The Early Universe and the Cosmic Microwave Background

The Big Bang Confirmed

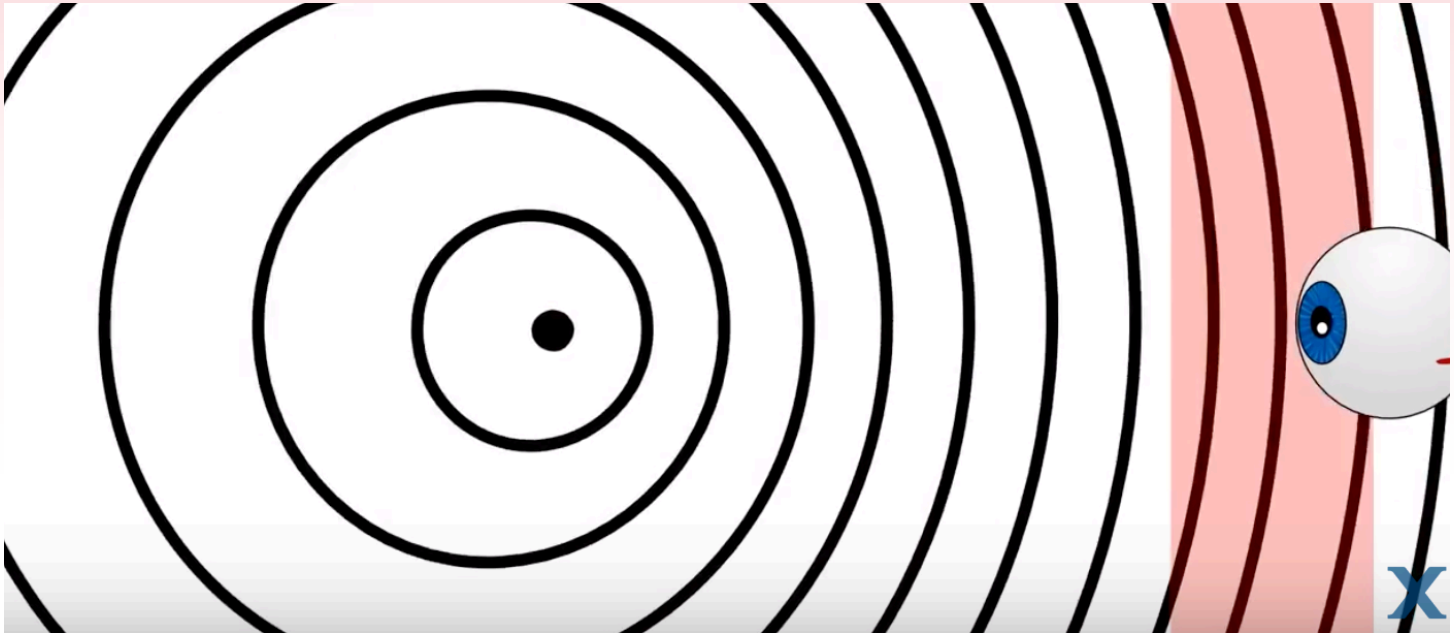
Physics 090

2020-05-11

SAINT MARY'S COLLEGE of CALIFORNIA

Nice Doppler Effect Animation

https://youtu.be/h4OnBYrbCjY



How fast source is moving away

Sound

$$\lambda_{observed} = \lambda_{source}\left(1 + \frac{v}{v_{sound}}\right)$$

Light

Extra factor comes from relativity

$$\lambda_{observed} = \lambda_{source}\left(1 + \frac{v}{c}\right) \cdot \frac{1}{\sqrt{1 - v^2/c^2}}$$

$$= \lambda_{source}\left(1 + \frac{v}{c}\right) \cdot \frac{1}{\sqrt{1+v/c}\sqrt{1-v/c}}$$

$$= \lambda_{source} \frac{\sqrt{1+v/c}}{\sqrt{1-v/c}}$$

Extreme red shift

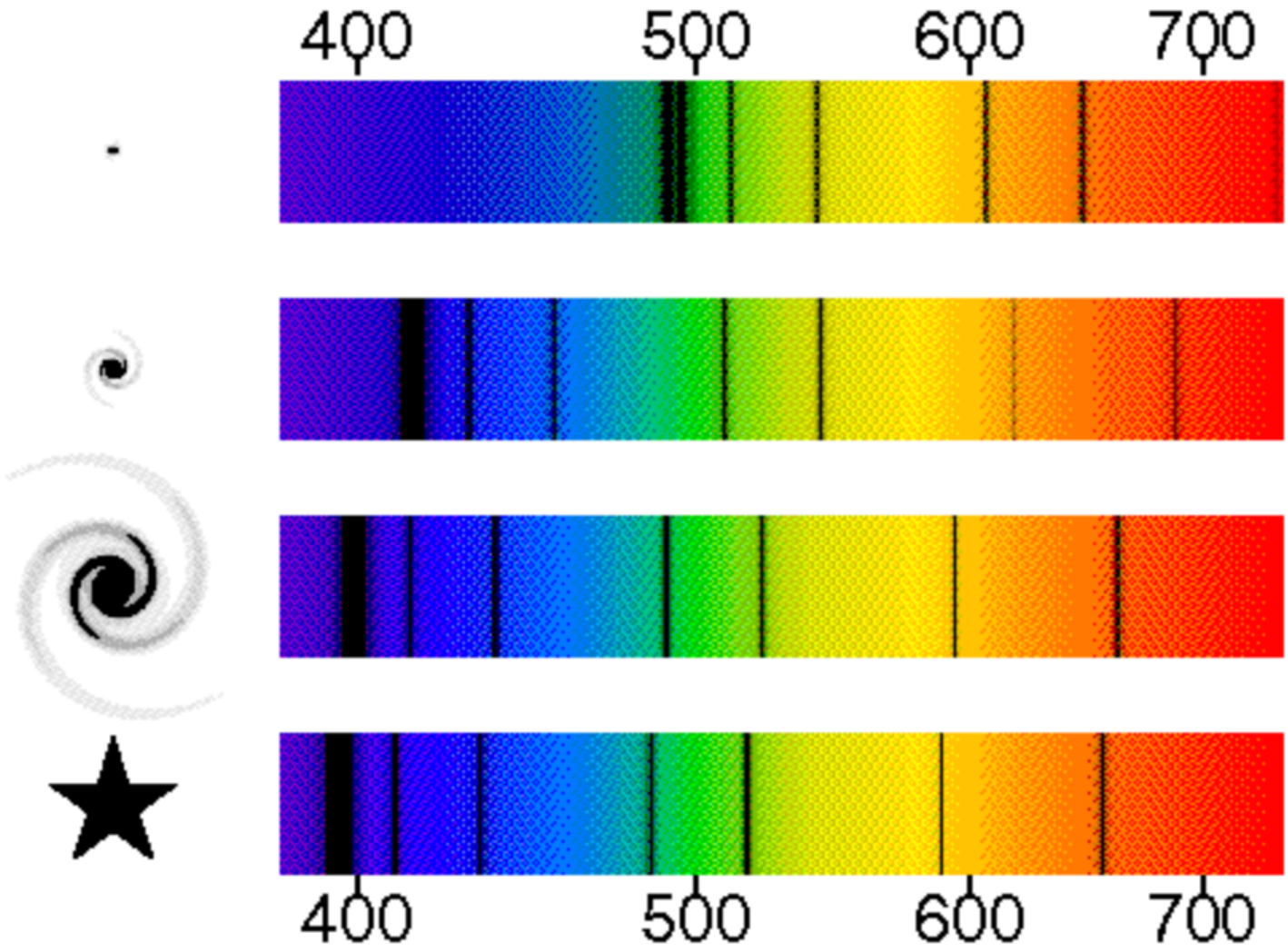
v almost c

$$\frac{\lambda_{observed} - \lambda_{source}}{\lambda_{source}} = \frac{\lambda_{source}\sqrt{1+v/c}/\sqrt{1-v/c} - \lambda_{source}}{\lambda_{source}}$$

$$= \frac{\sqrt{1+v/c}}{\sqrt{1-v/c}} - 1 \equiv z$$

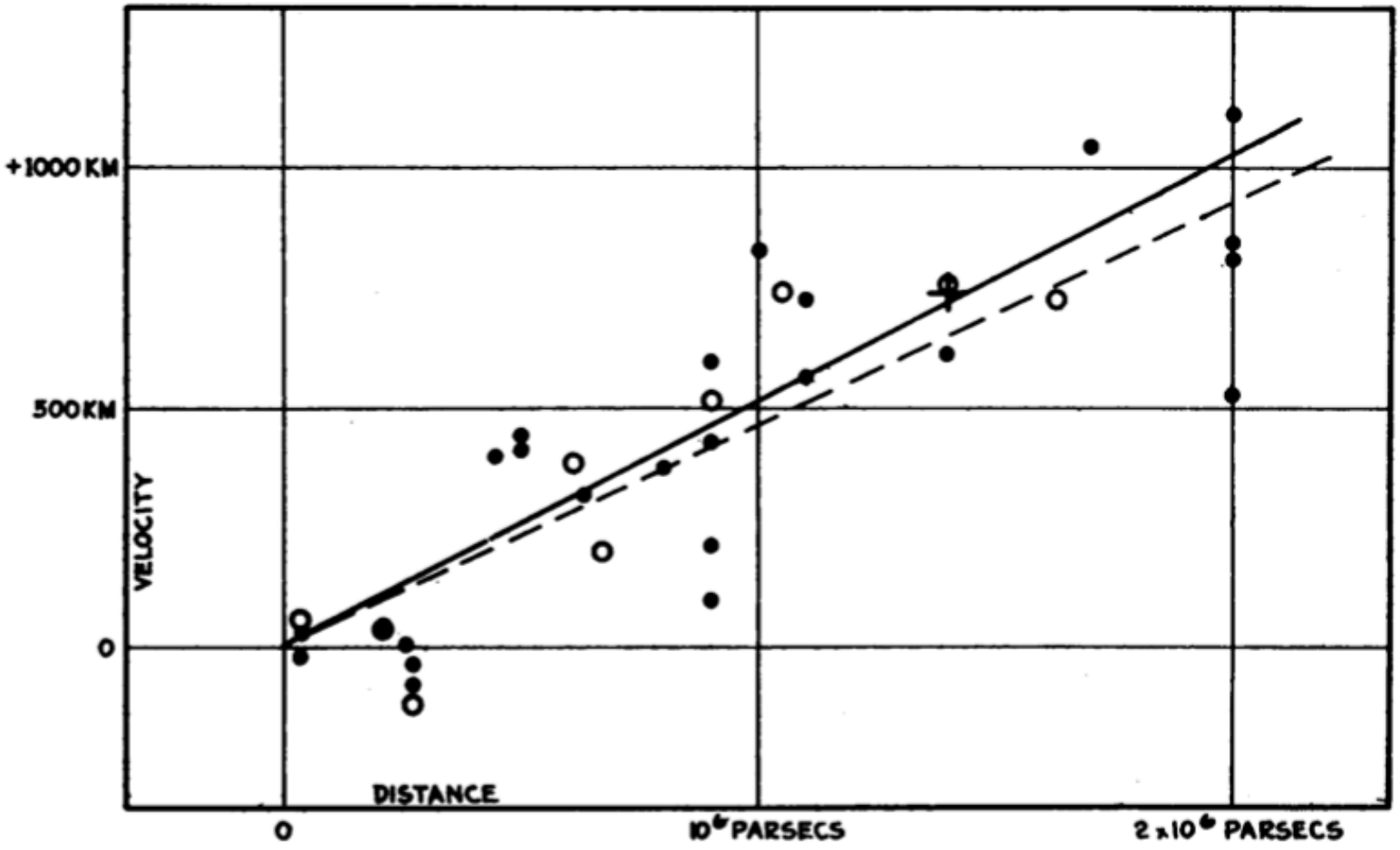
Astronomers use z instead of v

High $z \iff$ v almost c


400
500
600
700
400
500
600
700

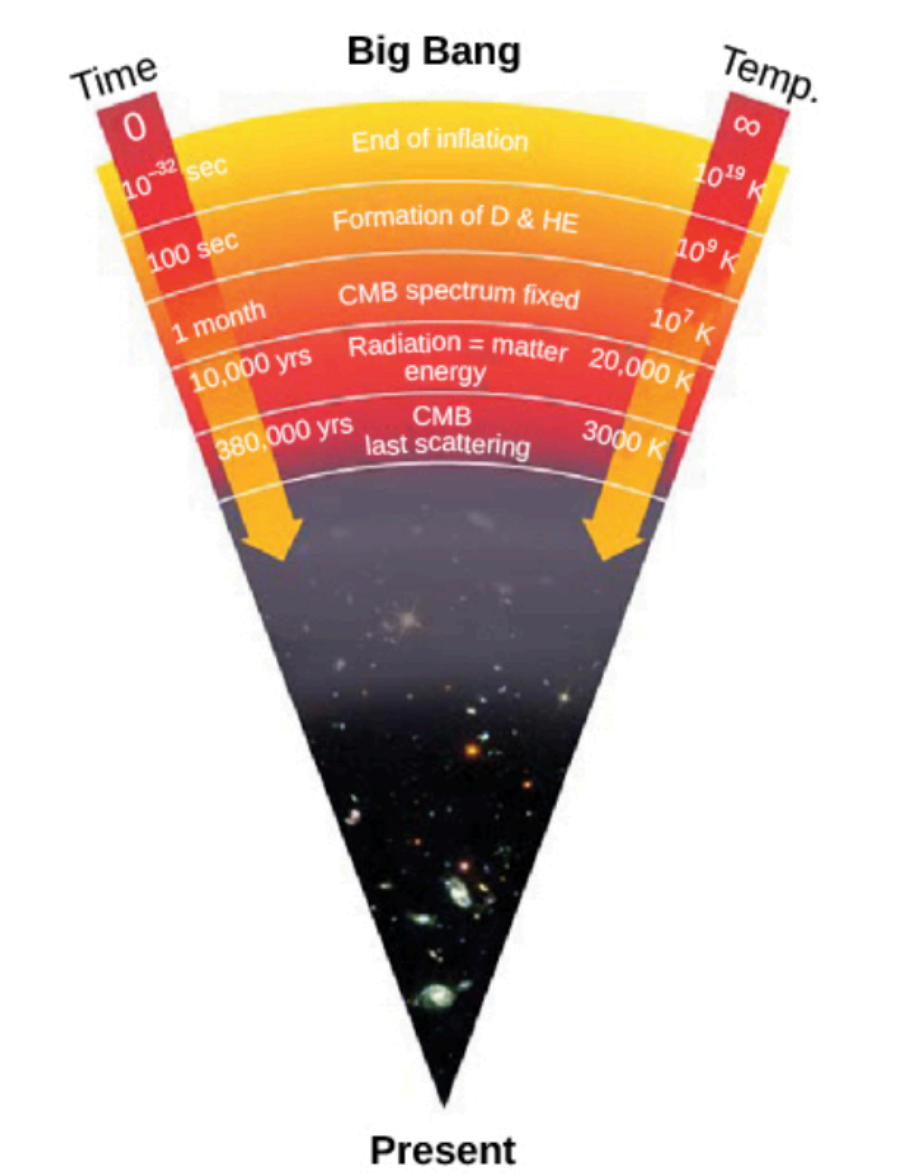
Doppler Shift is how Hubble Knew how Fast the Spiral Nebula were Moving Away

Cepheid Brightness is How he Knew How Far Away they Were



Hubble, 1929

New Theoretical Prediction, 1948 Alpher, Bethe, Herman, Gamow



Early Universe Growth and Cooling

- Protons and Neutrons Form
- Protons and Neutrons Collide and Form Deuteriusm, Helium and Lithium Nuclei
- Continued Growth and Cooling
- Electrons Slow Down Enough to Begin Orbiting Nuclei
- Particles in Universe are Now Electrically Neutral!
- Photons are Free to Move without Scattering!
- These Photons Are at the Temperature (3000K) that Hydrogen Ionizes at

Cosmic Microwave Background (CMB)

On May 20, 1964, American radio astronomers Robert Wilson and Arno Penzias discovered the cosmic microwave background radiation (CMB), the ancient light that began saturating the universe 380,000 years after its creation. And they did so pretty much by accident.

Bell Labs' Holmdale Horn Antenna in New Jersey picked up an odd buzzing sound that came from all parts of the sky at all times. The noise puzzled Wilson and Penzias, who did their best to eliminate all possible sources of interference, even removing some pigeons that were nesting in the antenna. [CMB: Big Bang Relic Explained (Infographic)]

"When we first heard that inexplicable 'hum,' we didn't understand its significance, and we never dreamed it would be connected to the origins of the universe," Penzias said in a statement. "It wasn't until we exhausted every possible explanation for the sound's origin that we realized we had stumbled upon something big."

1964, Wilson and Penzias Set Up a Microwave Antenna

Photo in 1978, In Front of the "Horn" that catches the Microwaves

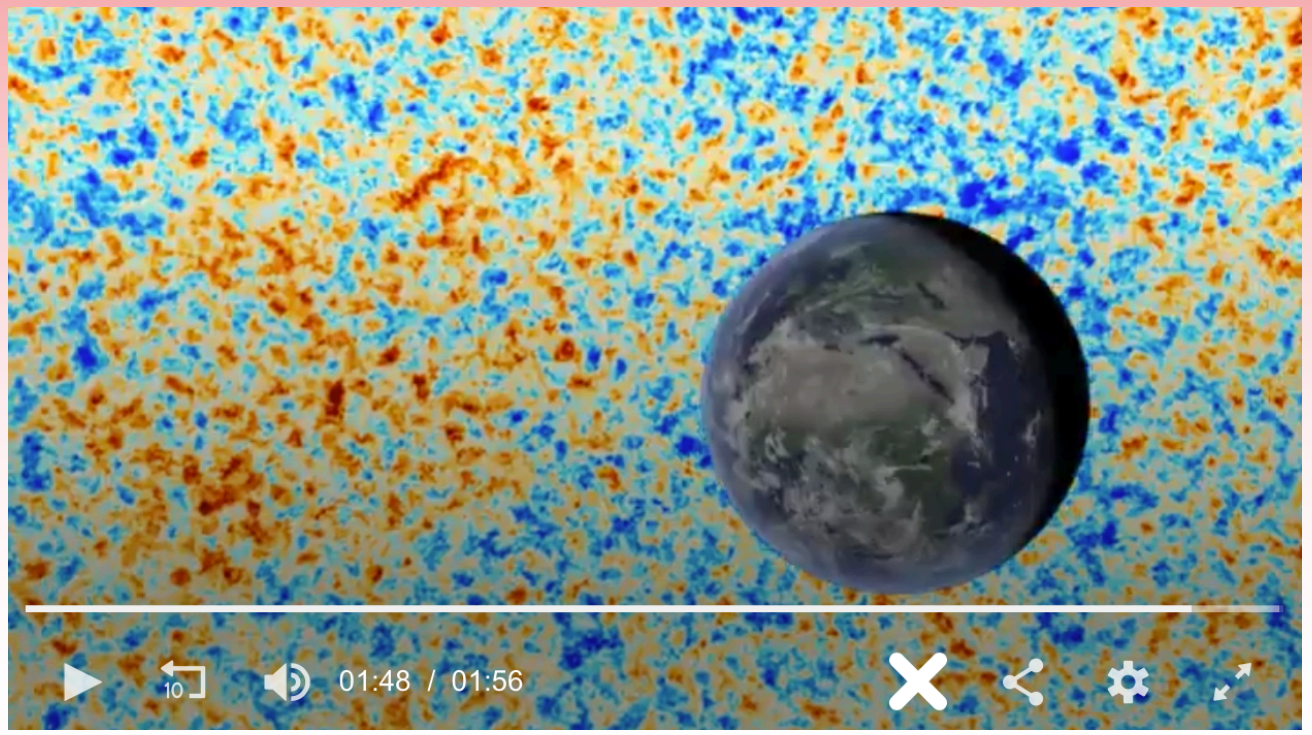
Prediction vs. Observation. How to Reconcile?

- Prediction
  - Alpher, Bethe, Herman, Gamow, 1948
  - 3000K Radiation, 0.001mm, near infrared
- Observation
  - Penzias, Wilson, 1964
  - 3K Radiation, 1mm, microwaves

Reconciliation

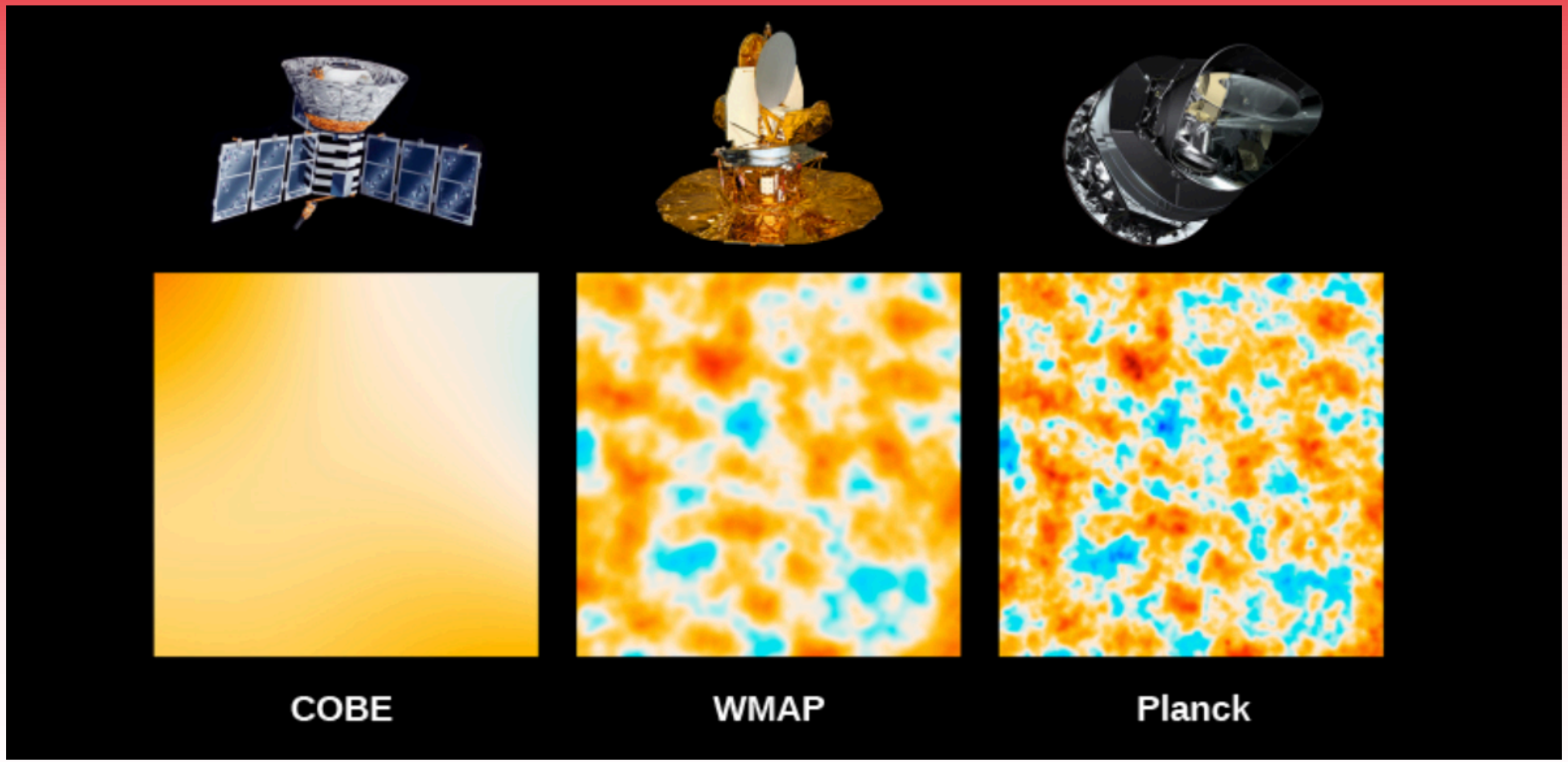
The earliest light we can see, from 380,000 years after the Big Bang (over 13,000,000,000 years ago) comes from so far away that it is red-shifted with z of about 1000! This is the definitive confirmation of the Big Bang.

First Satellite Launched to Improve CMB Measurements: COBE

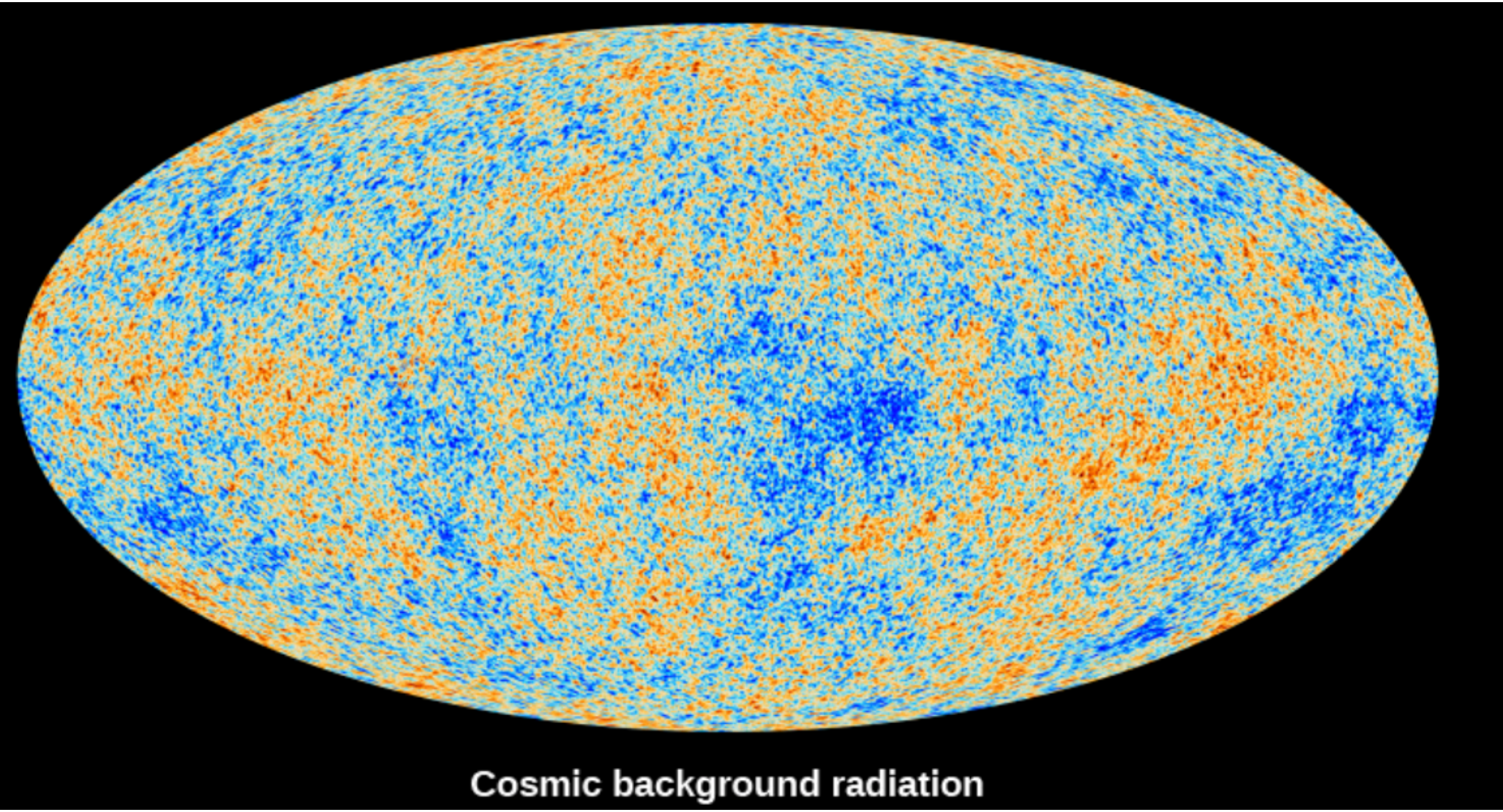


Understanding the COBE Measurements

https://youtu.be/6e-uxx155EY



Better Measurements: After 1989 COBE Satellite, comes 2001 WMAP Satellite, and 2009 Planck Satellite. Each shows more detail in the earliest light remaining from the Big Bang



European Space Agency, Planck Collaboration