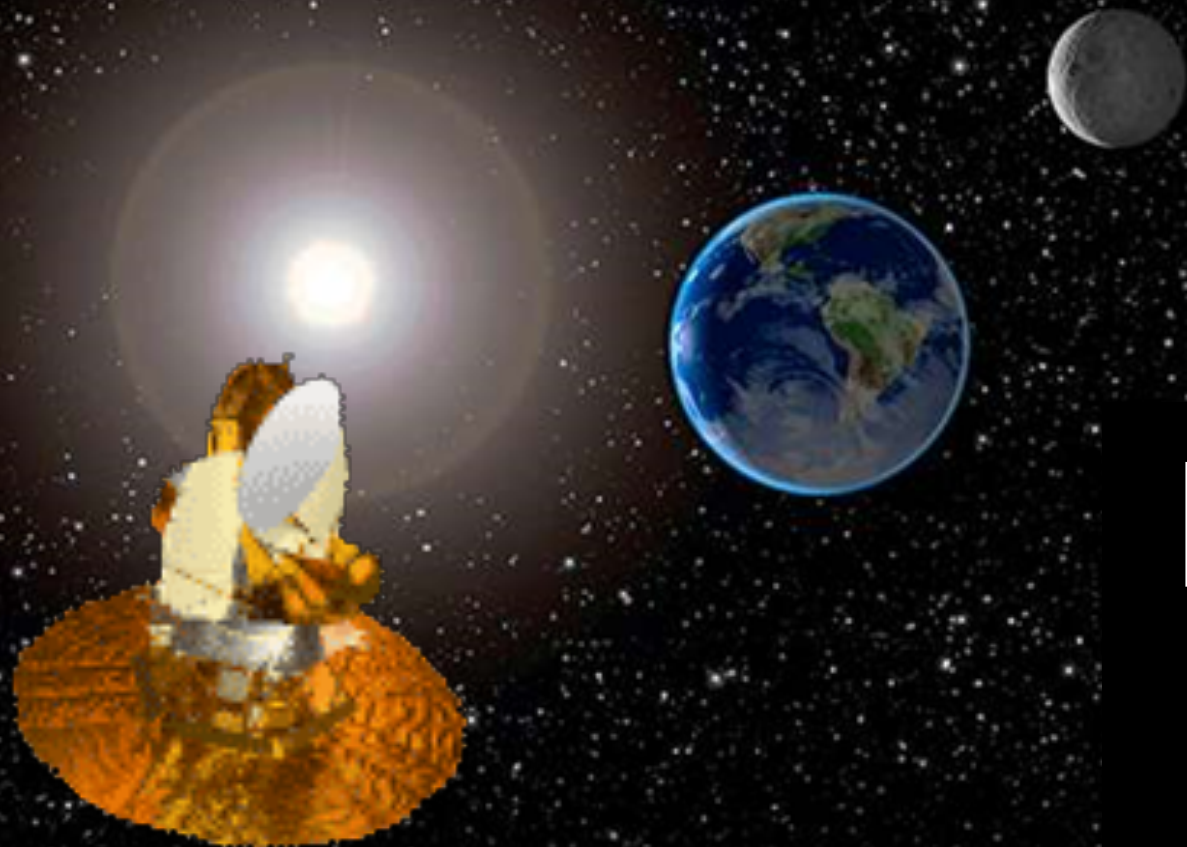
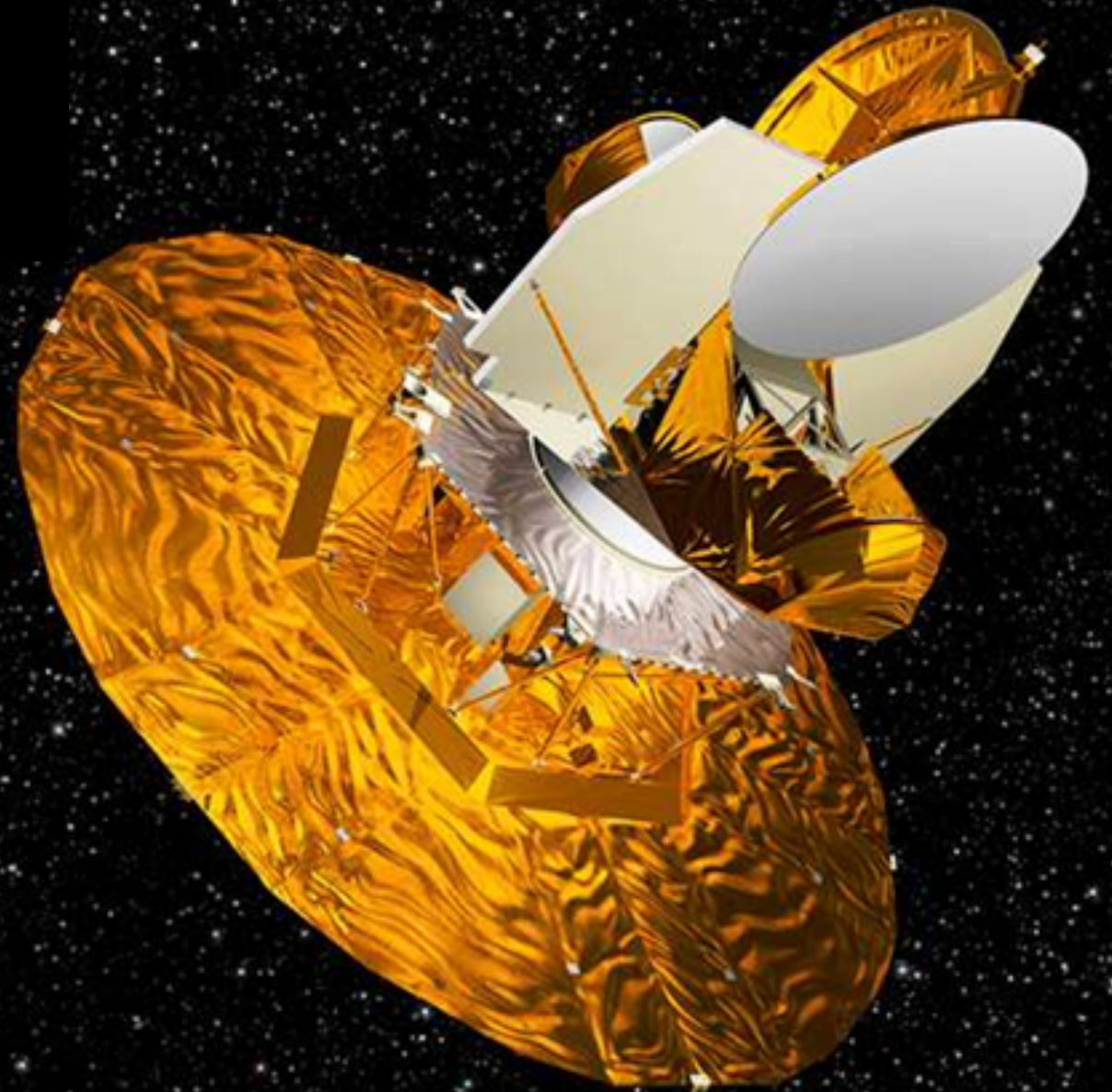


Unser Universum: Der Anfang — und ein Ende

Öffentlicher Vortrag
COSMO-19, RWTH Aachen
5. September 2019



Eiichiro Komatsu
Max-Planck-Institut für
Astrophysik

We have seen the beginning
of the Universe, using this
space telescope called
“**WMAP**”



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of the Universe, using this
space telescope called
“WMAP”

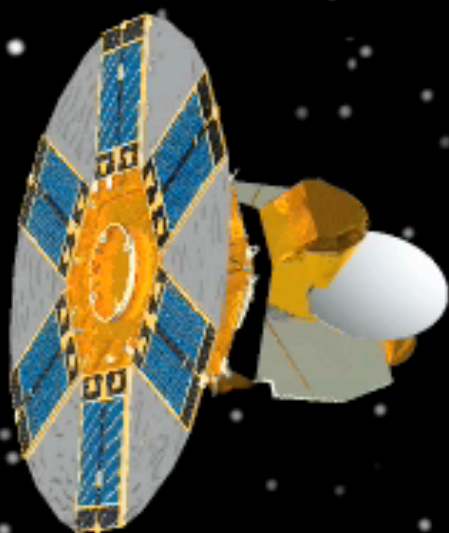


I am serious!





June 30, 2001: WMAP was launched on the Delta 2 rocket from Cape Canaveral, Florida, USA

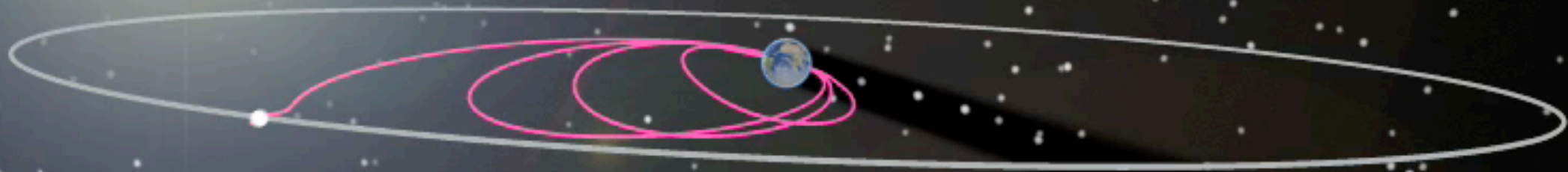


WMAP leaves Earth

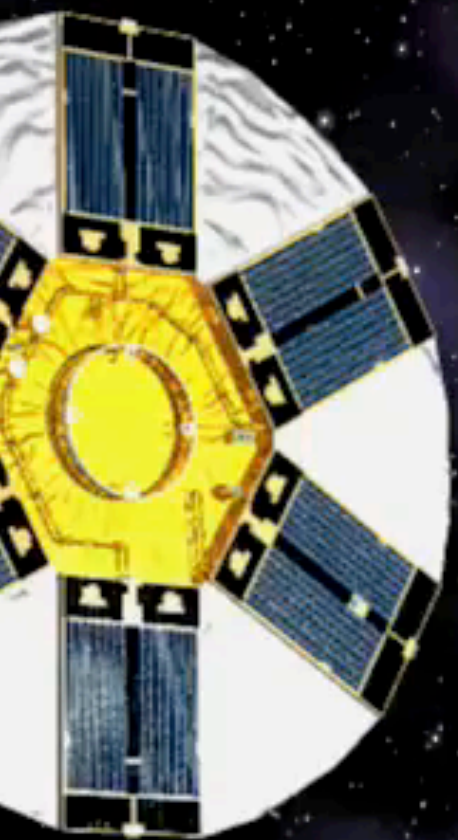


WMAP goes beyond Moon!

WMAP circles around the “Lagrange 2 Point”



1.5 million kilometers from Earth



**WMAP observes the Universe with
Sun, Earth and Moon being behind**

Seeing the beginning?

- **Looking into the distance = Looking into the past**
 - **The sun light takes 8 minutes** to reach Earth
 - The next nearest star is 4 light years away
 - The next nearest galaxy is 2.5 million light years away
 - *Und so weiter*
- **You keep looking farther away, and eventually reach the beginning of the Universe!**

WAS?!

- I am sure that some of you thought that I am crazy
- Today's goal: I will convince you that

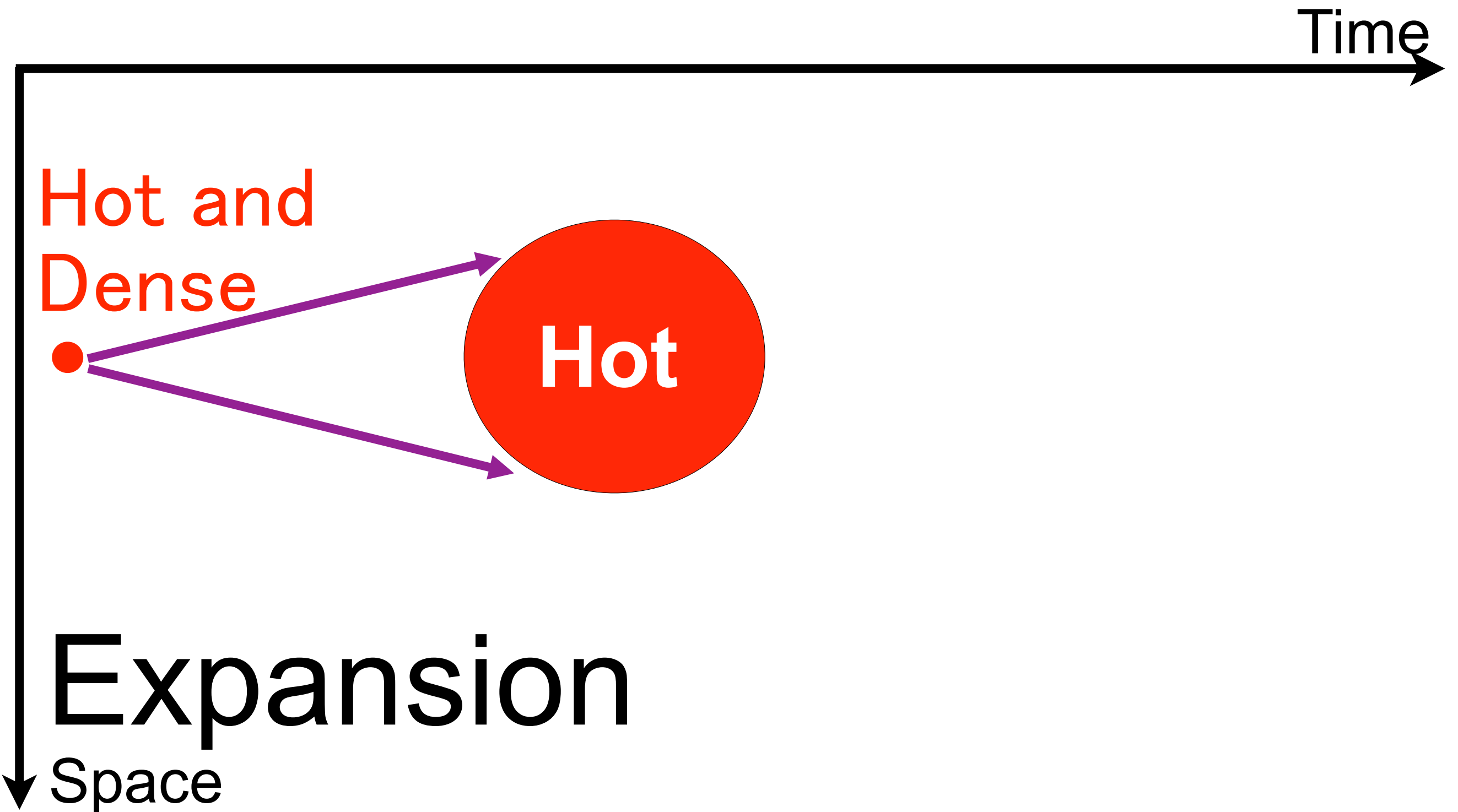
“Komatsu is not crazy, but he is saying something real. We can really see the beginning of the Universe!”

- In my lecture, you will be hearing well-established results from a series of observations and measurements made over the last half century

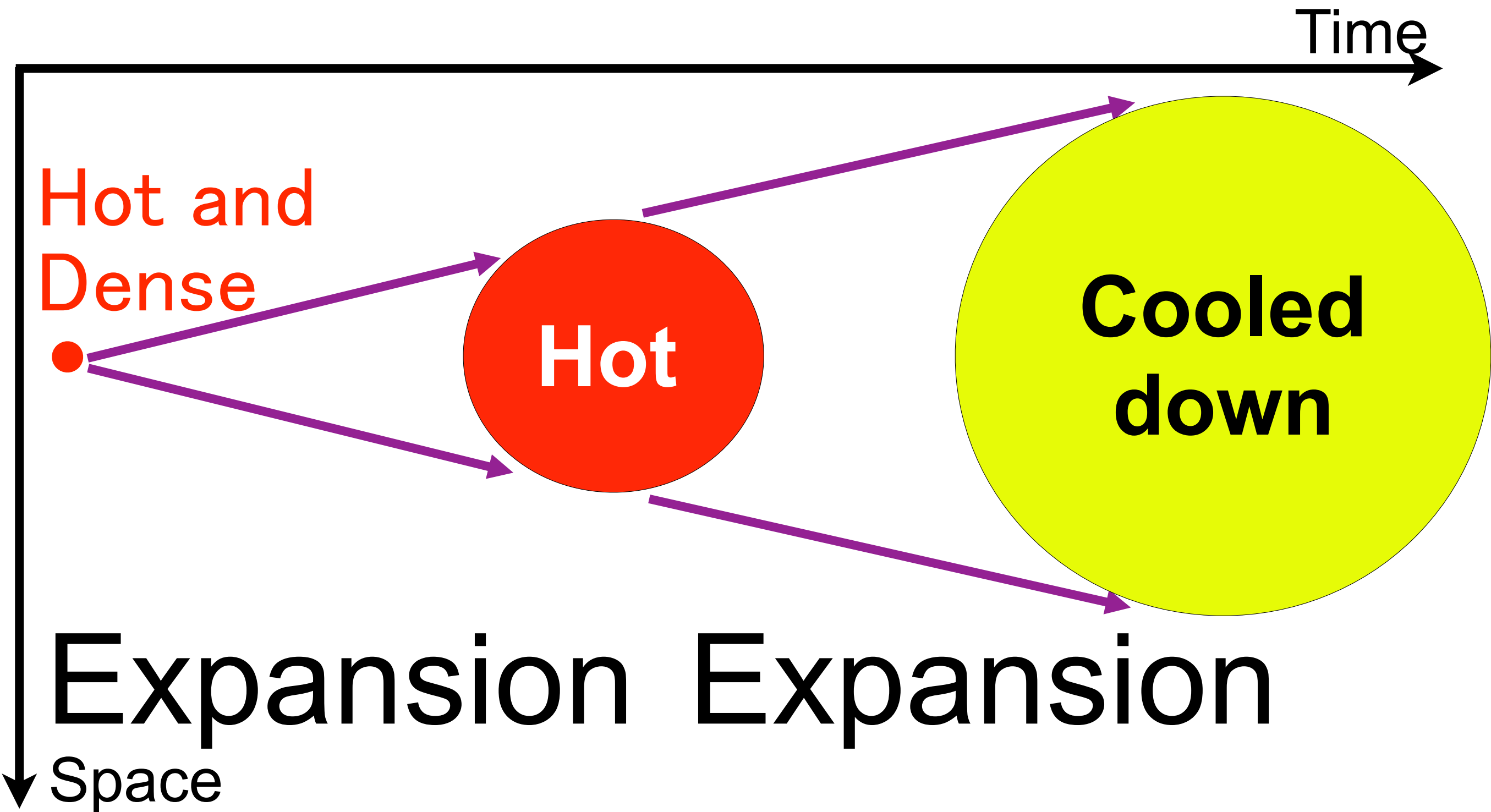
Fireball Universe



Fireball Universe



Fireball Universe



Definitive Result

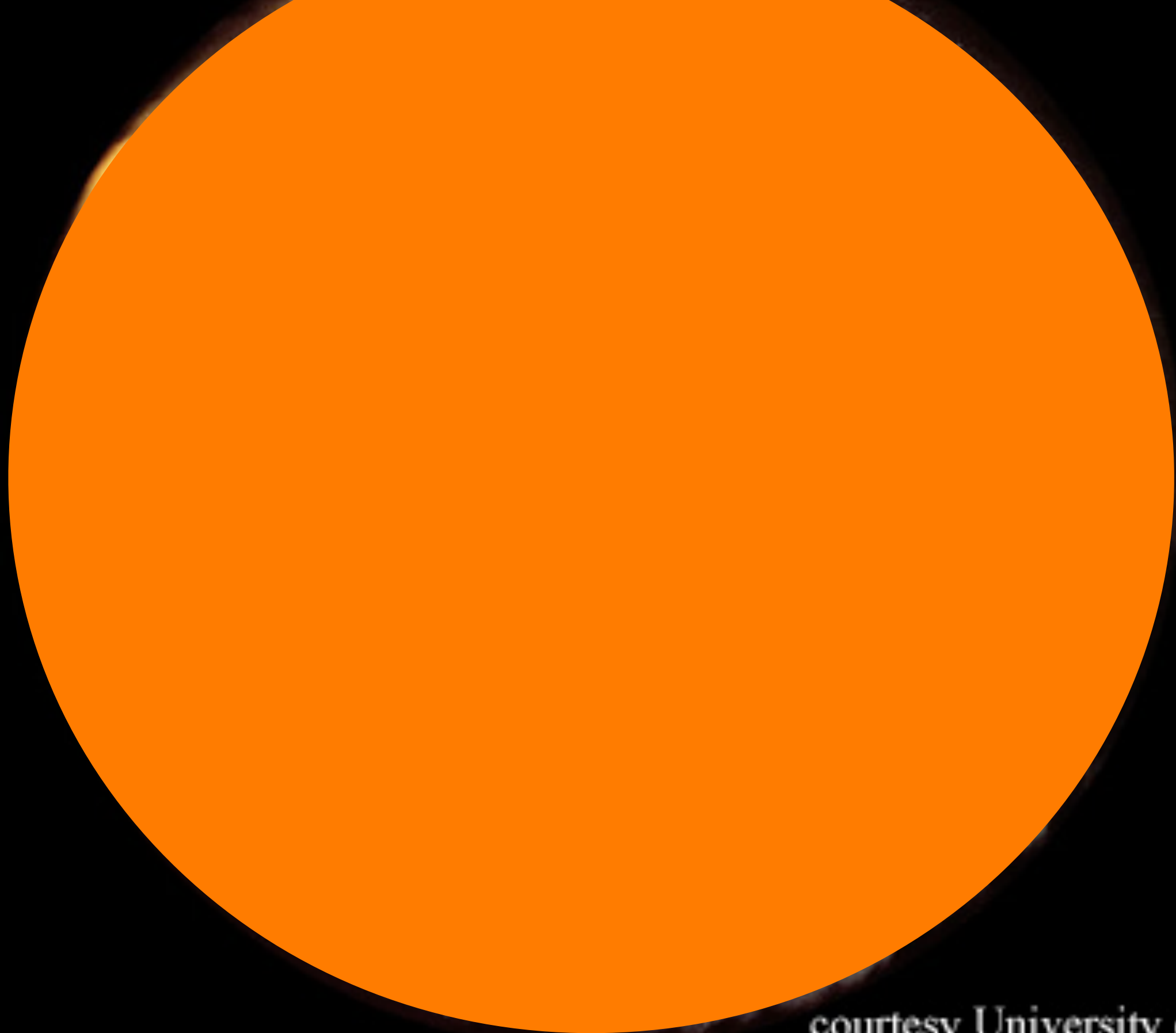
- Those photons which filled the fireball Universe are still with us
- There are **410 such photons per cubic centimetre**
- These photons are pouring on us all the time!

Sky in the visible light [$\sim 500\text{nm}$]



courtesy University of Arizona

Sky in the microwaves [$\sim 1\text{mm}$]



courtesy University of Arizona

Sky in the microwaves [$\sim 1\text{mm}$]

*Light from the fireball Universe
filling our sky*

**The Cosmic Microwave
Background (CMB)**

Die kosmische Mikrowellenhintergrundstrahlung

courtesy University of Arizona

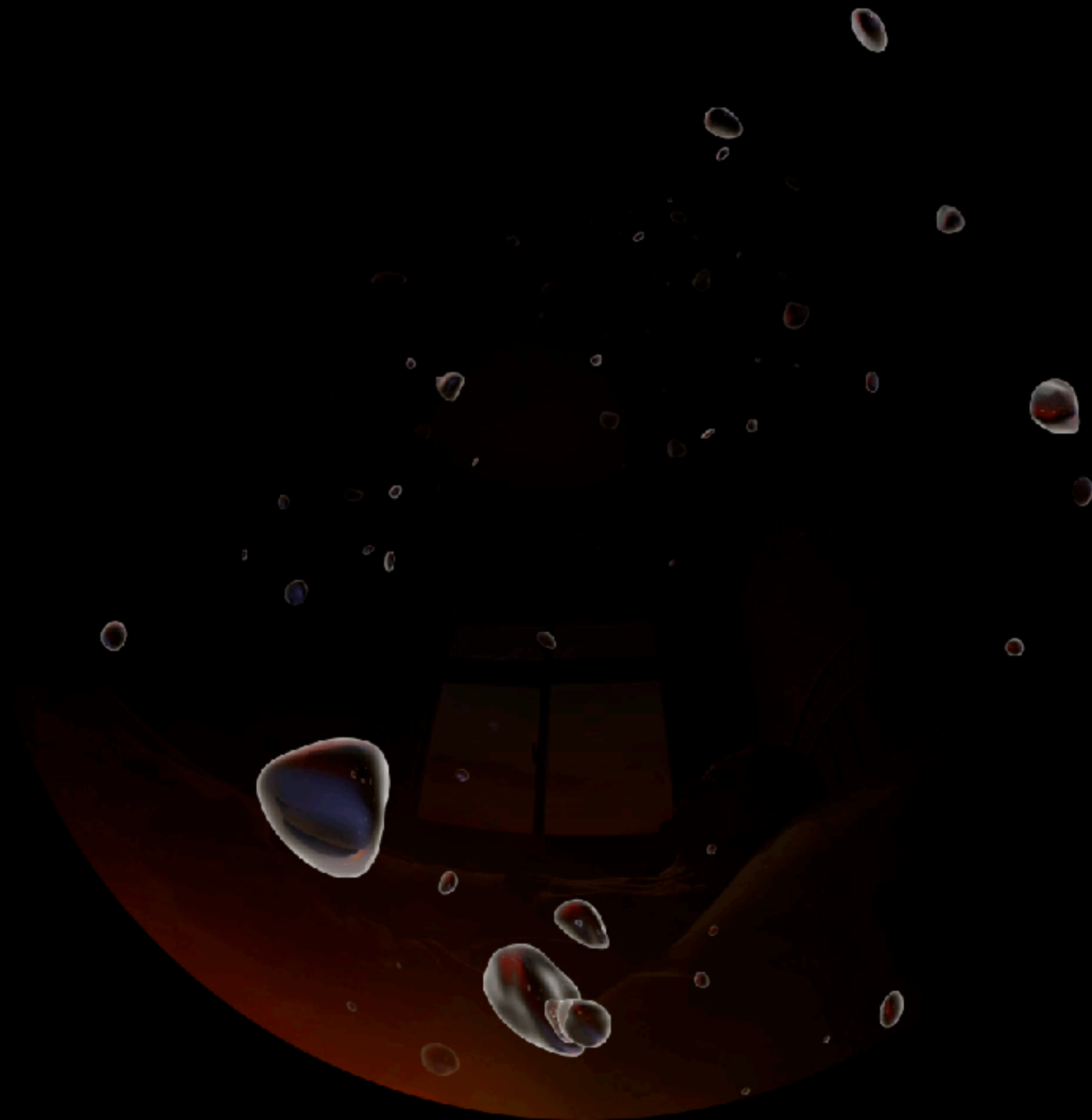


Full-dome movie for planetarium

Director: Hiromitsu Kohsaka



HORIZON :Beyond the Edge of the Visible Universe [Trailer]

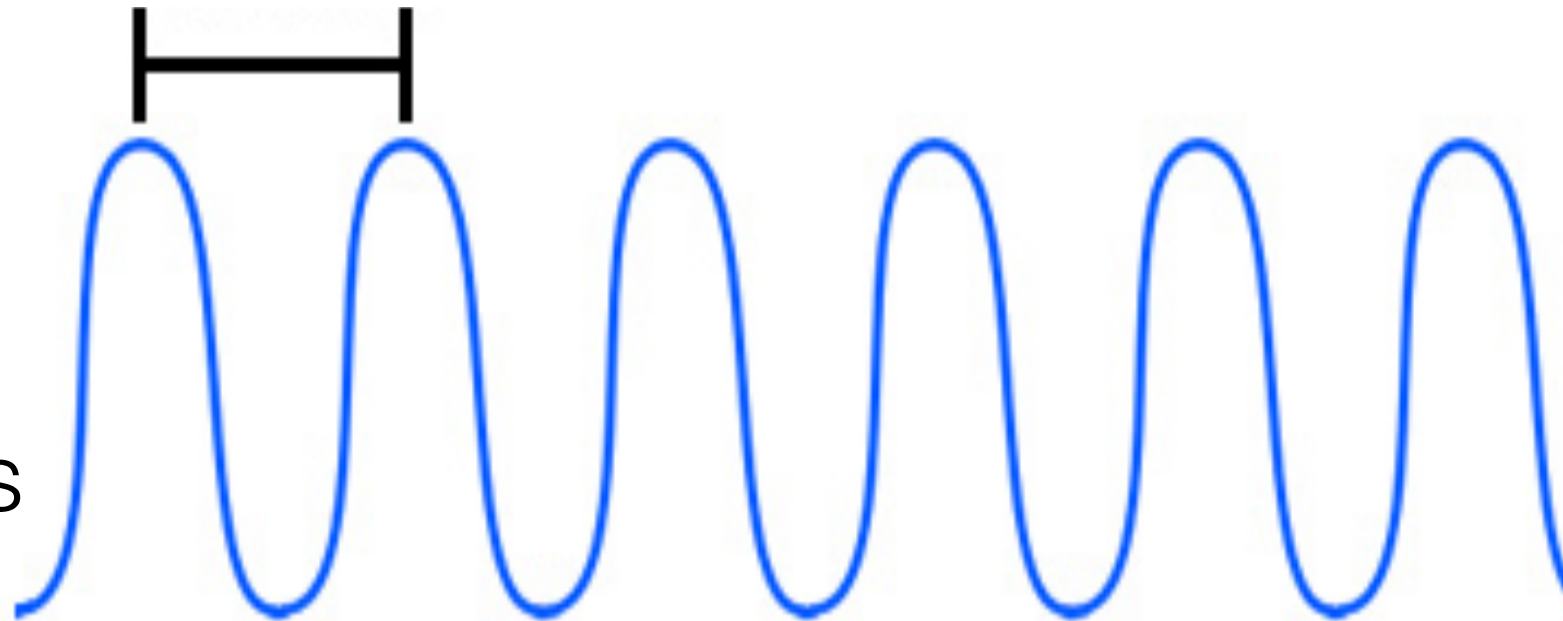


Wavelength of Light

- **Visible light is**

- shorter wavelength
- 380–740 nanometers

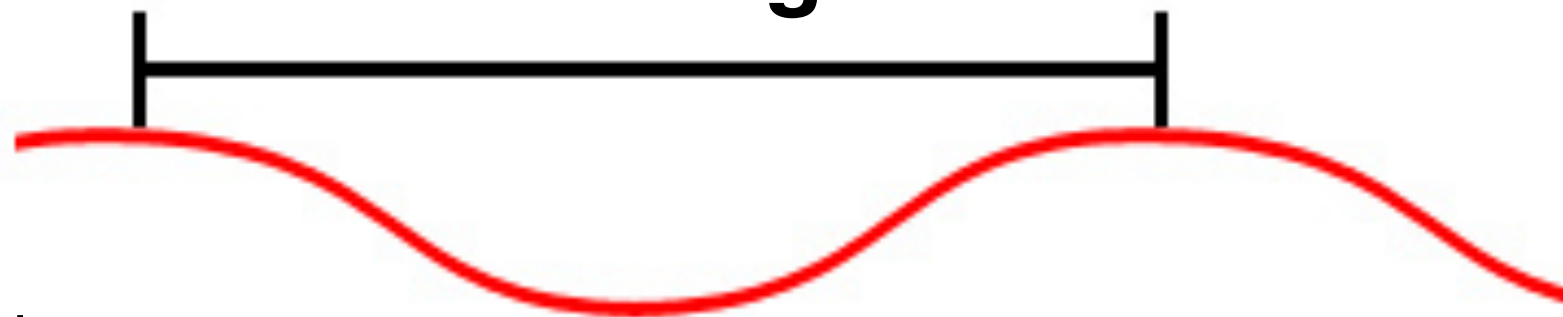
Wavelength



- **Microwave is**

- longer wavelength
- millimeter to centimeter

Wavelength

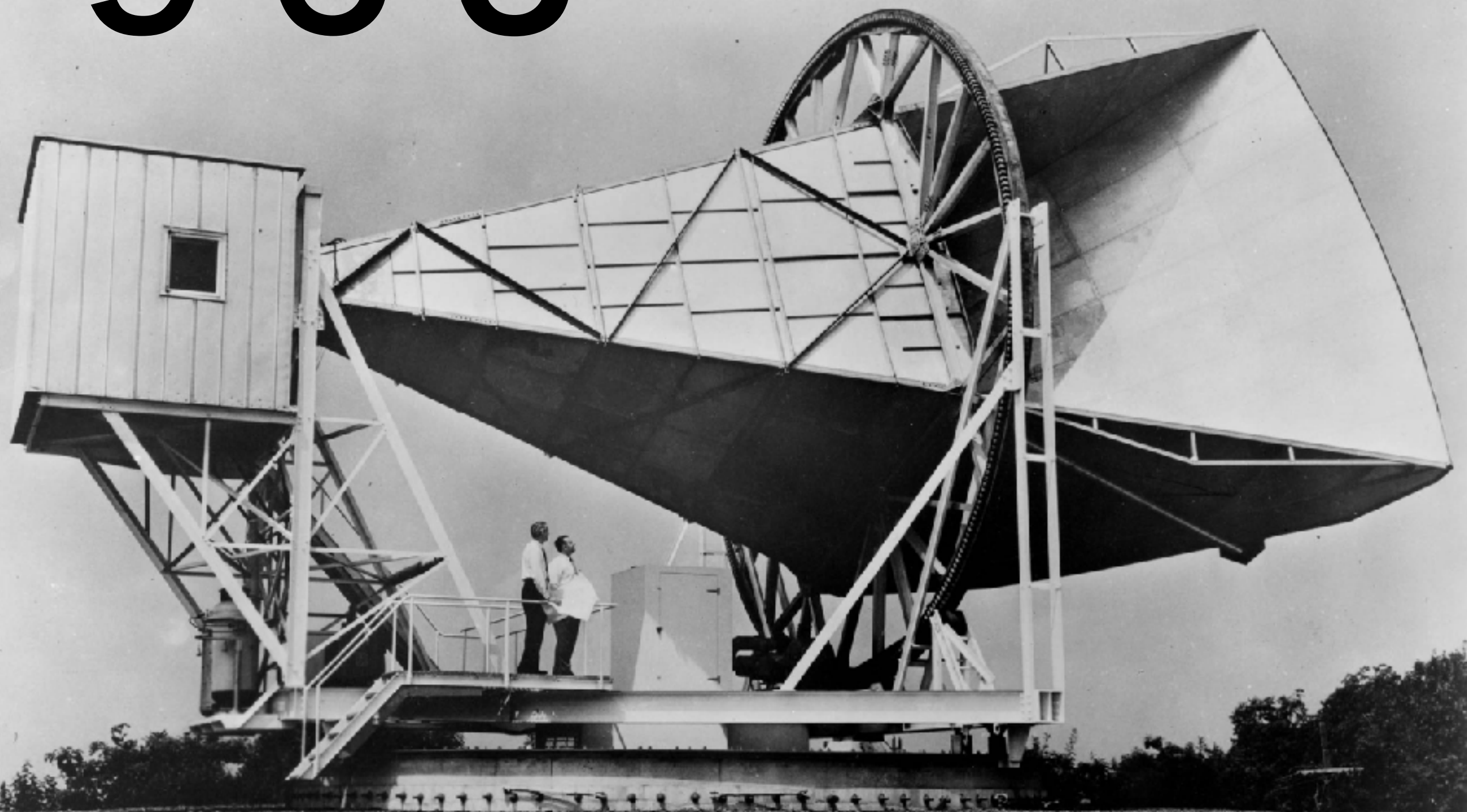


A woman with long dark hair, wearing a black cardigan over a black top with a colorful patterned collar, is holding a vintage white television set. The television screen displays a blue and white static noise pattern. A thin white circle is drawn around the top of the television. The background is dark, and a wooden ledge is visible at the bottom.

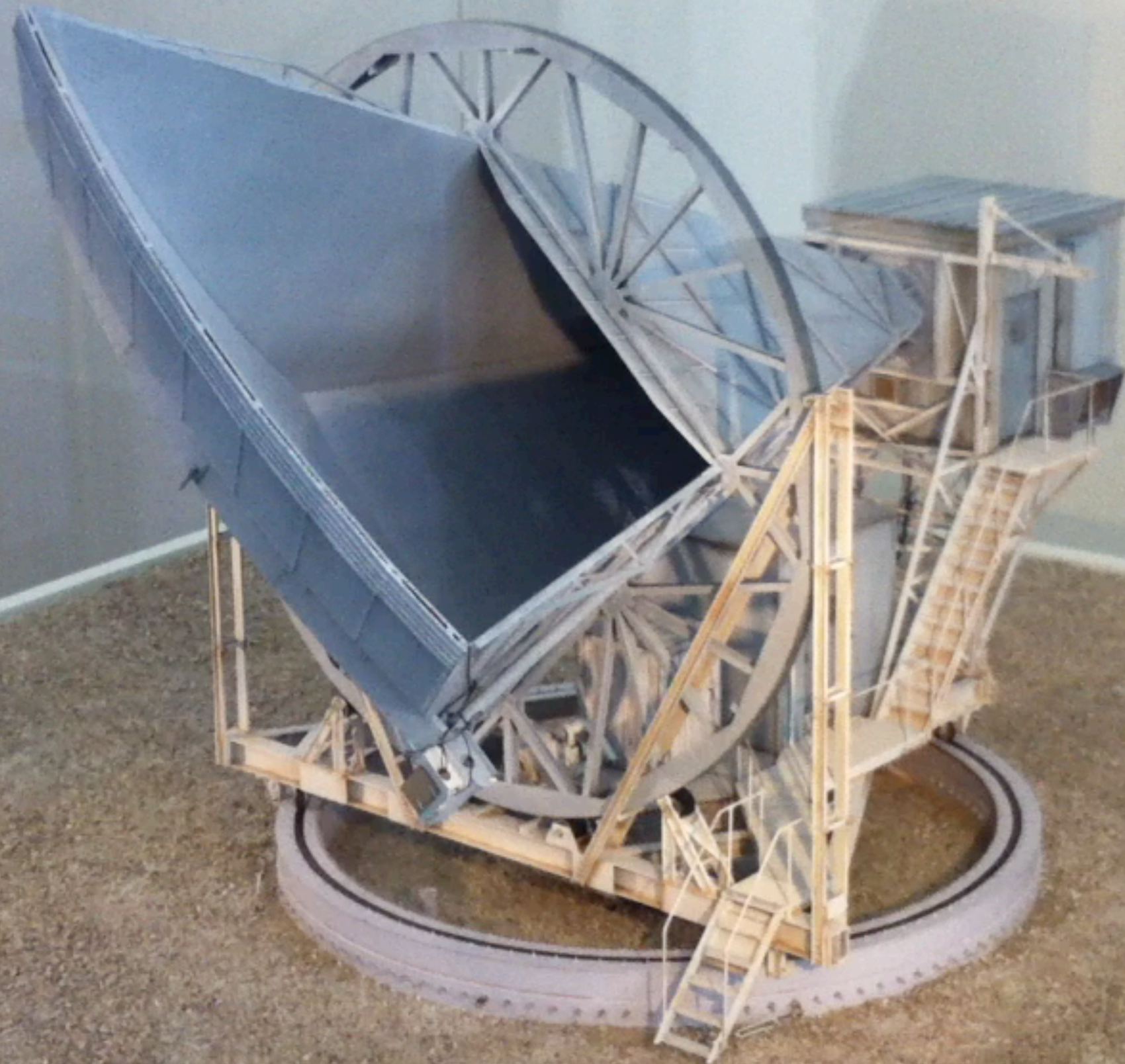
Dr. Hiranya Peiris
(University College London)

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

1965



1:25 model of the antenna at Bell Lab
The 3rd floor of Deutsches Museum



The real detector system used by Penzias & Wilson

The 3rd floor of Deutsches Museum



**Donated by Dr. Penzias,
who was born in Munich**



Horn antenna

Calibrator, cooled
to 5K by liquid helium

Amplifier

Recorder

Hornantennenanschluss

Hohlleiterzug

V
Vergleichs-
quelle

R
Rauschquelle

F
Frequenzmischer
und Verstärker

M
MASER-Verstärker

Schreiber

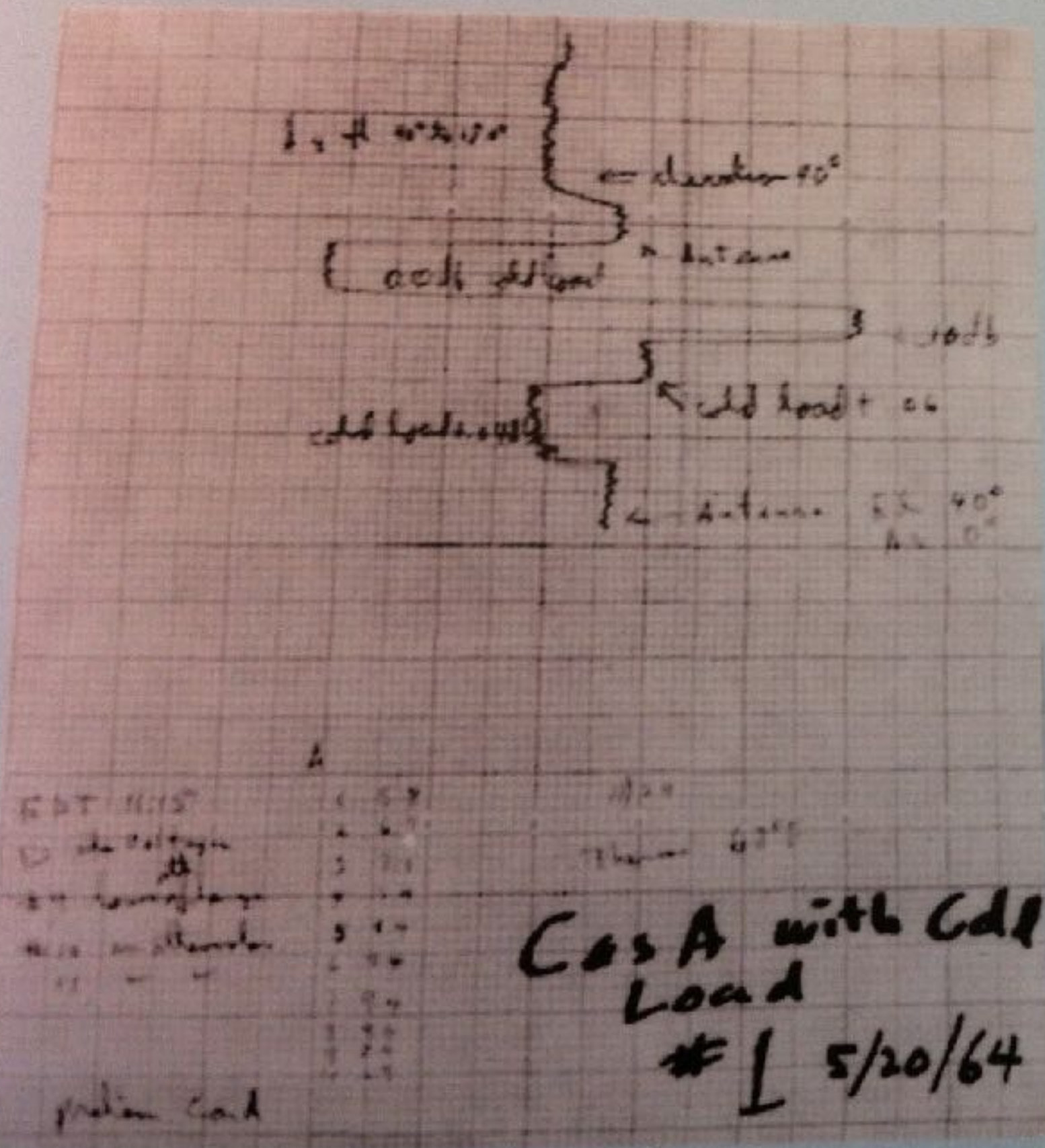
many
radio

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May 20, 1964 CMB Discovered

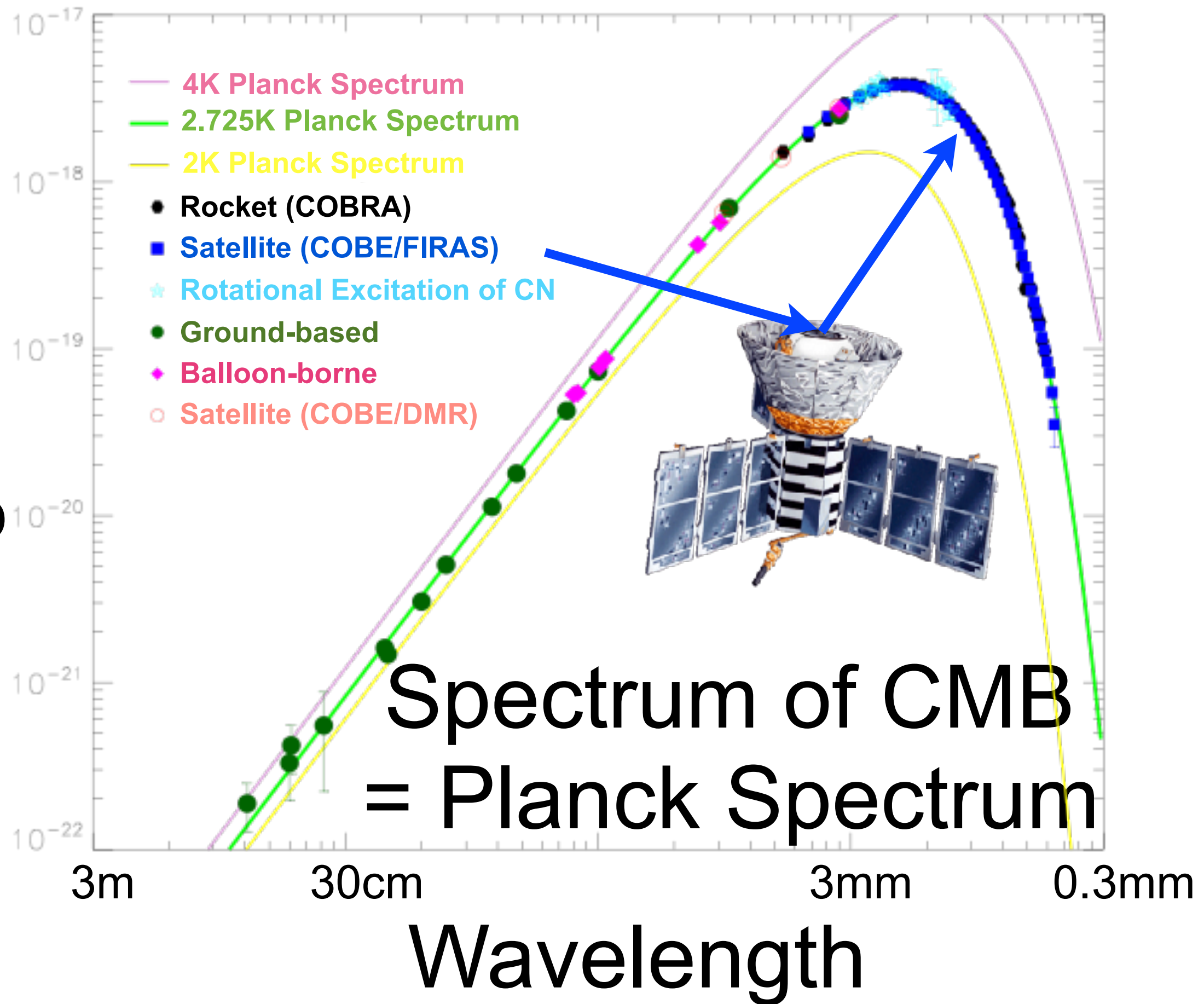
$$6.7 - 2.3 - 0.8 - 0.1 \\ = 3.5 \pm 1.0 \text{ K}$$



Schreiberaufzeichnung der ersten
Messung des Mikrowellenhinter-
grundes am 20.5.1964

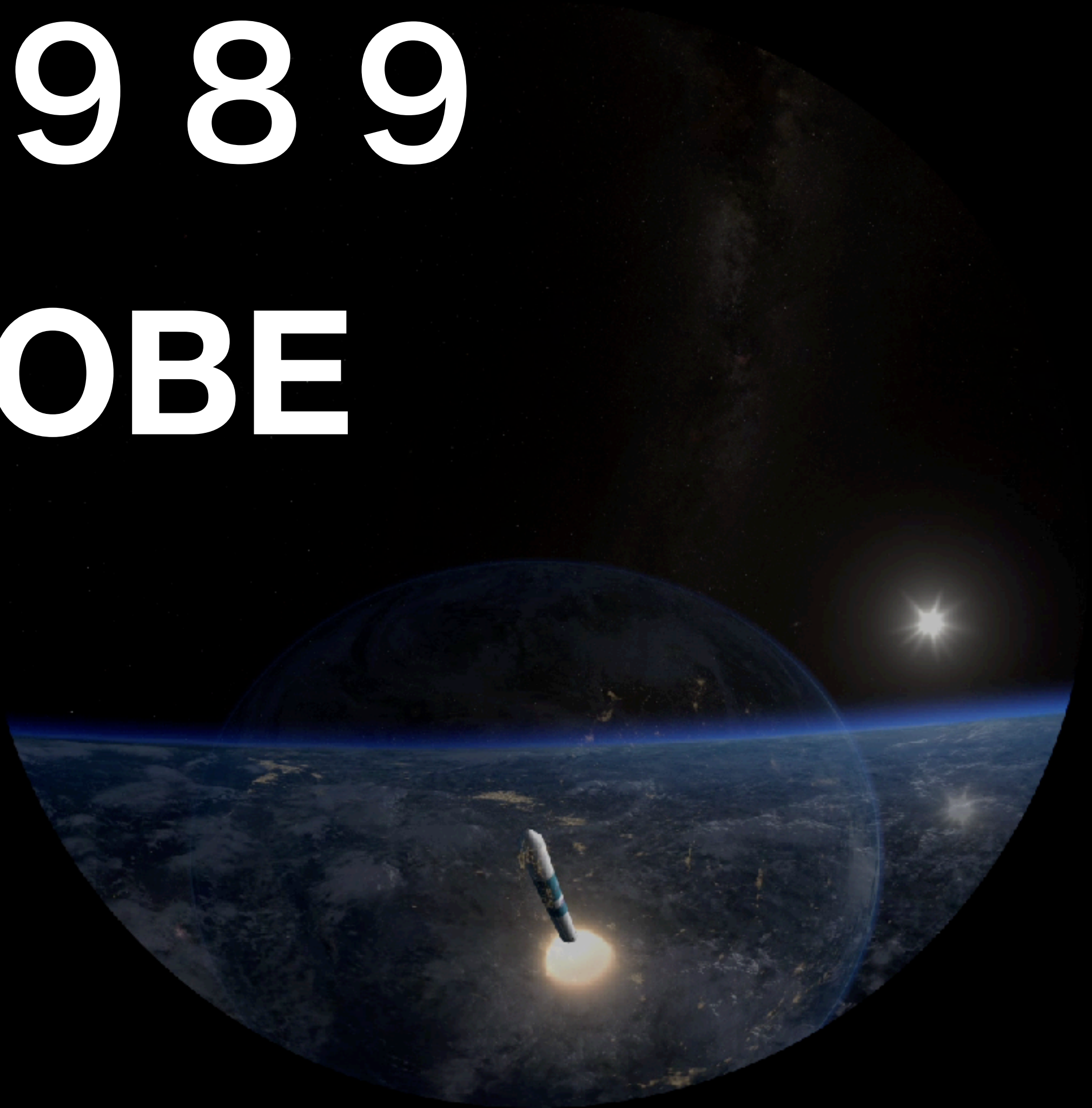
Recording of the first measurement
of cosmic microwave background
radiation taken on 5/20/1964.

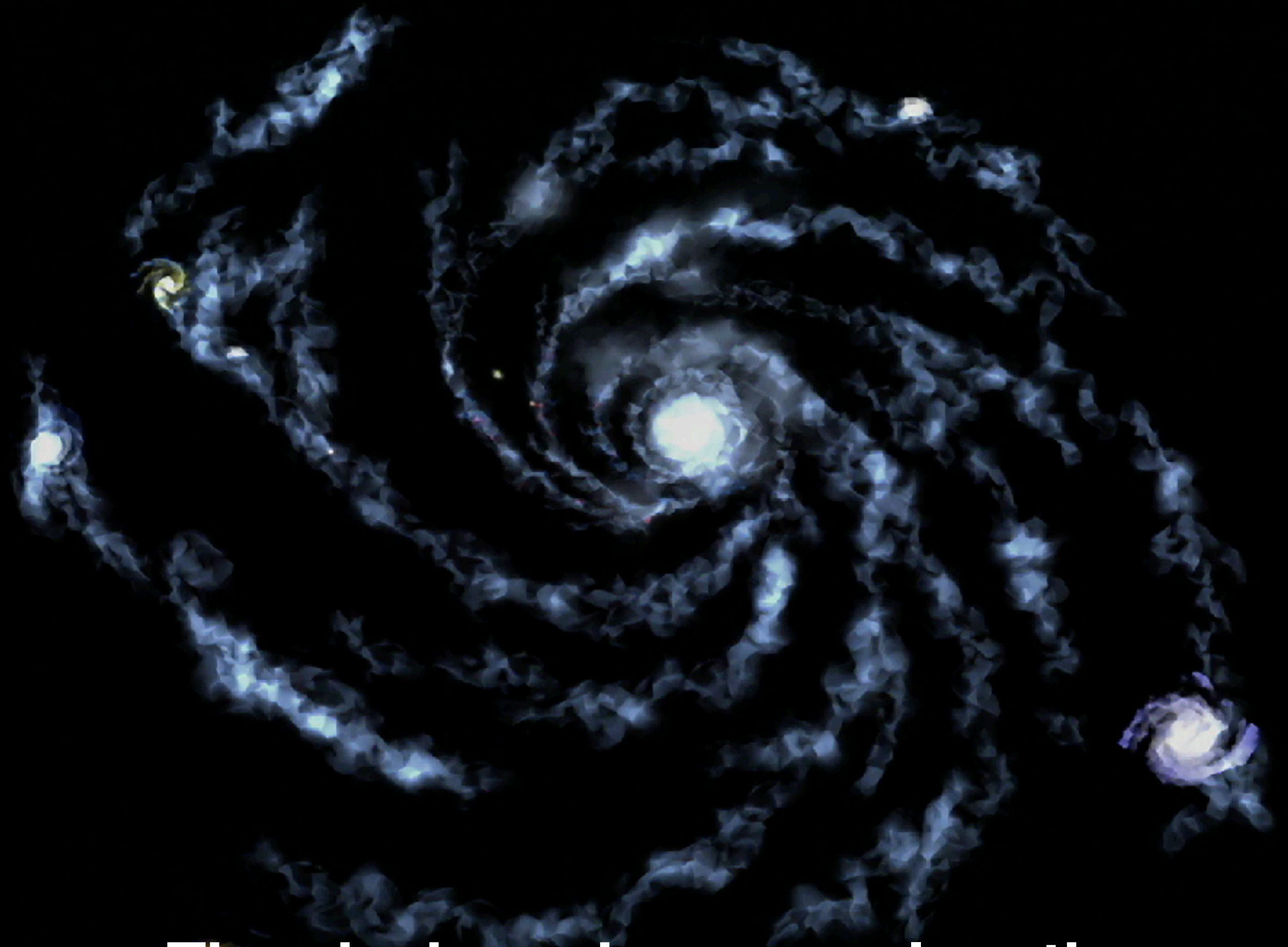
Brightness



1989

COBE



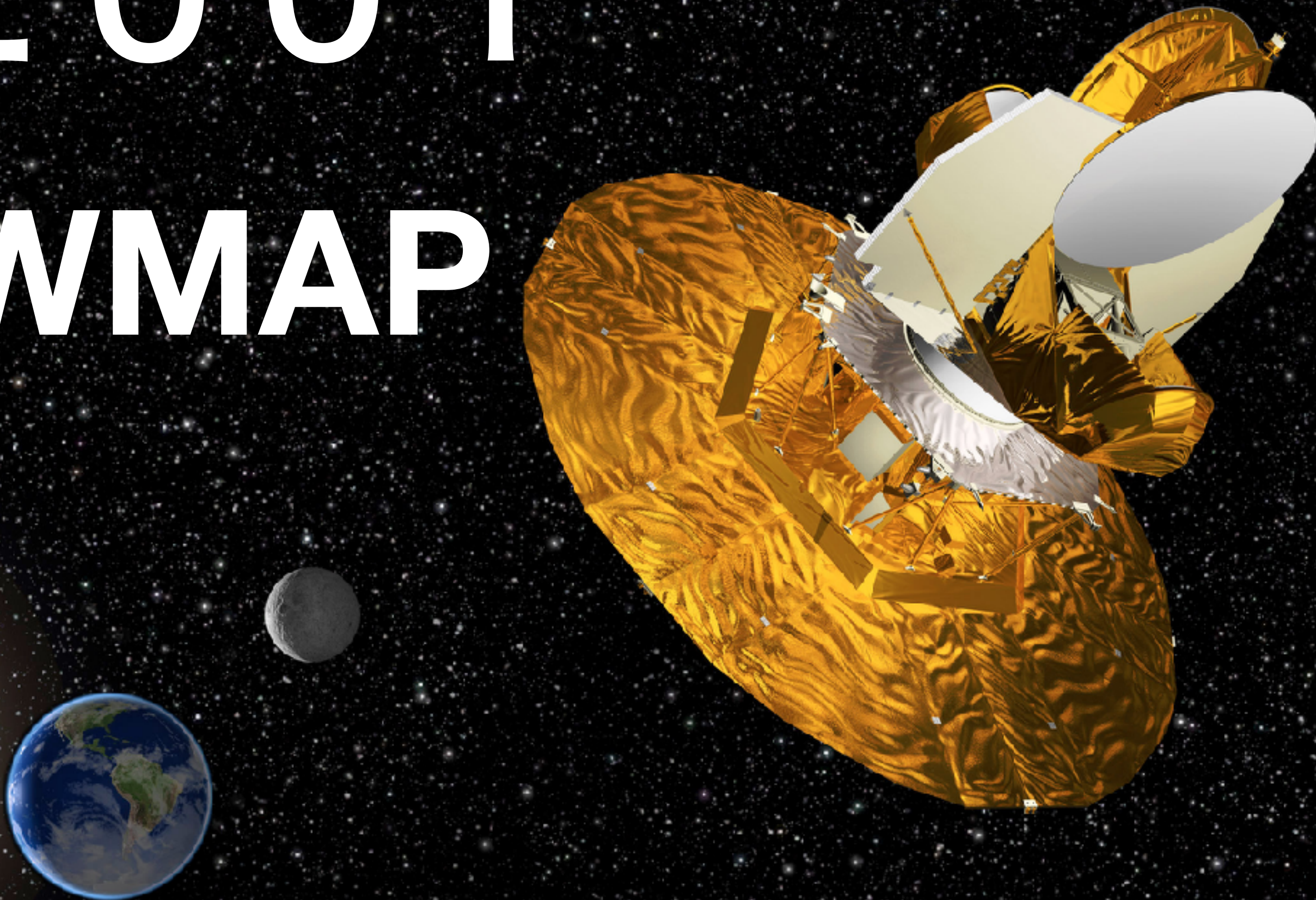


The sky in various wavelengths

Visible -> Near Infrared -> Far Infrared -> Submillimeter -> Microwave

2001

WMAP



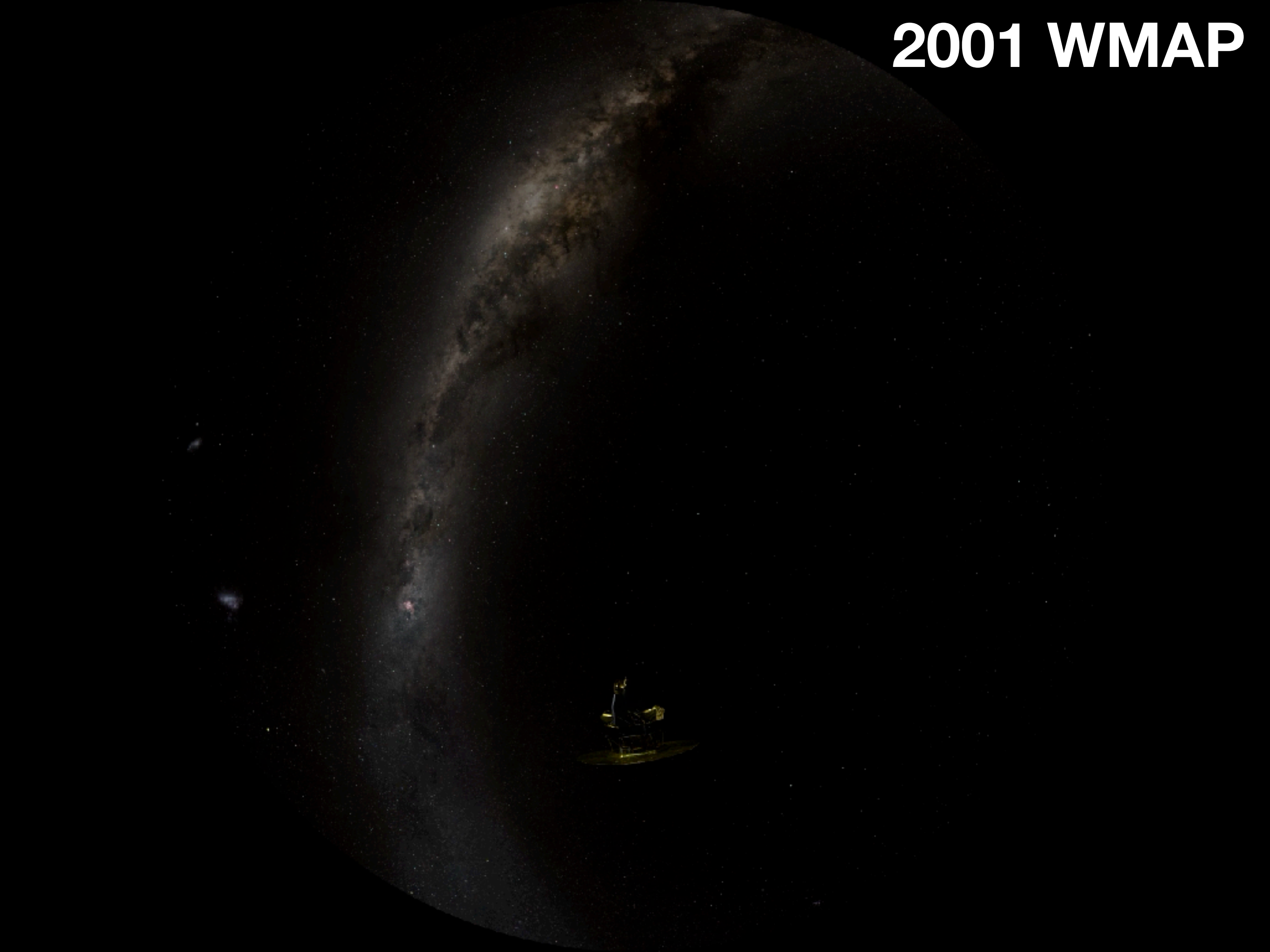
WMAP Science Team

July 19, 2002

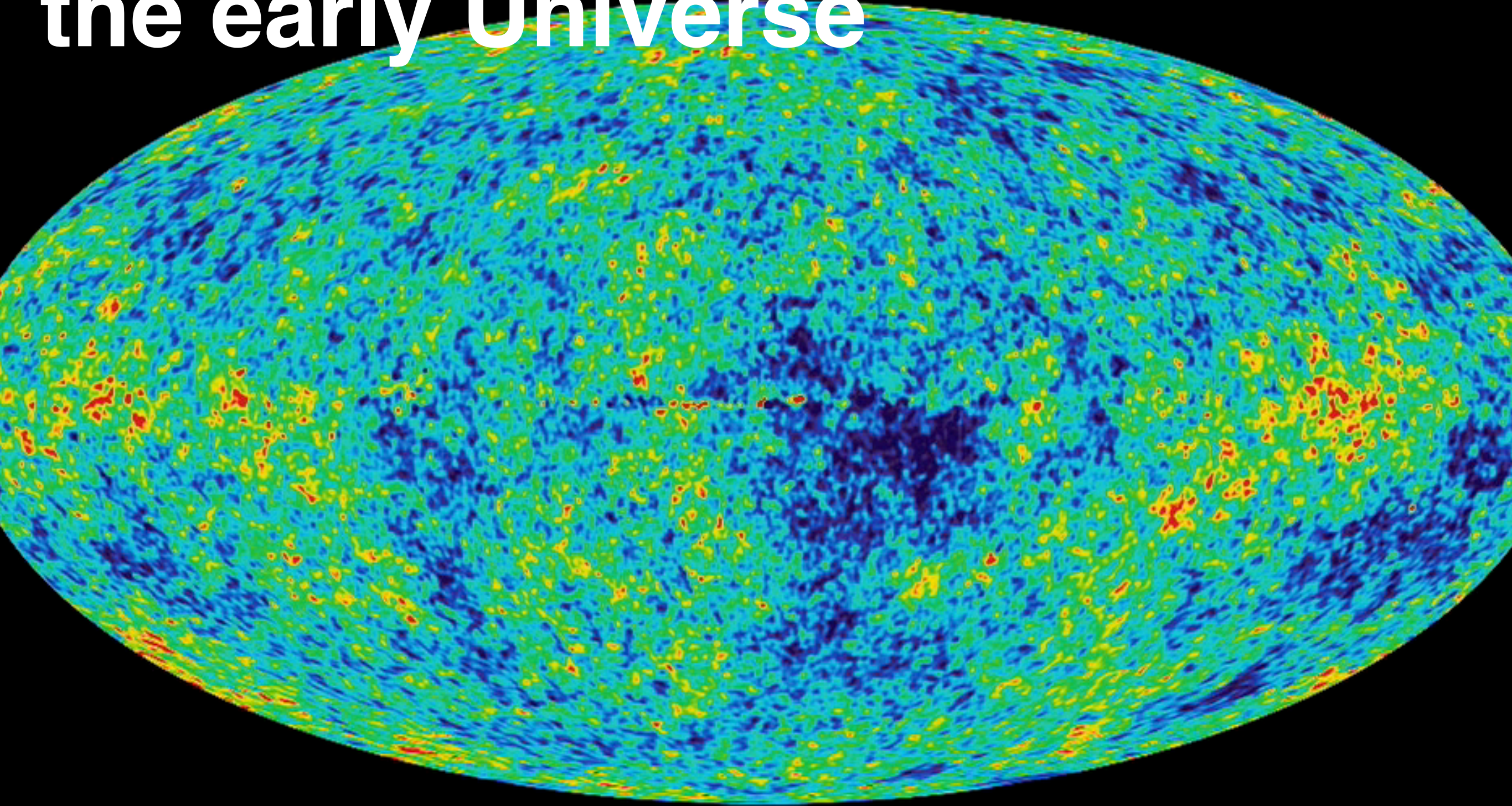


- WMAP was launched on June 30, 2001
- The WMAP mission ended after 9 years of operation

2001 WMAP



Our Origin: Tiny fluctuations in the early Universe



A Remarkable Story

- Observations of the cosmic microwave background and their interpretation taught us that **galaxies, stars, planets, and ourselves originated from tiny fluctuations in the early Universe**

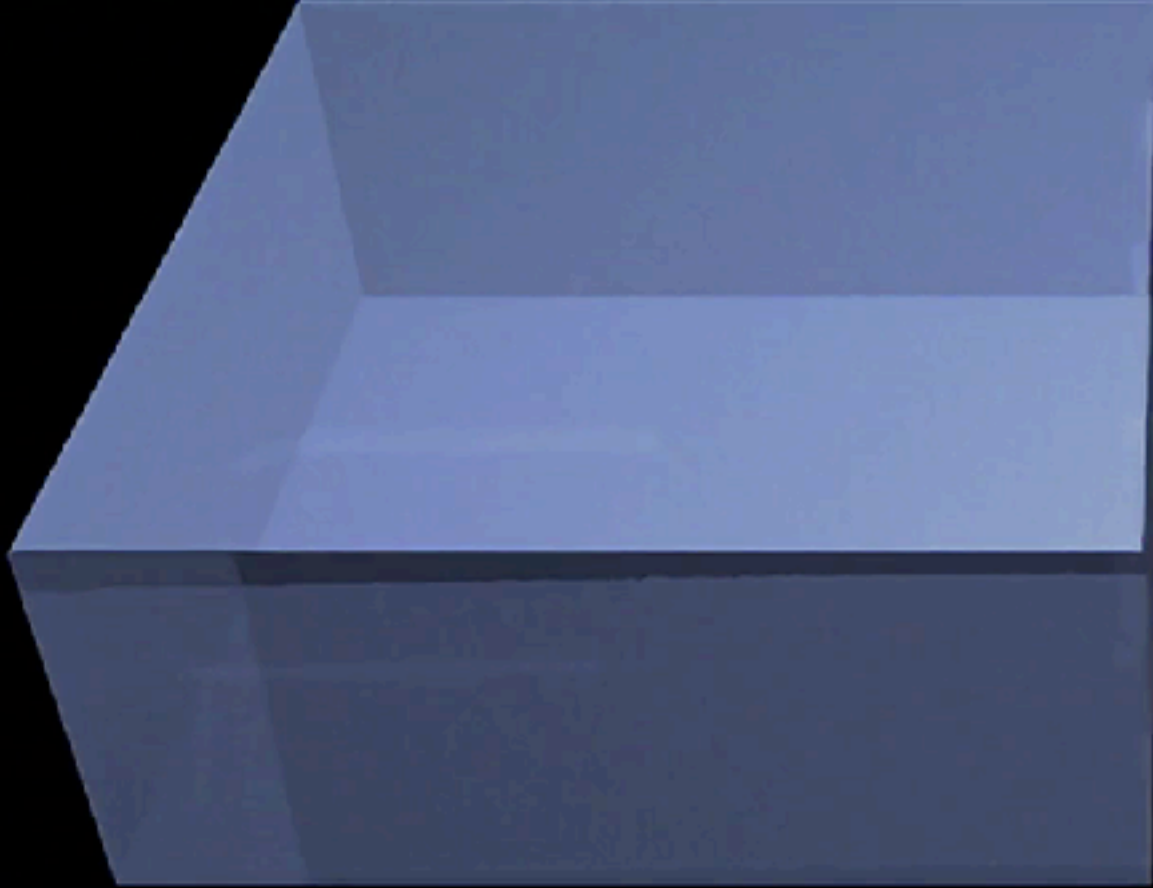
Some of the findings

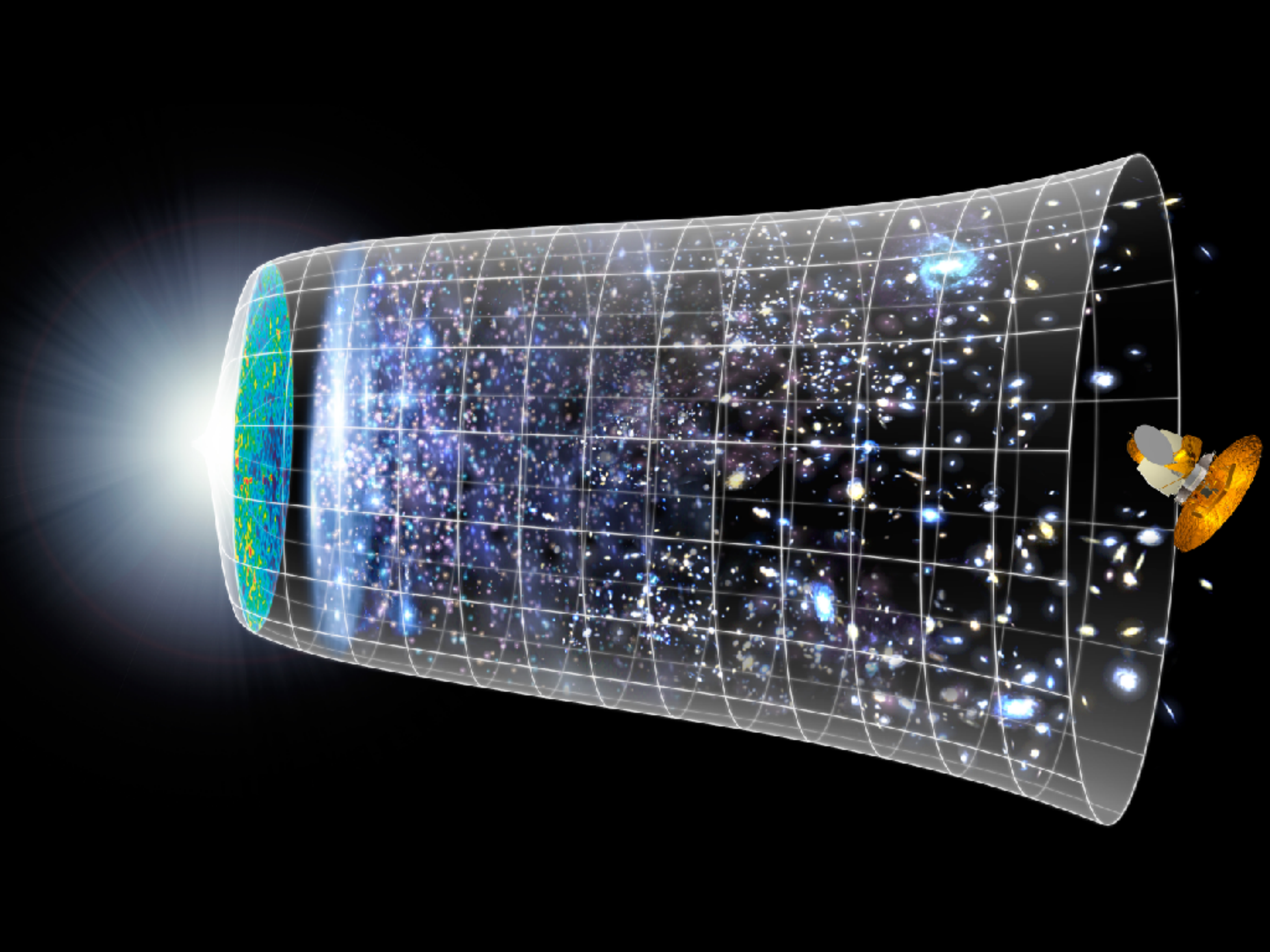
- We determined the age of the Universe
 - **13.8 billion years**
- We determined the composition of the Universe
 - **What is the Universe made of?**

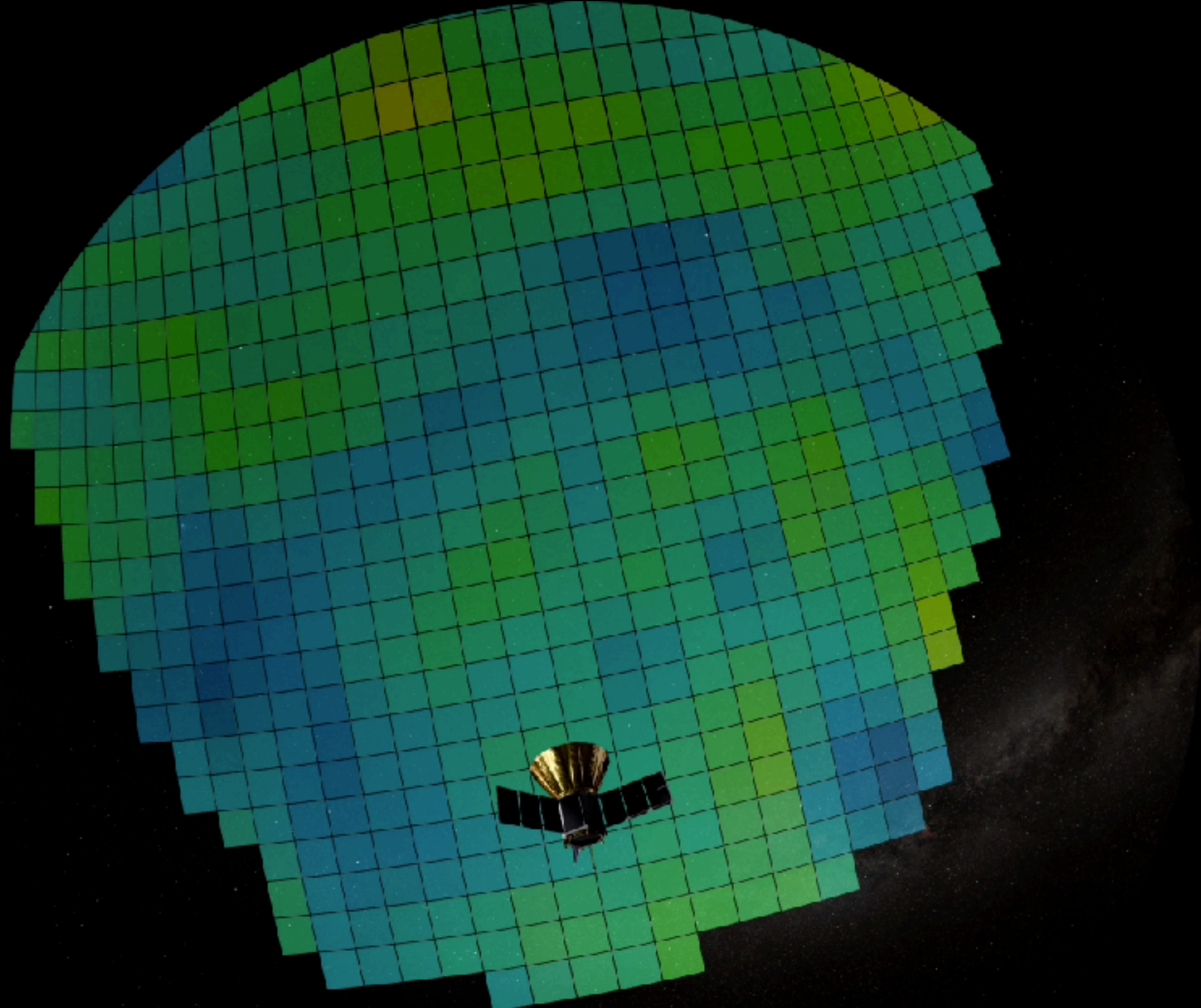


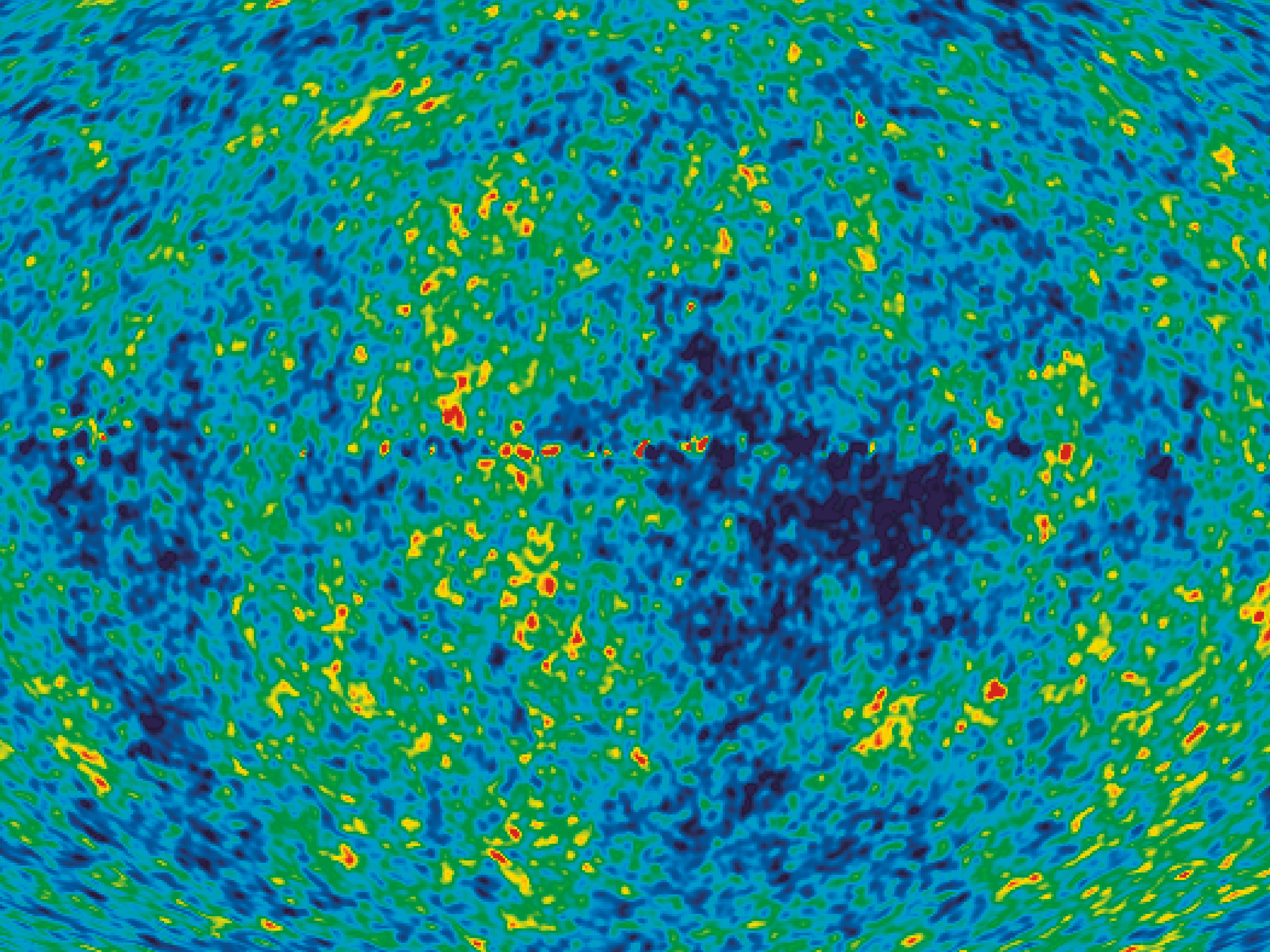
Kosmische Miso Suppe

- 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 ripples are created and propagate throughout the soup



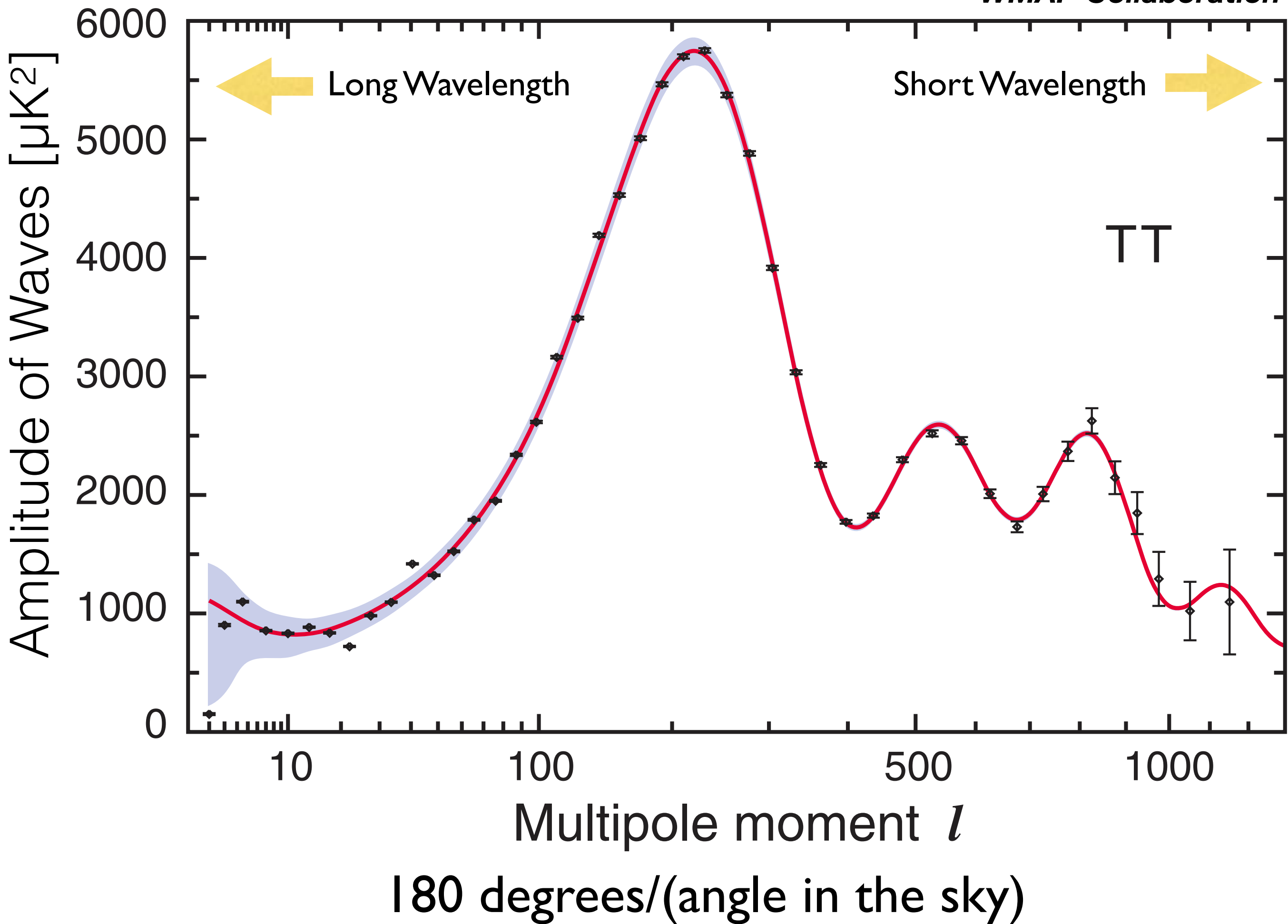






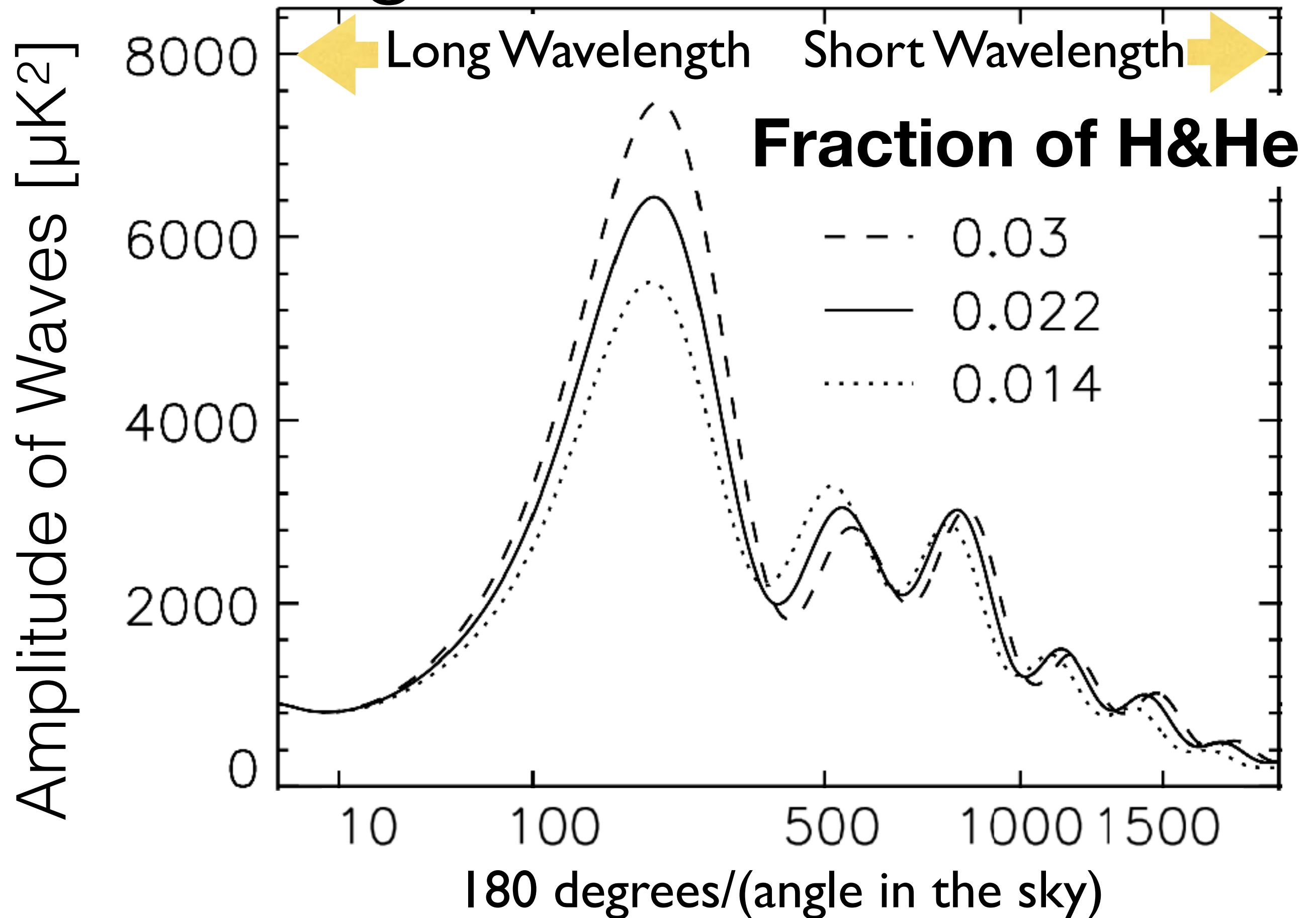
Data Analysis

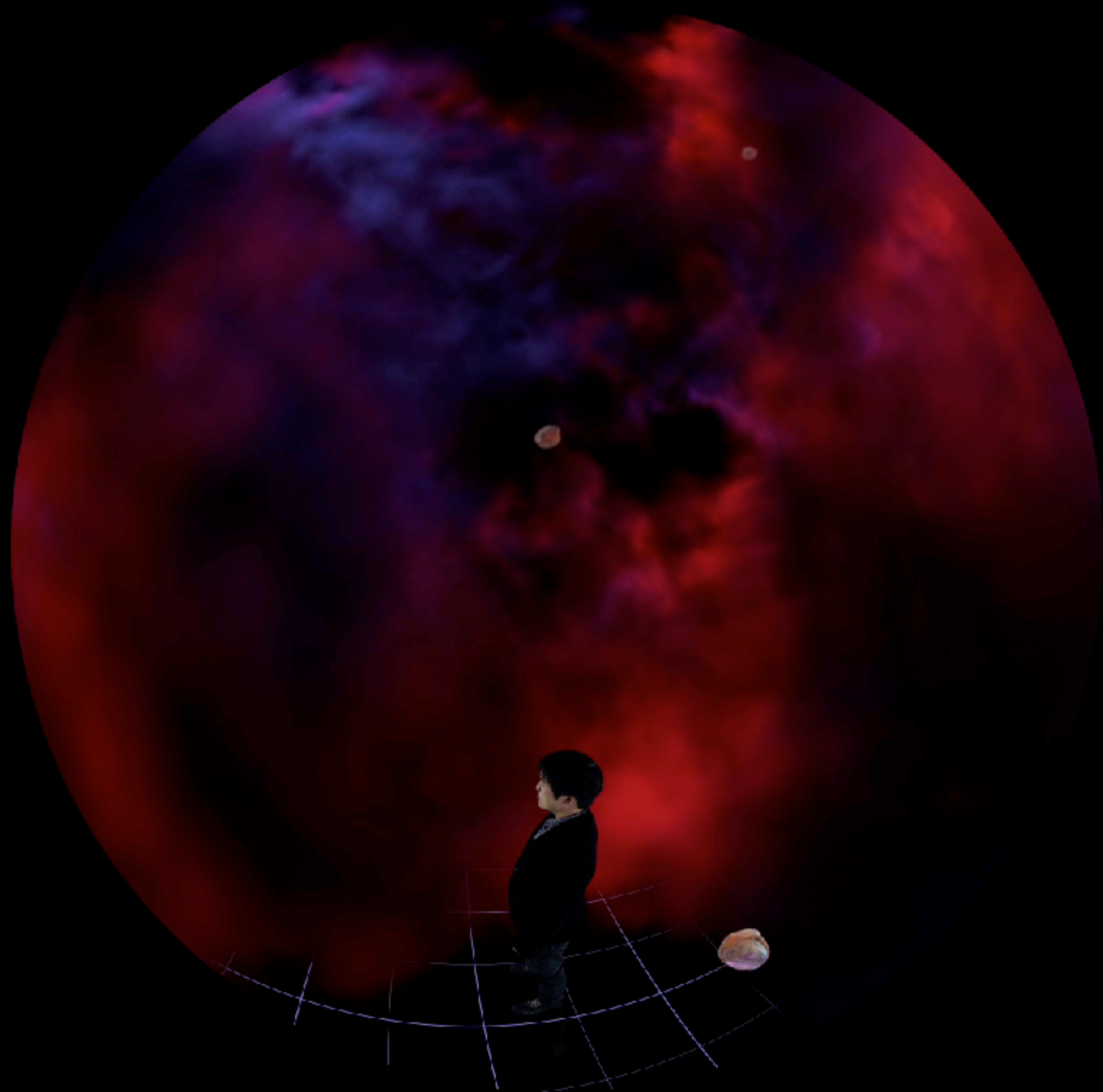
- Decompose temperature fluctuations in the sky into a set of waves with various wavelengths
- Make a diagram showing the strength of each wavelength



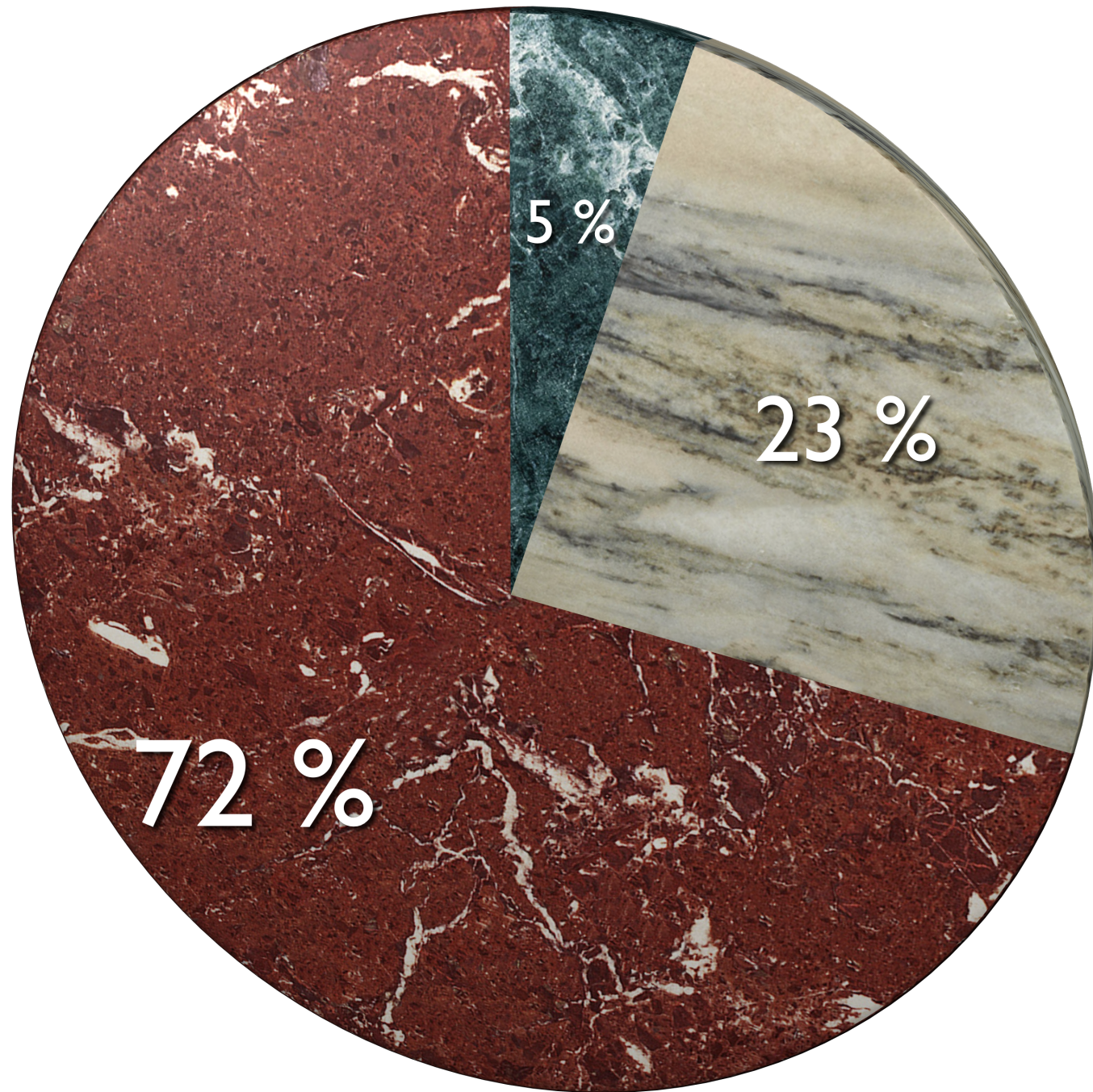


Measuring Abundance of H&He





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

Matter and Expansion

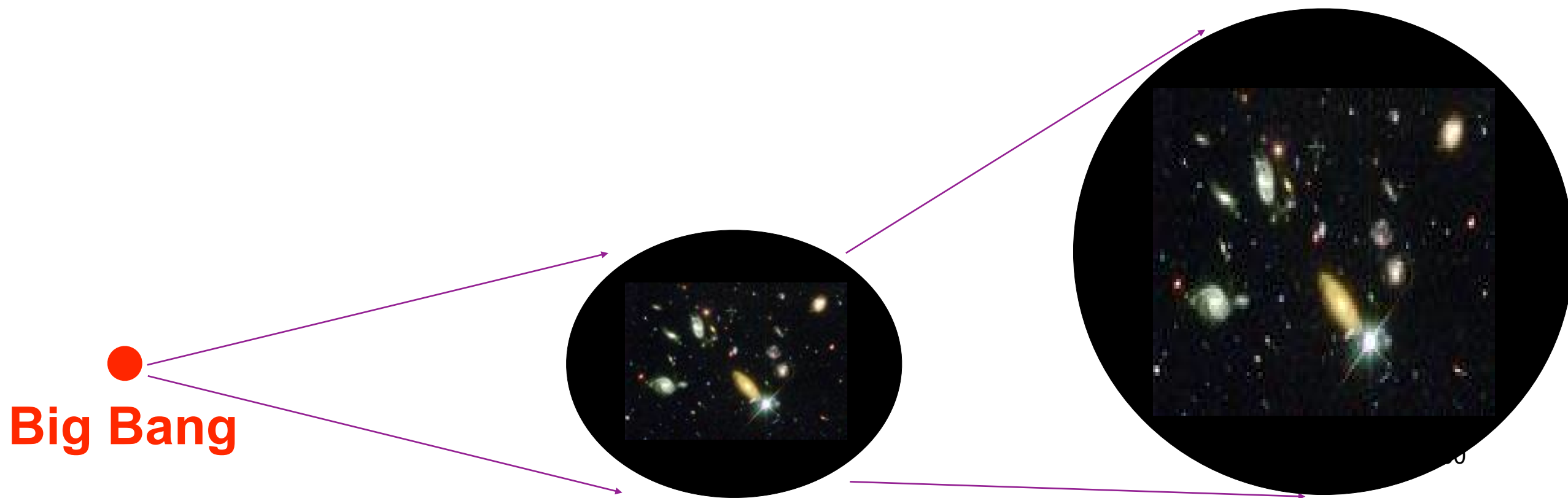
- How would space expand in an empty Universe?
 - A: Continue to expand with a constant velocity (i.e., no acceleration or deceleration)
- How would space expand in a matter-dominated Universe?
 - A: Gravity pulls space and expansion decelerates
- Too much matter means a re-collapse of the Universe!



Accelerating Universe

- However, the observations tell us that expansion is speeding up!
- This cannot be due to matter

—Something that is not even matter: **Dark Energy**





No Dark Energy on Earth



ZERO

暗黒エネルギーが支配する場合

What if Dark Energy dominates?

**Dark Energy determines
the future of the Universe**

Future of the Universe

- It all depends on what Dark Energy will do!
 - We are “safe” in Earth because there is a lot more matter than Dark Energy on Earth today
- If Dark Energy stays the same or decreases in the future, we will be safe forever
- If Dark Energy increases over time, it will eventually exceed the matter density, and everything will be ripped apart. A catastrophic ending called “Big Rip”



衝撃の終末
ビッグリップ

Big Rip

Der Anfang, und ein Ende

- Our origin: tiny fluctuations in the early Universe
 - How were we born? See it by yourself in the last scene of the movie “HORIZON”
- And remember from today: **We are always surrounded by the light from the beginning of the Universe!**
- Finally, all of this research has been made possible by tax payer's money. We are always very, very grateful to your support. **Vielen Dank für Ihre Unterstützung und Ihr Zuhören!**

