

Dark Matter and Dark Energy

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Max Planck Forum, Botschaft von Japan
April 19, 2018

Best Evidence

- The **best evidence** (though not the first evidence) for both dark matter and dark energy came from measurements of the **Cosmic Microwave Background** (*kosmische Mikrowellenhintergrundstrahlung*)

Fireball Universe

Time

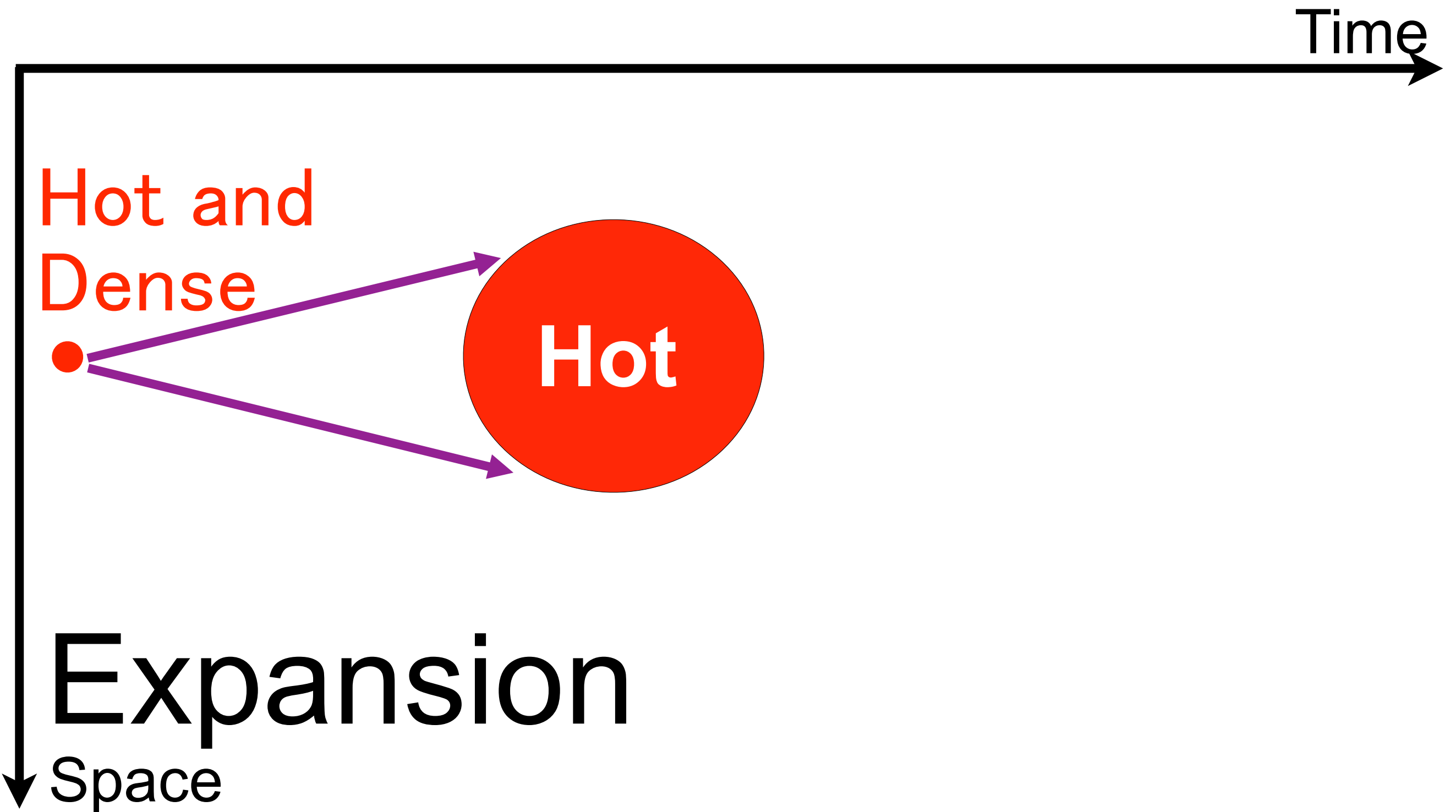


Hot and
Dense

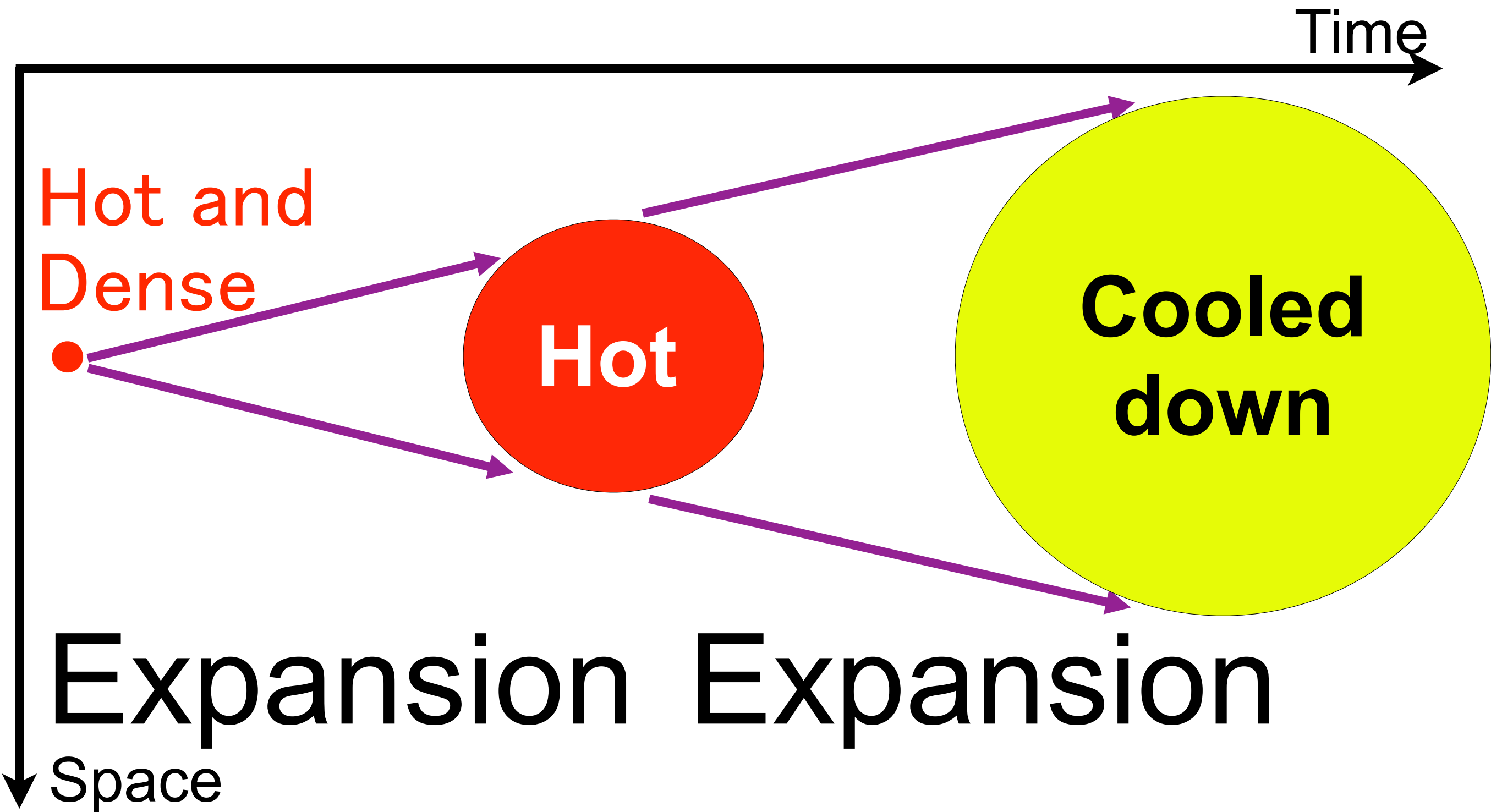


Space

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**
- Due to the expansion of space and cooling down, these photons are cold, and their wavelength is in the radio/microwave region



Full-dome movie by Director Hiromitsu Kohsaka

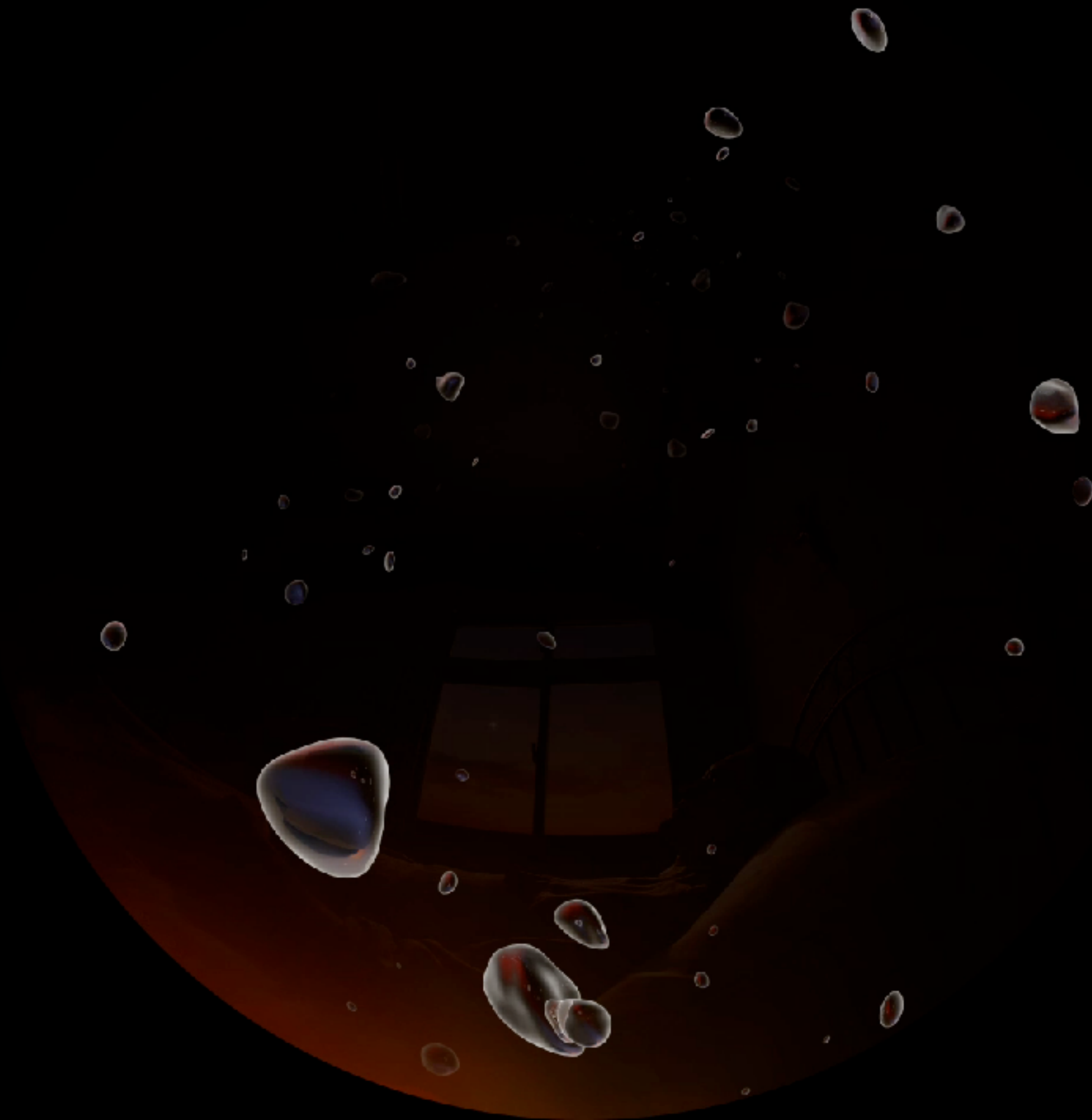
“HORIZON”

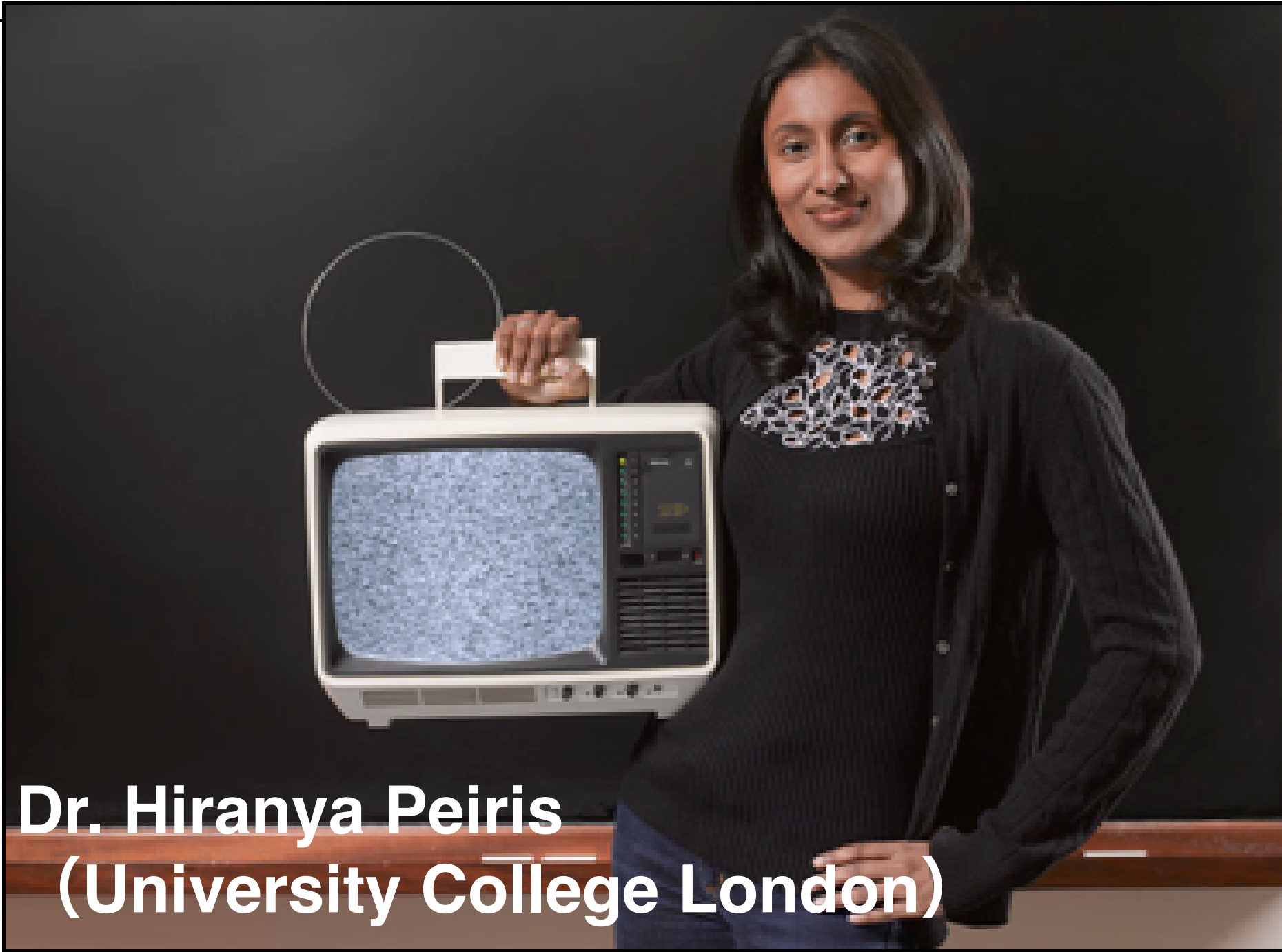
Beyond the Edge of the Visible Universe

Trailer available on YouTube

**Nominated for one of 12 movies,
which will be shown at the upcoming
“FullDome Festival” at Jena, May 23–26, 2018**

<http://fulldome-festival.de>



A woman with long dark hair, wearing a black cardigan over a black top with a colorful patterned collar, stands against a dark background. She is holding a vintage, light-colored television set with a handle. The television screen displays a blue, grainy, noisy pattern. A thin, circular wire is visible behind the television handle.

Dr. Hiranya Peiris
(University College London)

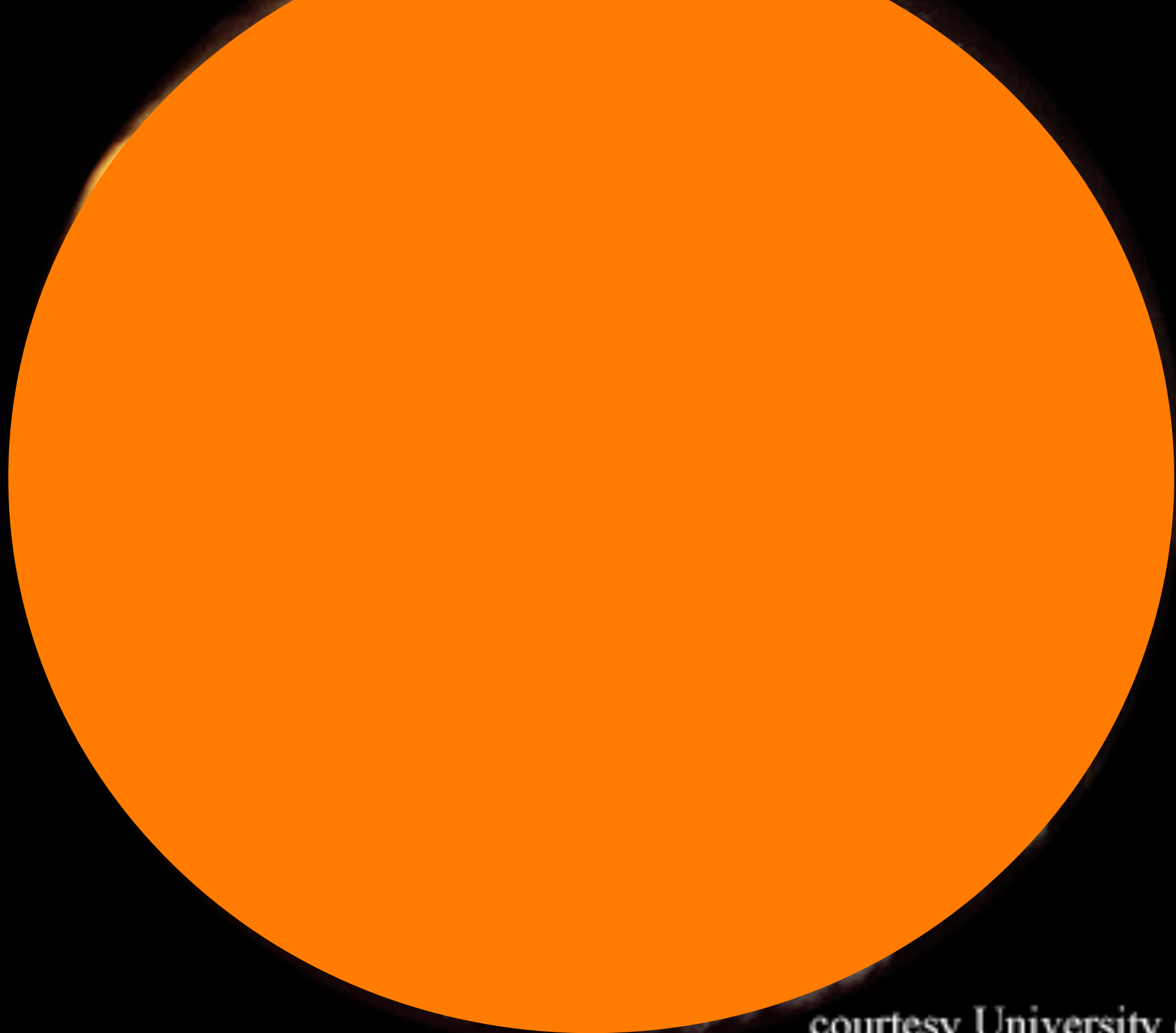
All you need to do is to detect radio waves. For example, 1% of noise on the TV is from the fireball Universe

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



courtesy University of Arizona

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

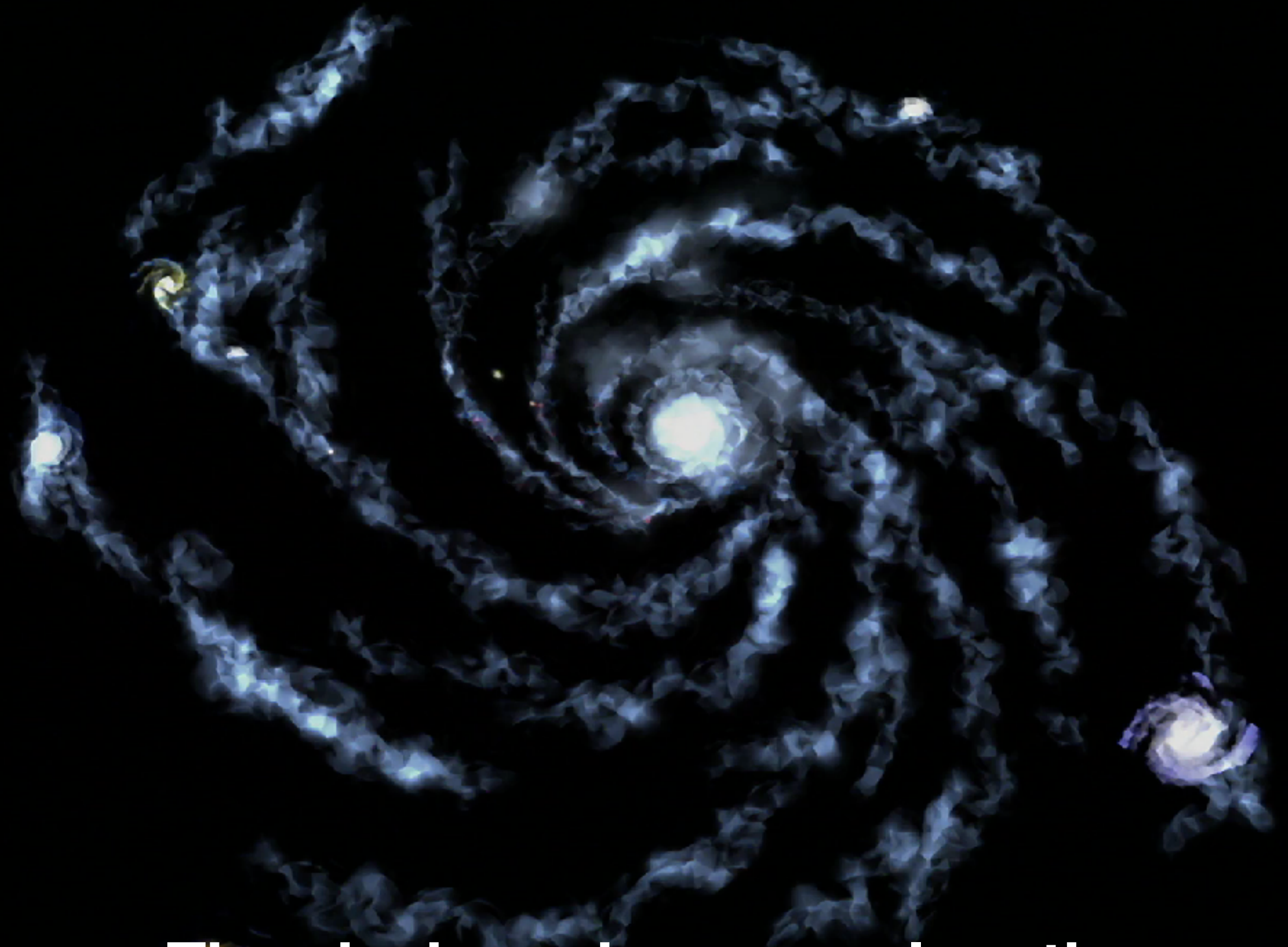


courtesy University of Arizona

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

*Light from the fireball Universe
filling our sky*

**The Cosmic Microwave
Background (CMB)**



The sky in various wavelengths

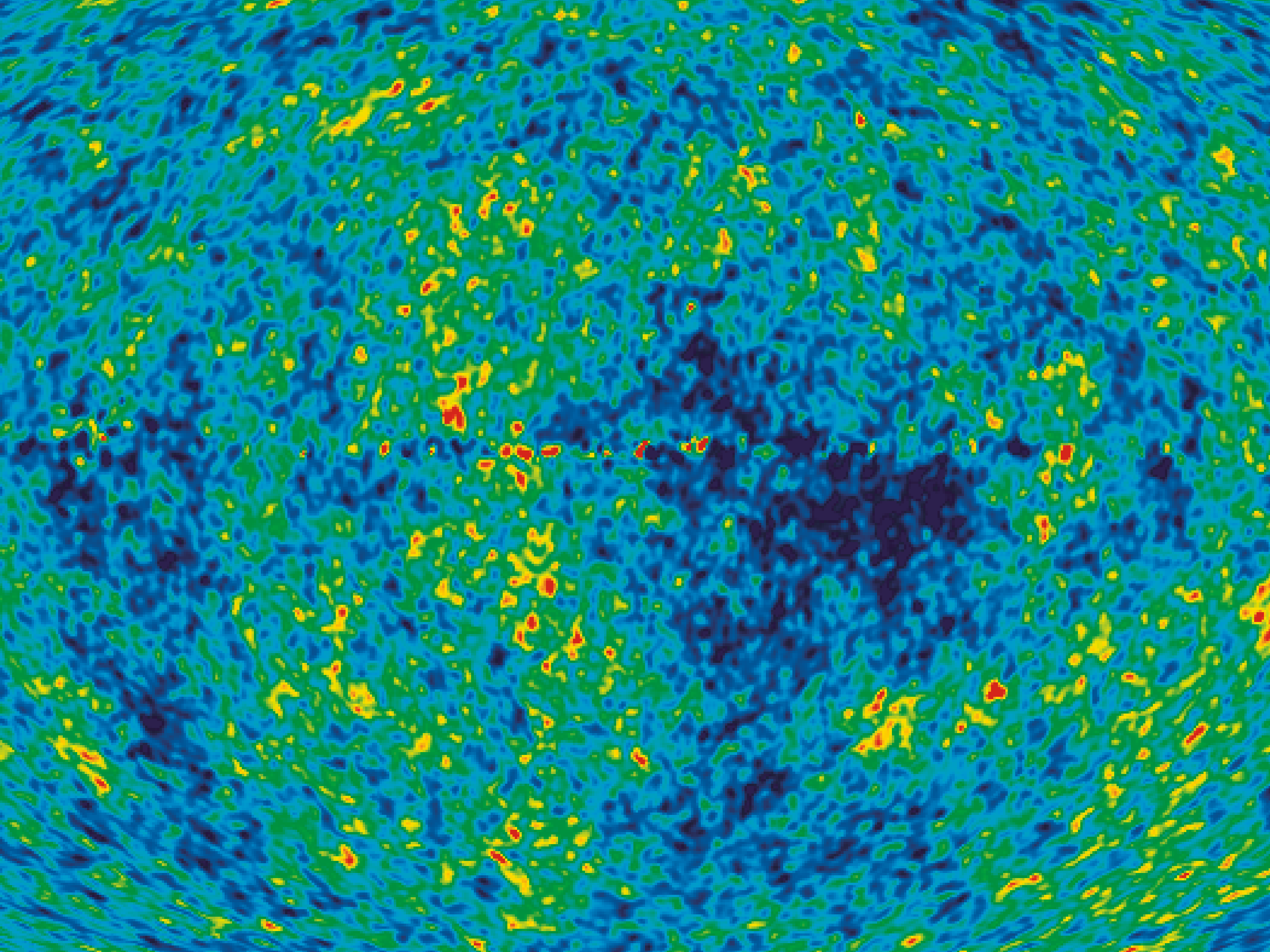
Visible -> Near Infrared -> Far Infrared -> Submillimeter -> Microwave

WMAP Science Team

July 19, 2002

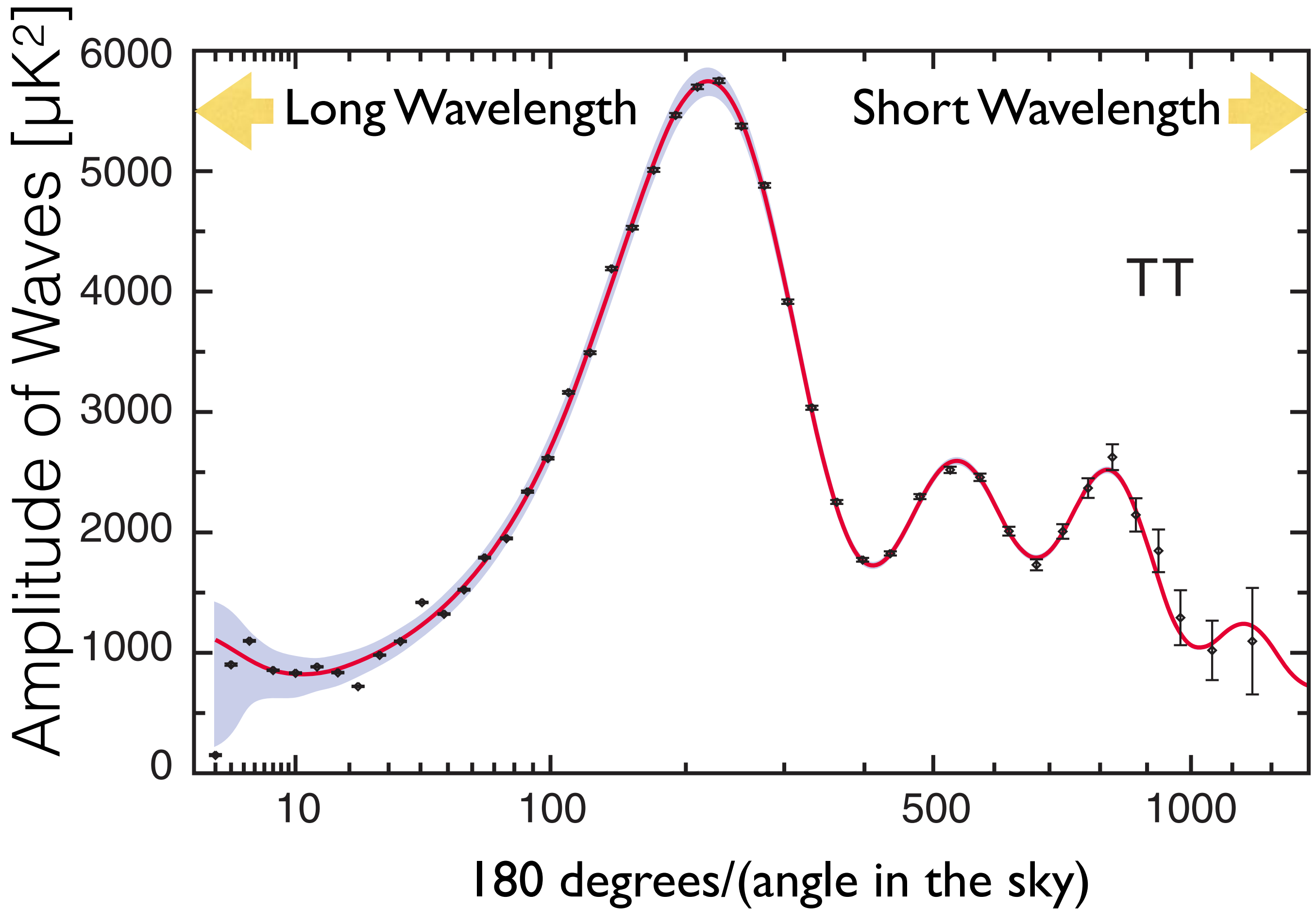


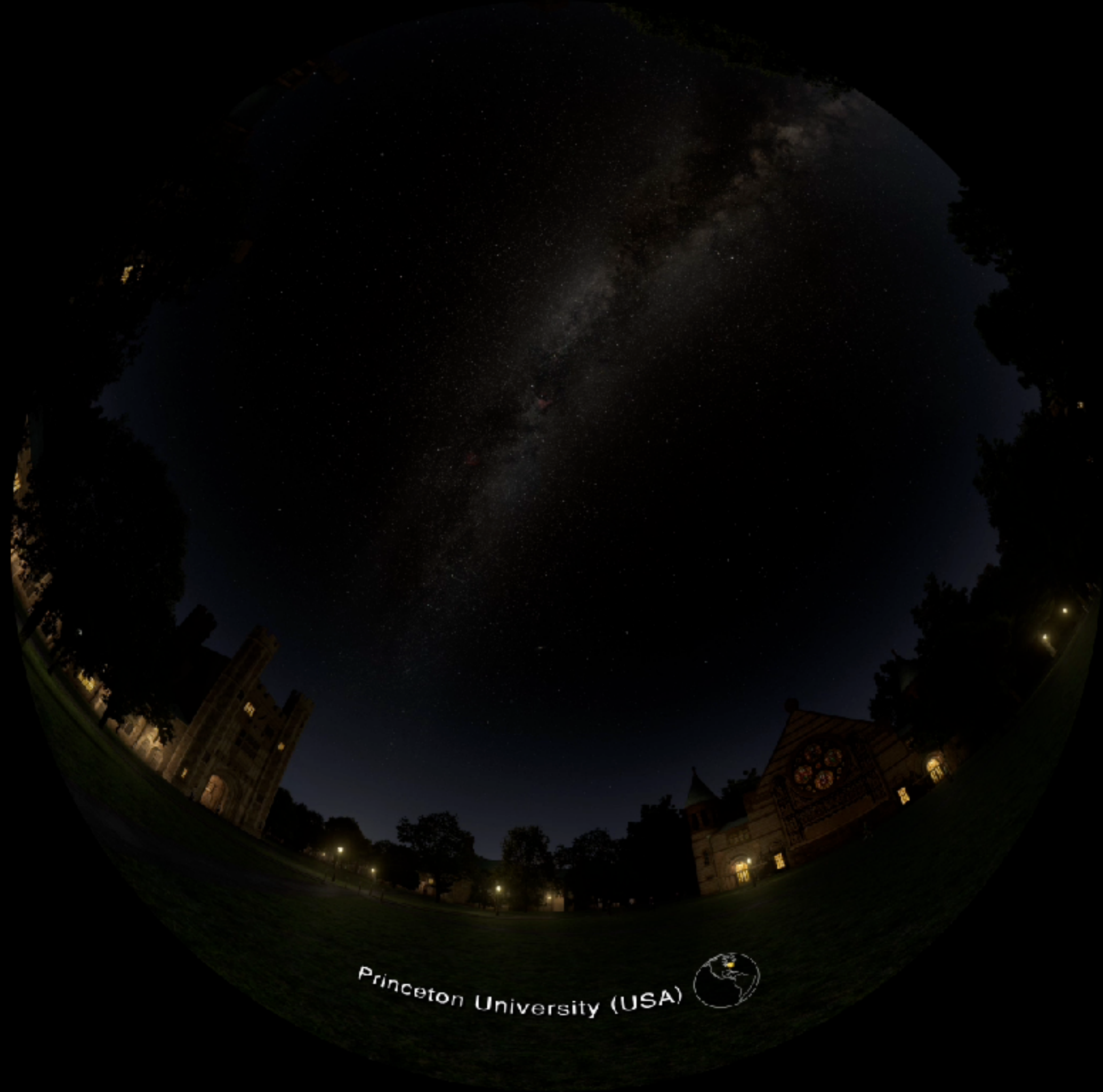
- WMAP was launched on June 30, 2001
- The WMAP mission ended after 9 years of operation



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





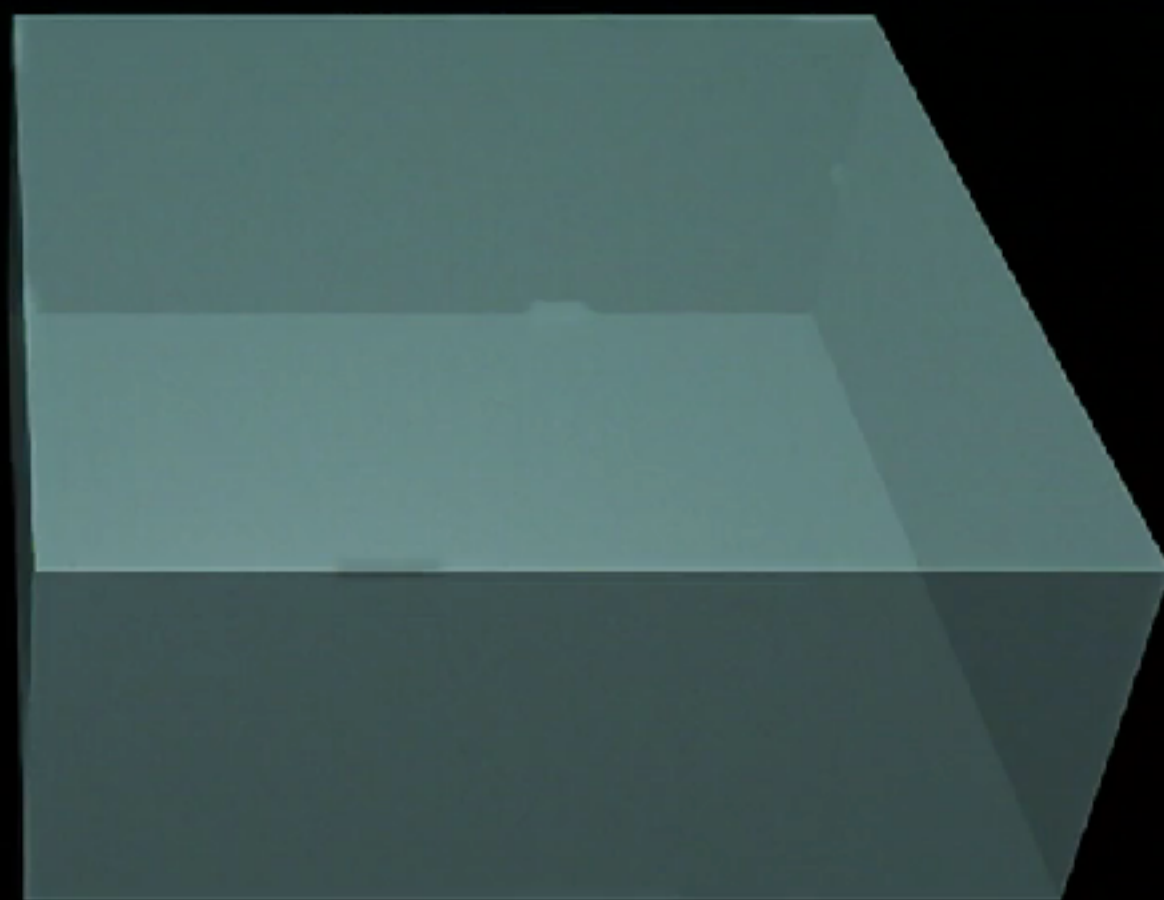
Princeton University (USA)

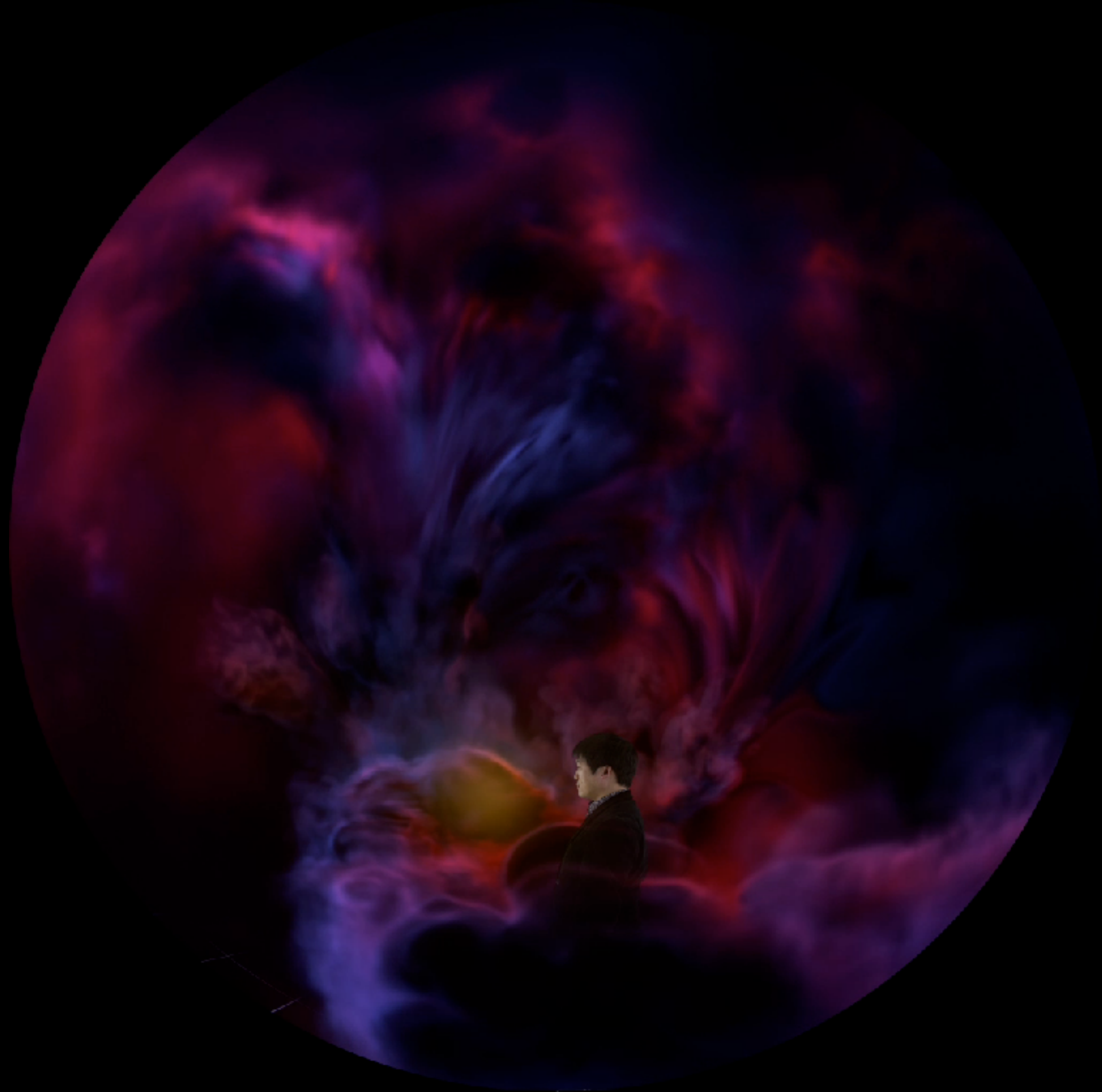




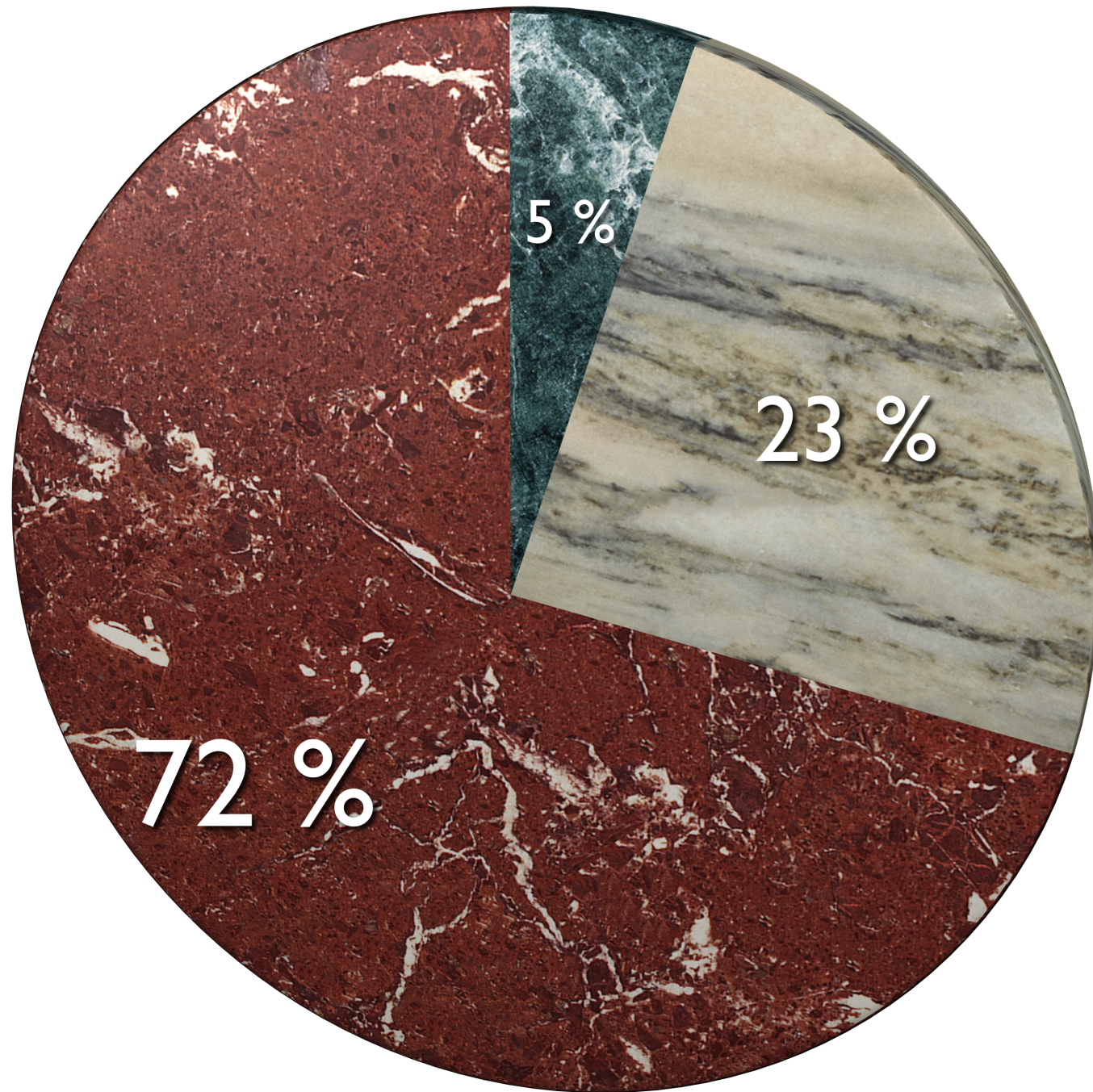
Kosmische Miso Suppe

- 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

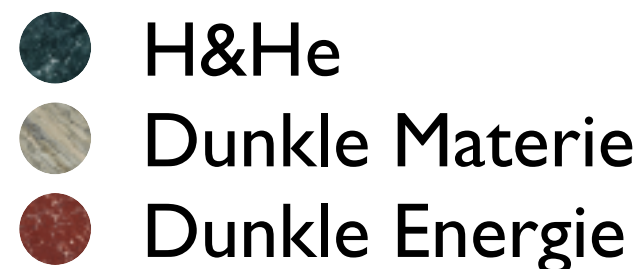




Cosmic Pie Chart



- 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...**



Matter and Expansion

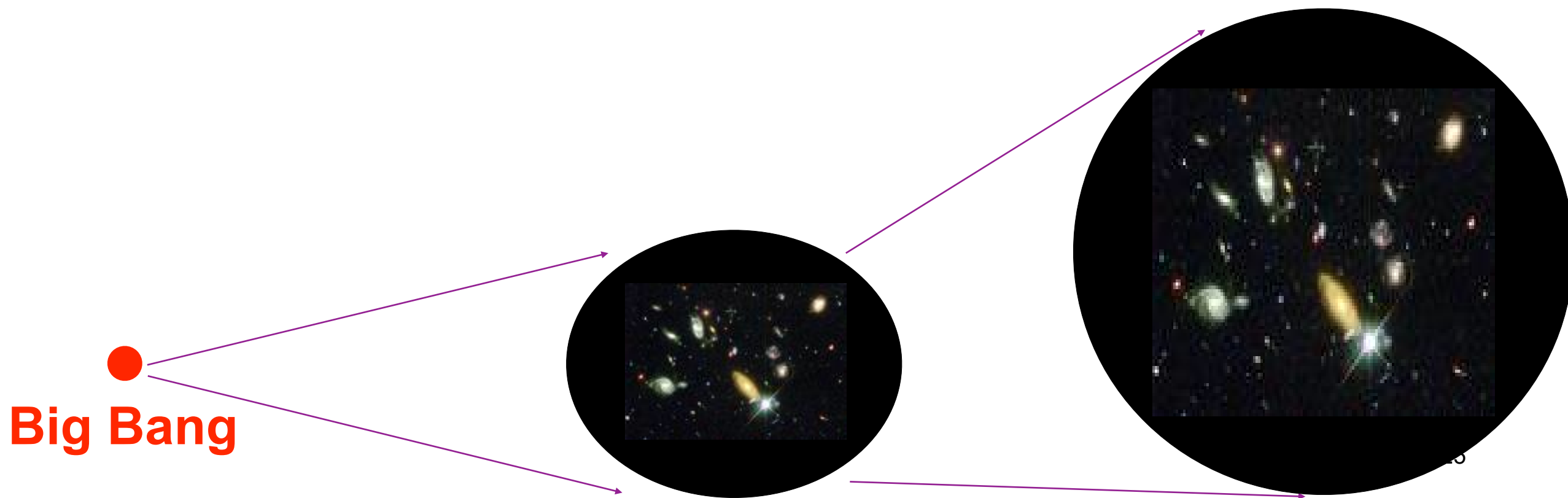
- How would space expand in an empty Universe?
 - A: Continue to expand with a constant velocity (i.e., no acceleration or deceleration)
- How would space expand in a matter-dominated Universe?
 - A: Gravity pulls space and expansion decelerates
- Too much matter means a re-collapse of the Universe!



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



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