

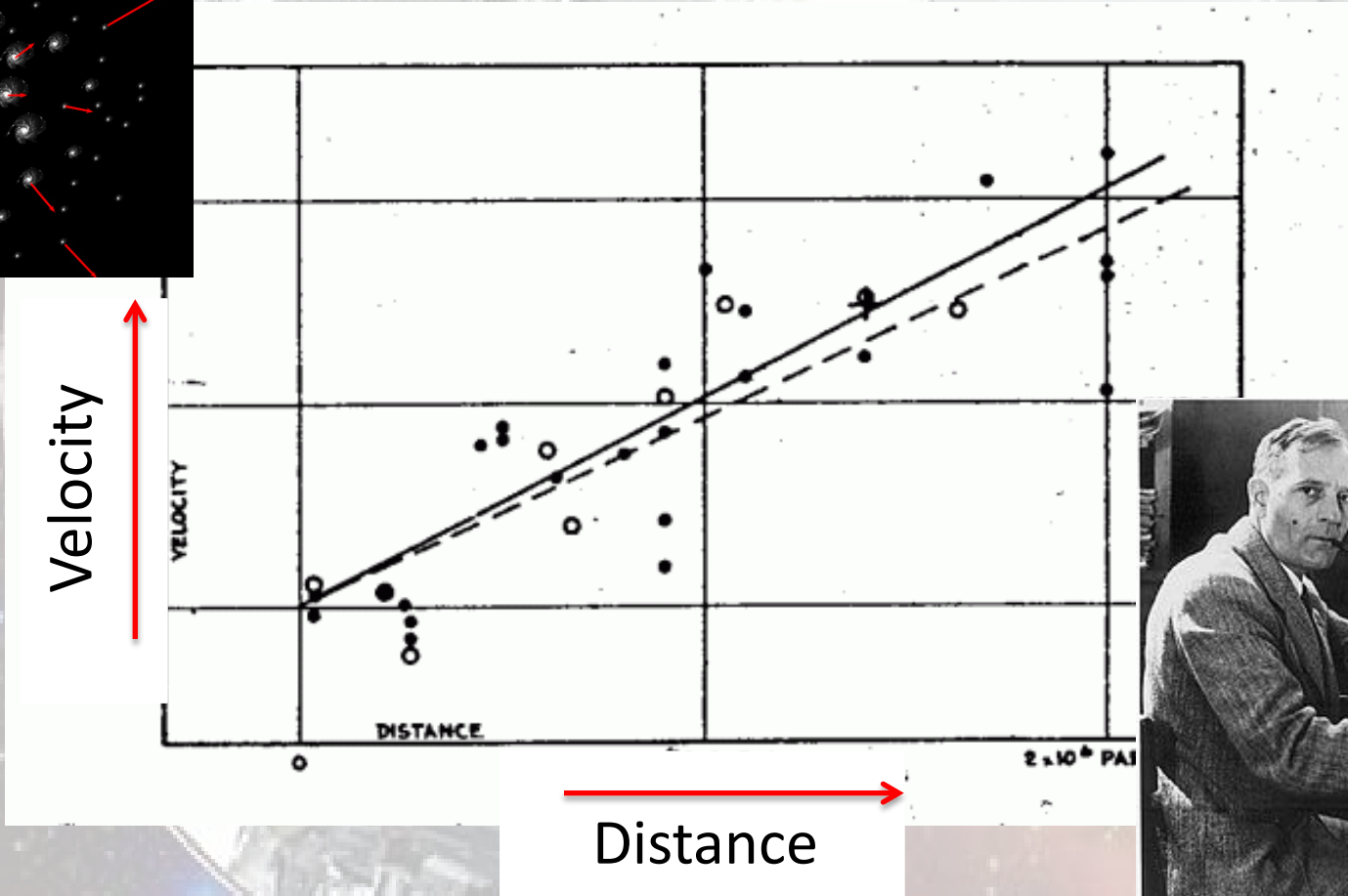
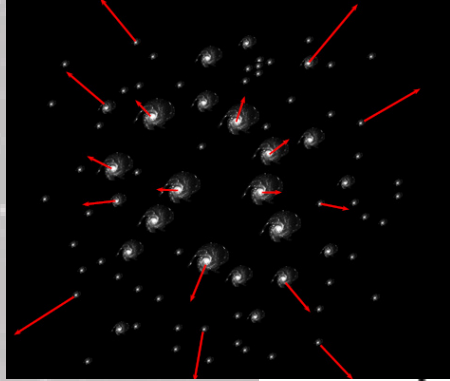


Monster Footprints in the Invisible Universe

James Allison

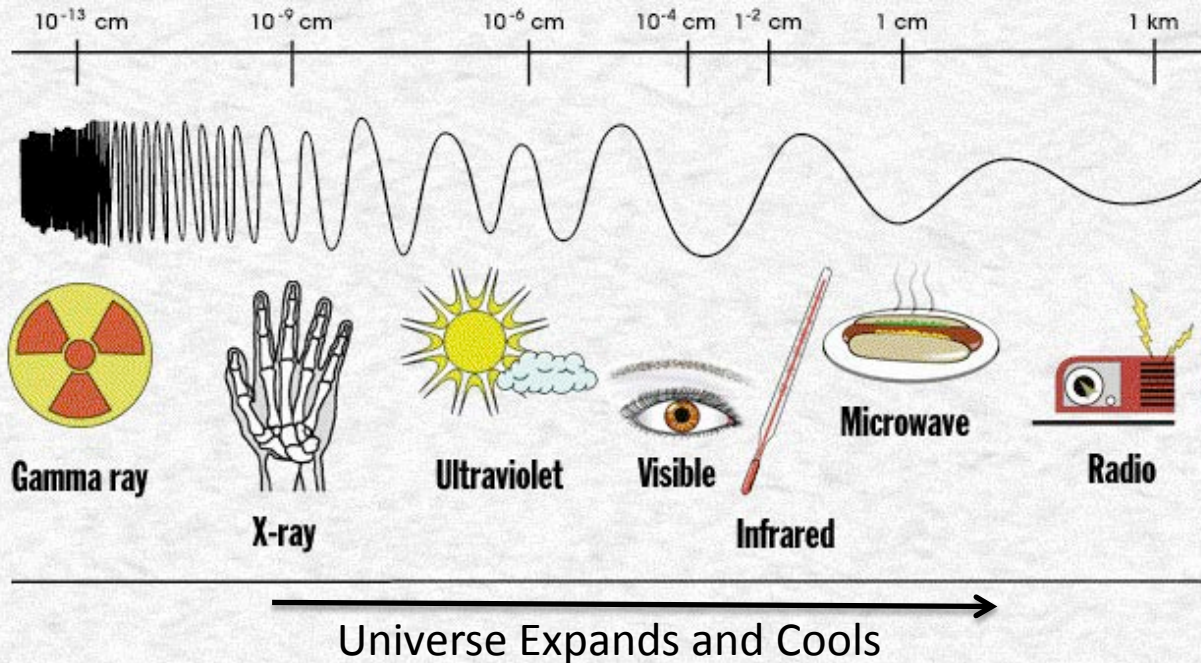
University of Sydney

The Expanding Universe (1930s)



The Big Bang Prediction 1930s-1960s

The Electromagnetic Spectrum



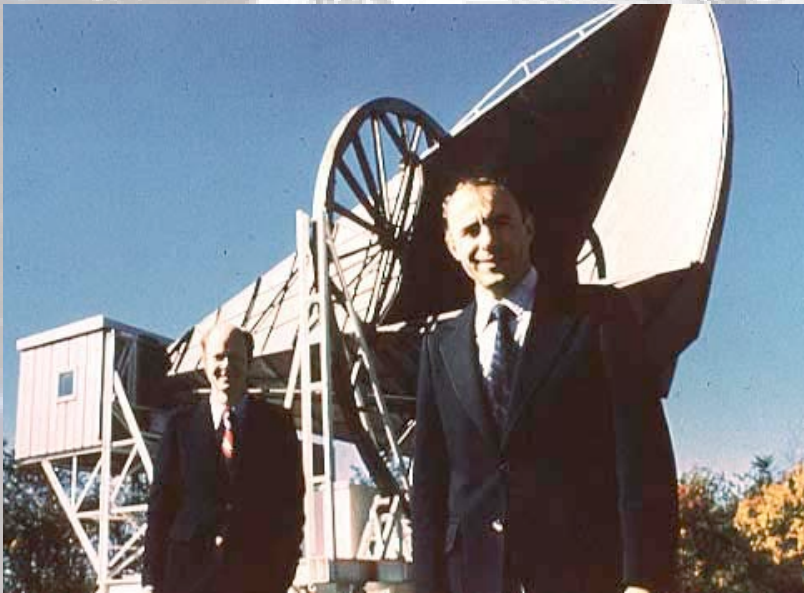
Big Bang



Radio Telescope

Discovery of the Cosmic Microwave Background in 1965

Arno Penzias and
Robert Woodrow Wilson



Holmdel Horn Antenna

-270°C / 3 Kelvin

“A Measurement of Excess
Antenna Temperature at
4080 Mc/s”

What was this -270°C
microwave radiation?

Discovery of the Cosmic Microwave Background in 1965

Radio signal from New York City?



Discovery of the Cosmic Microwave Background in 1965

Pigeon droppings in the antenna?



Discovery of the Cosmic Microwave Background in 1965

Answer: It was coming from the Sky!



Credit :Jean-Charles Cuillandre (CFHT)

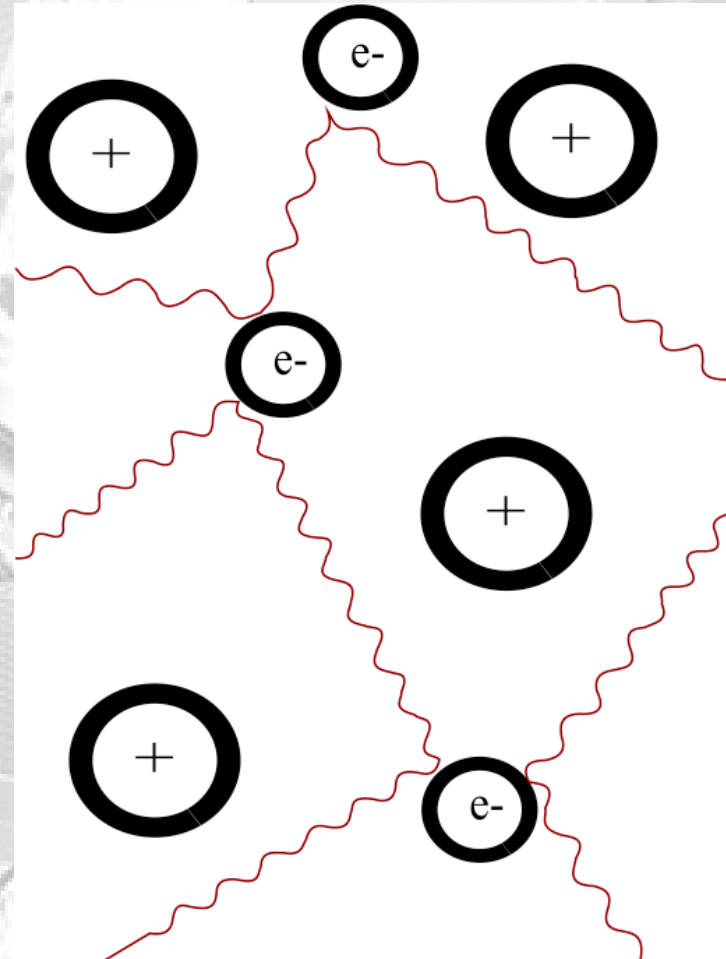
Discovery of the Cosmic Microwave Background in 1965



NOBEL PRIZE!

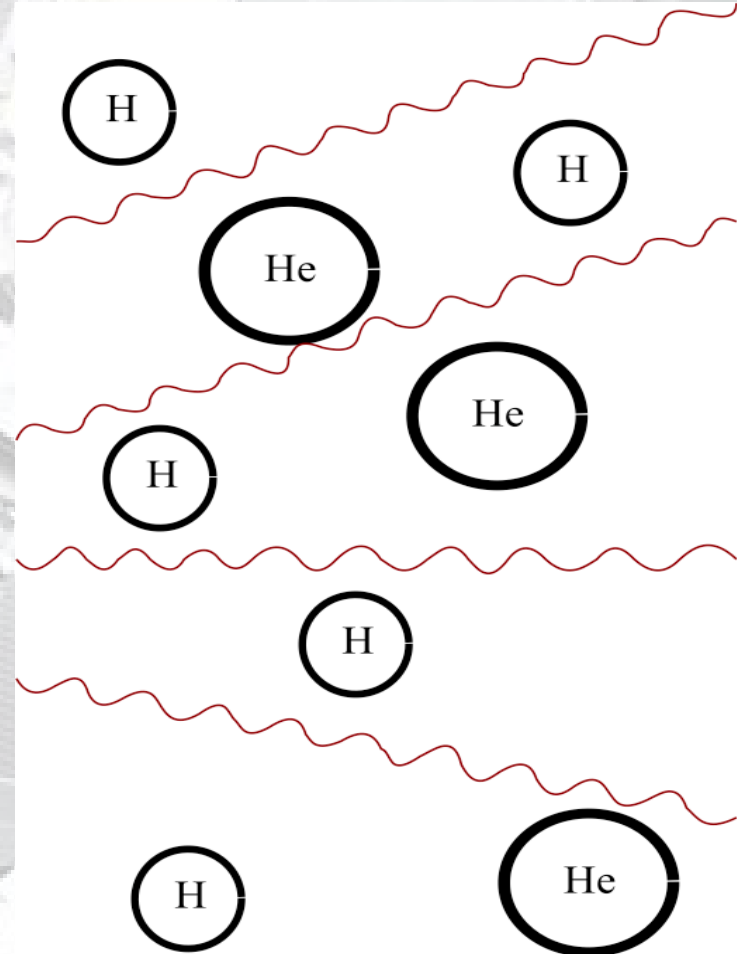
What is the CMB?

Hot Early Universe – Radiation & charged matter joined in a “soup”

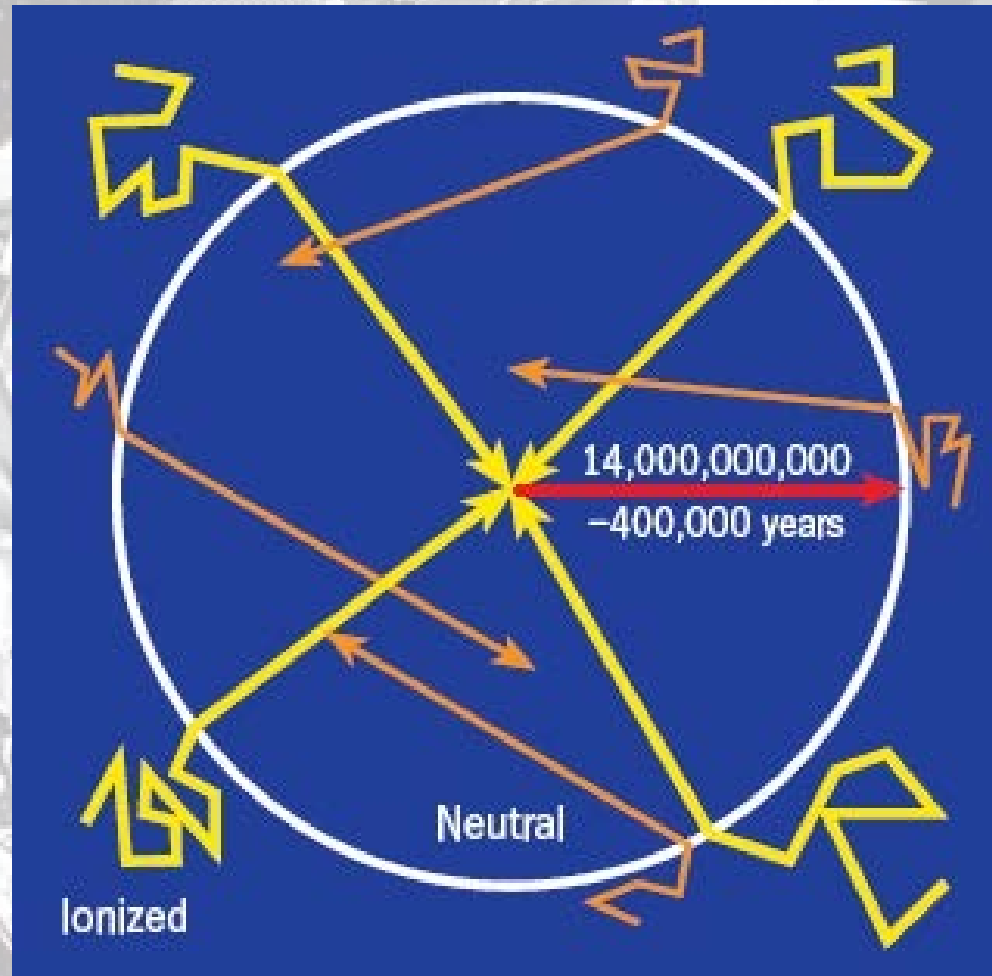


What is the CMB?

Universe cools – neutral Atoms form, the radiation and matter separate



What is the CMB?



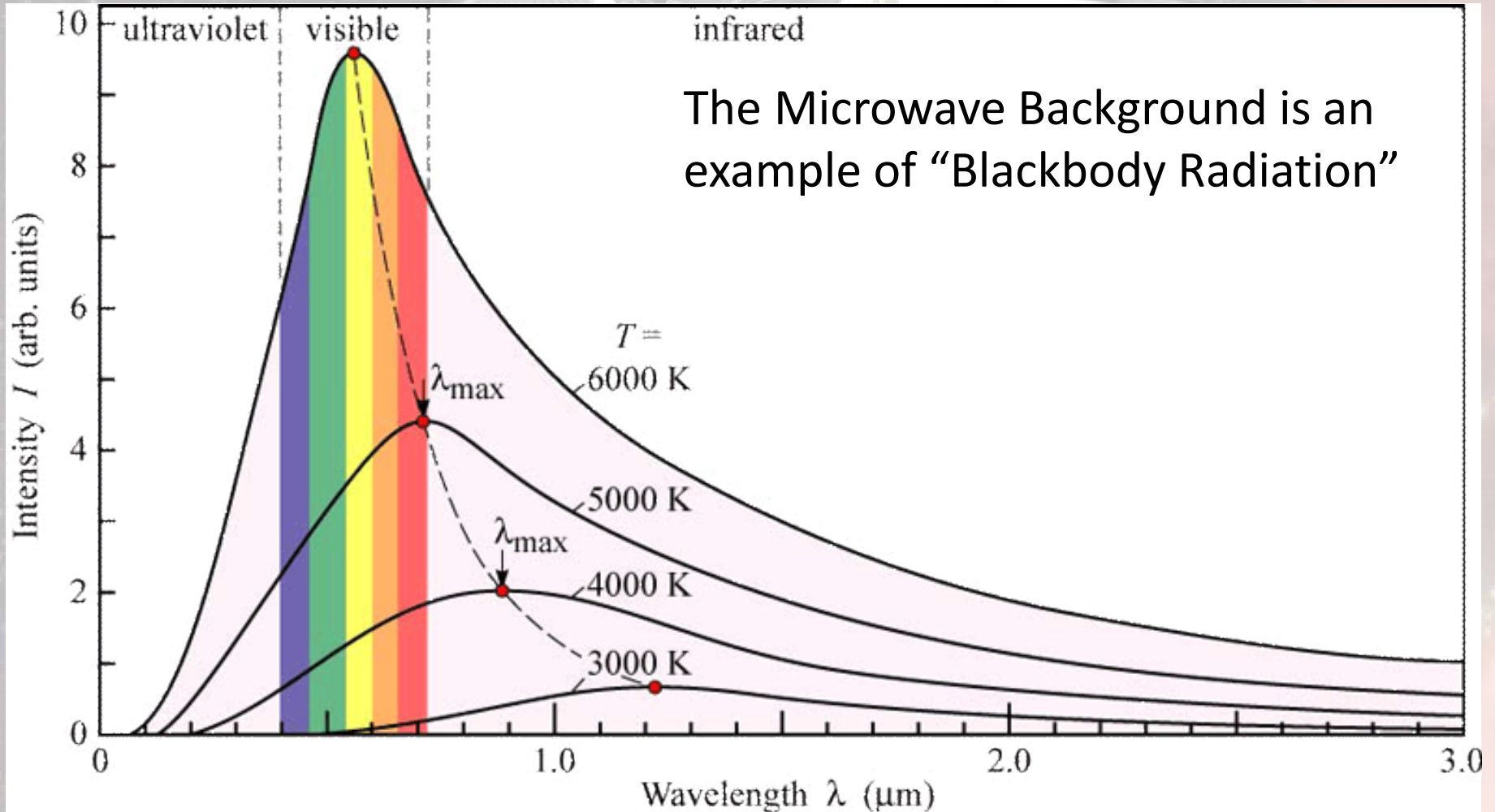
We see an all-sky image of the early hot Universe

What is the CMB?



A small percentage ($\sim 1\%$) of the noise picked up by radios and TVs is CMB radiation

What is the CMB?



Problem: Why was the measured CMB so smooth?

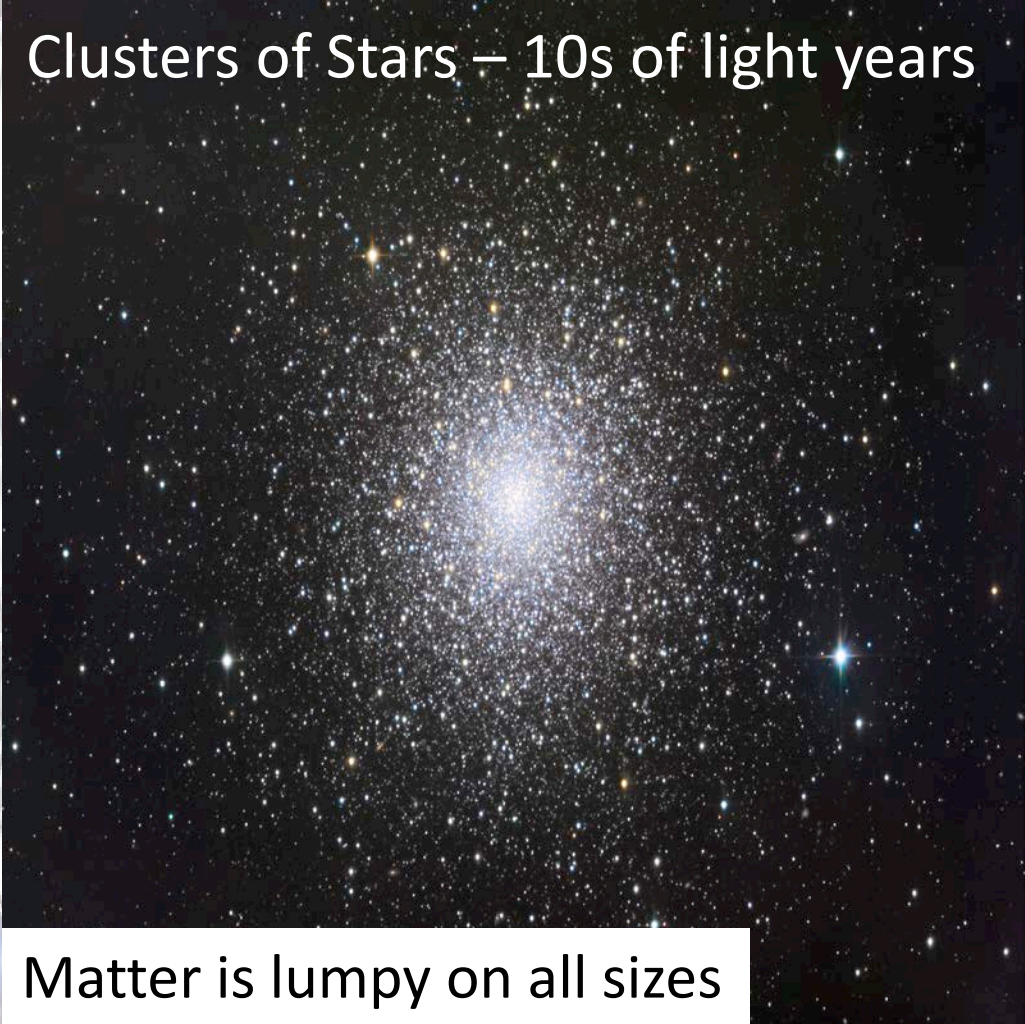
Stars – a few light years

A detailed view of a star cluster or galaxy core, showing a dense field of stars of various colors (blue, white, yellow, orange) and sizes. The stars are distributed in a clumpy, irregular pattern, illustrating the lumpy nature of matter on small scales.

Matter is lumpy on all sizes

Problem: Why was the measured CMB so smooth?

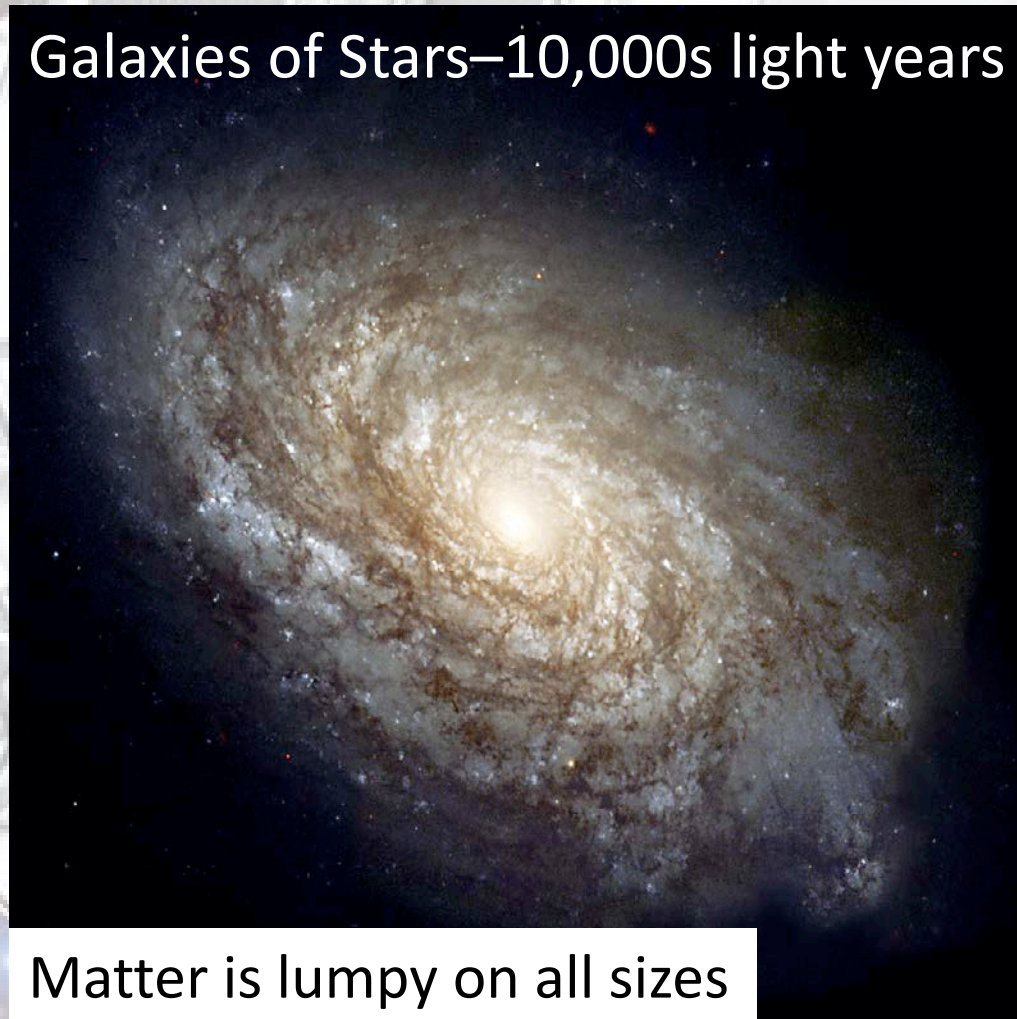
Clusters of Stars – 10s of light years

A large, dense cluster of stars, likely a star cluster or galaxy core, showing significant lumpiness in the distribution of matter. The stars are concentrated in a central region, with a bright core and a diffuse outer envelope. The background is dark, making the individual stars stand out.

Matter is lumpy on all sizes

Problem: Why was the measured CMB so smooth?

Galaxies of Stars—10,000s light years



Matter is lumpy on all sizes

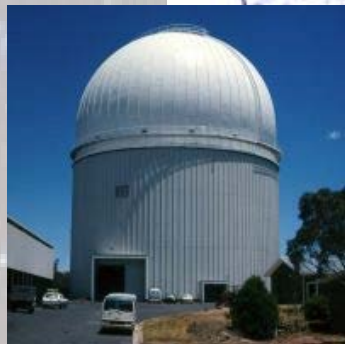
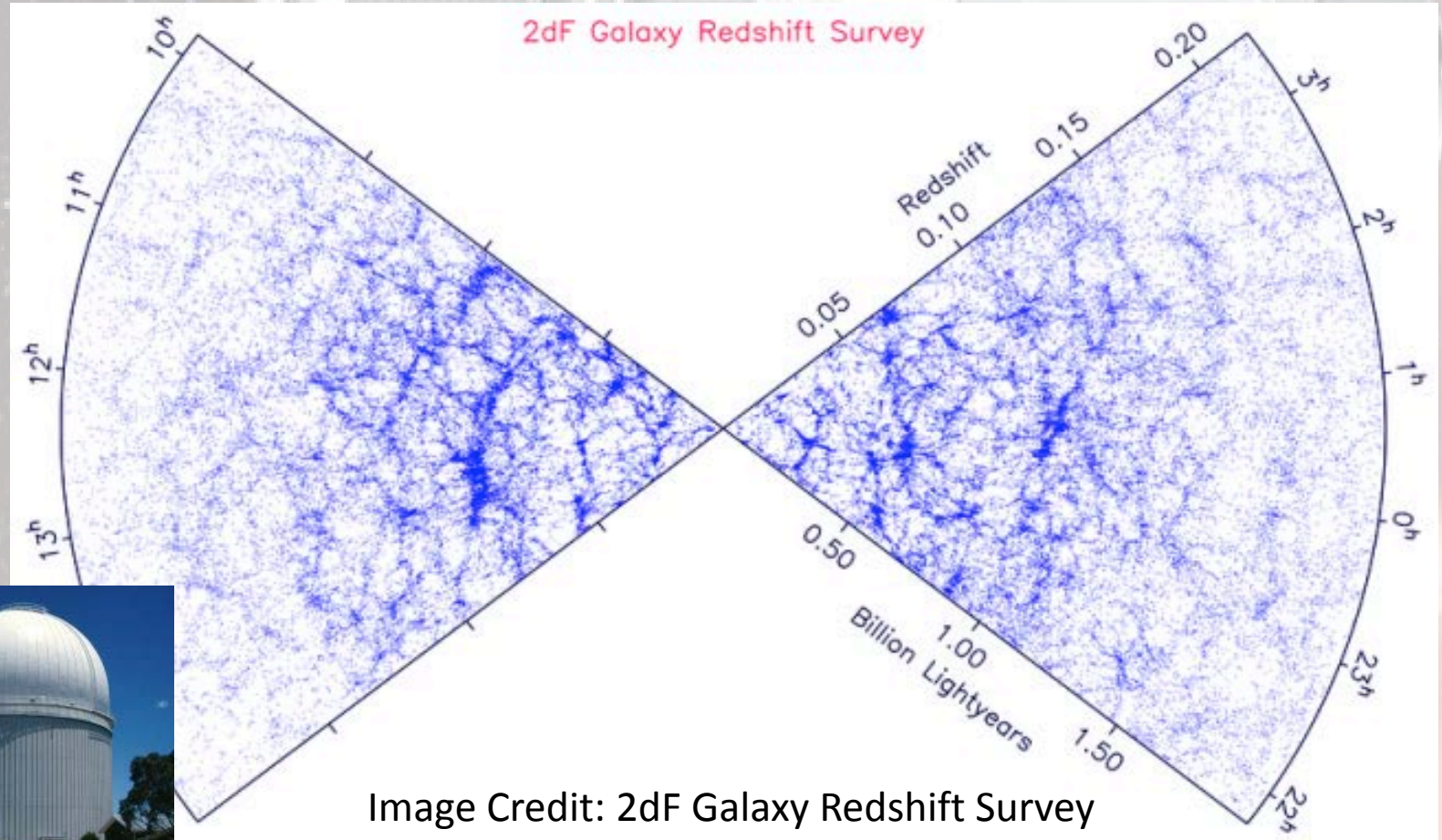
Problem: Why was the measured CMB so smooth?

Galaxy Clusters—Millions light years



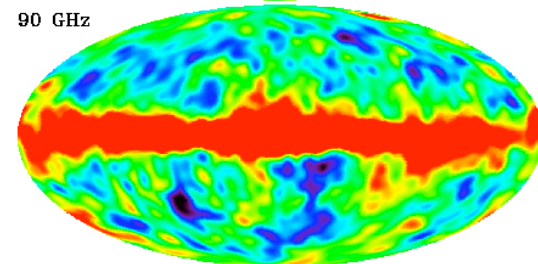
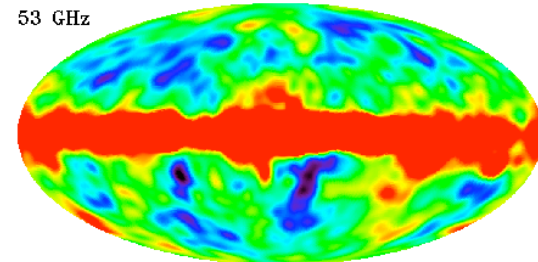
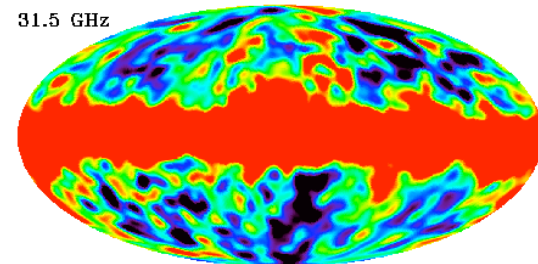
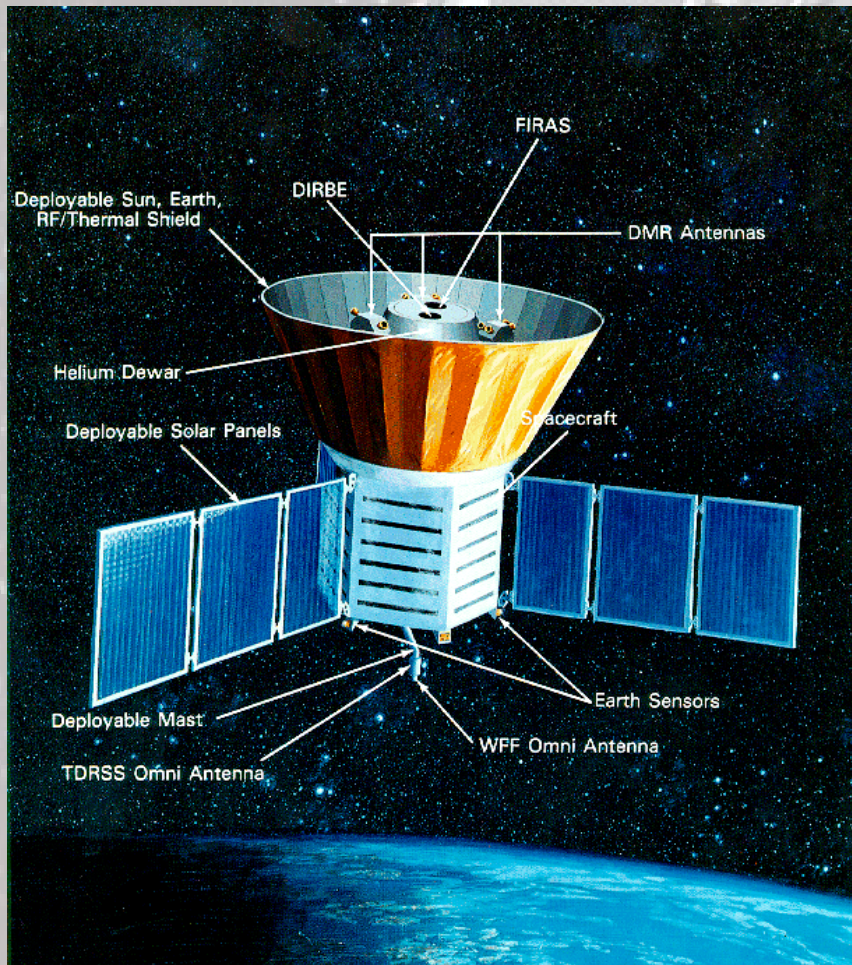
Matter is lumpy on all sizes

Problem: Why was the measured CMB so smooth?



The COBE Satellite - 1990

Primordial Ripples discovered!



-100 μK  +100 μK

Detecting the ripples is hard!

- The change in temperature of the CMB due to a massive cluster of galaxies is only a few millikelvin
- The telescope electronics need to be cooled with liquid Helium to reduce the noise added to the signal
- The atmosphere needs to be dry so as not to add any noise to the signal

Mapping the CMB

The Atacama Cosmology Telescope



The South Pole Telescope

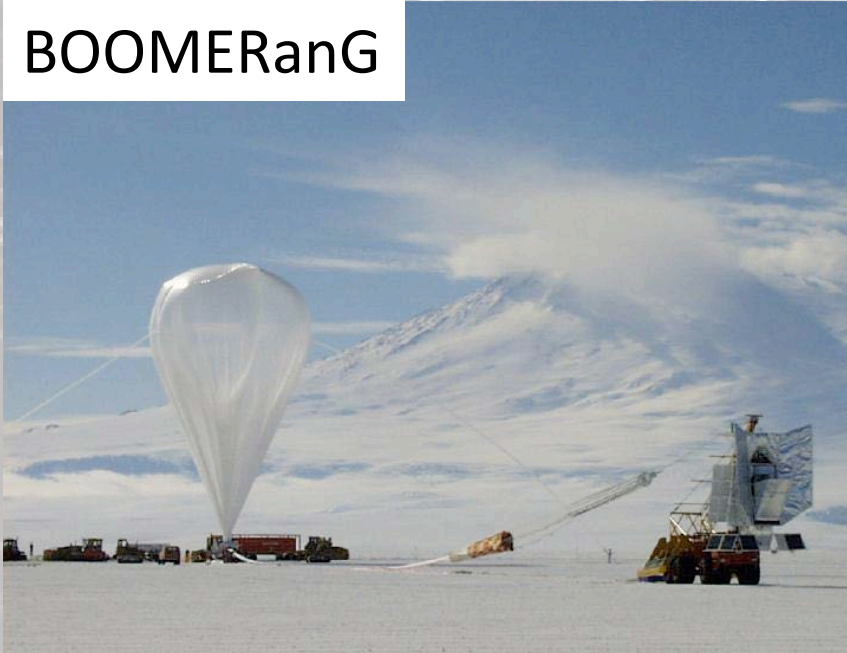


The SZ Array



Mapping the CMB from the Air

BOOMERanG



MAXIMA

Mapping the CMB from Space

The Planck Satellite

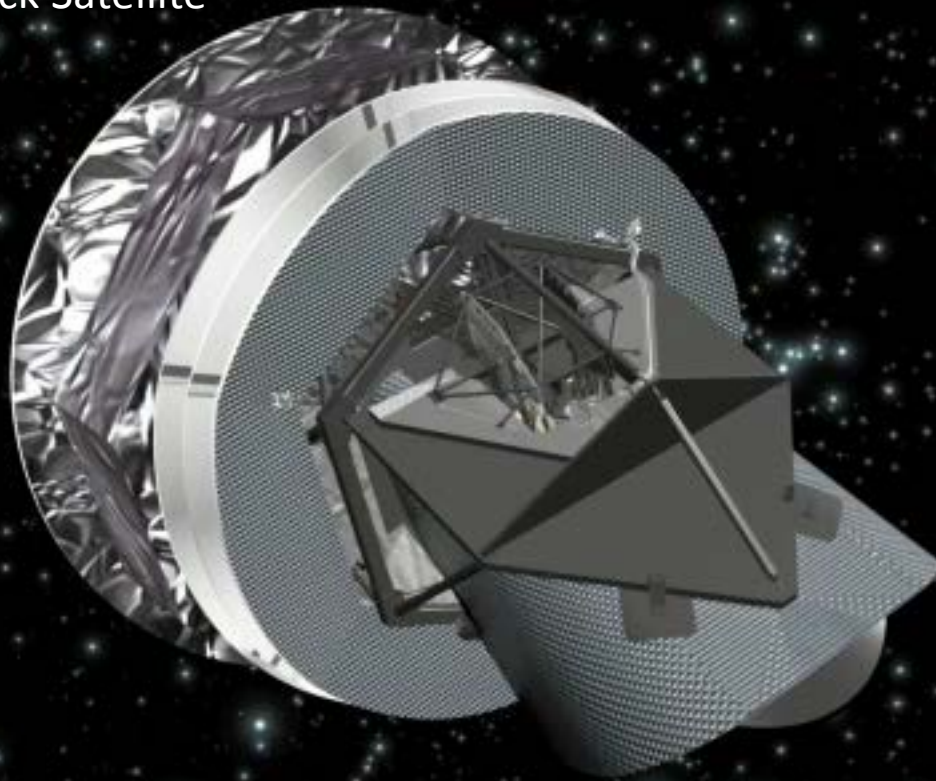
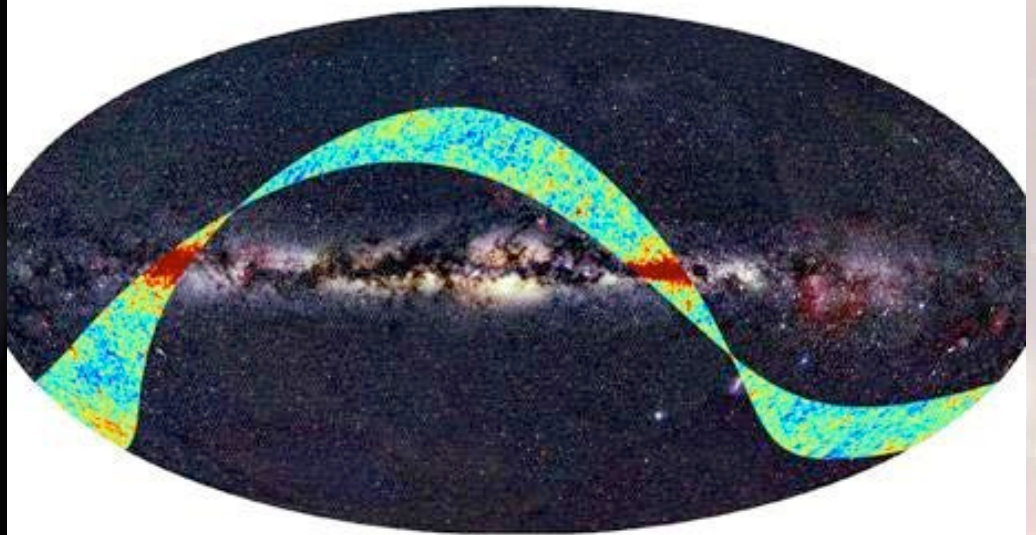
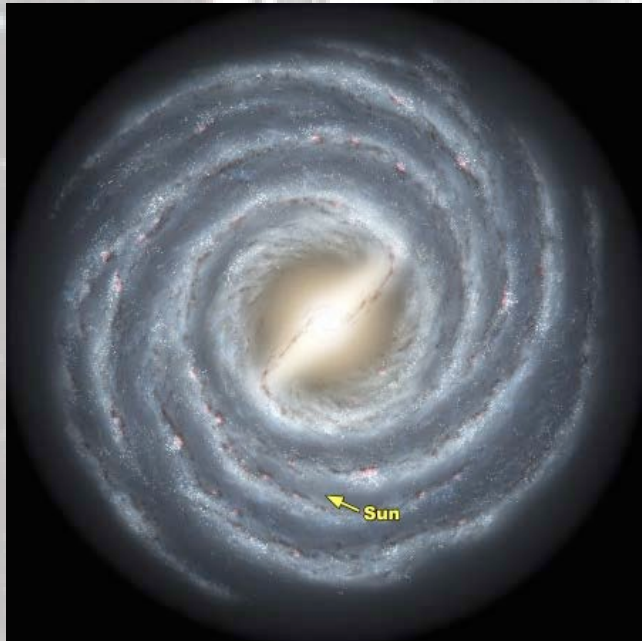


Image Credit: ESA/Planck Collaboration

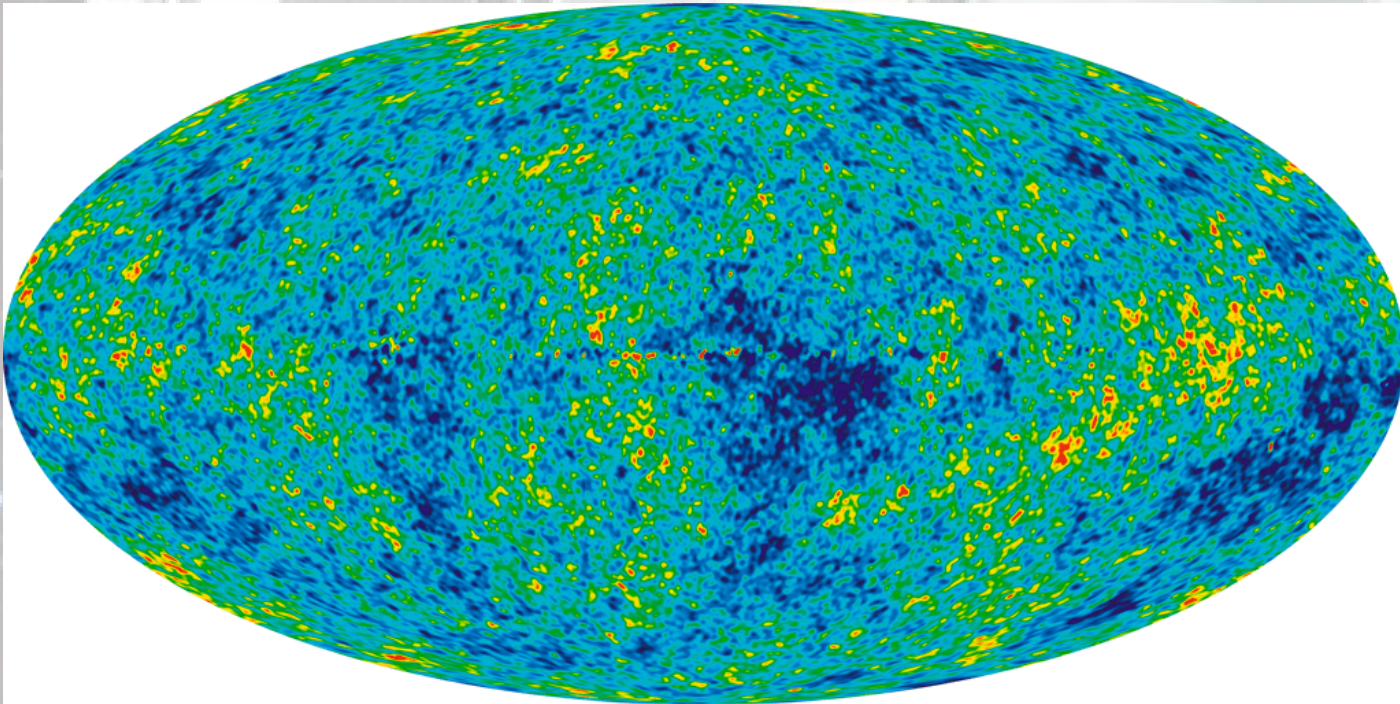
What makes up the CMB Sky?

- The band in the middle is microwave emission from our own Galaxy

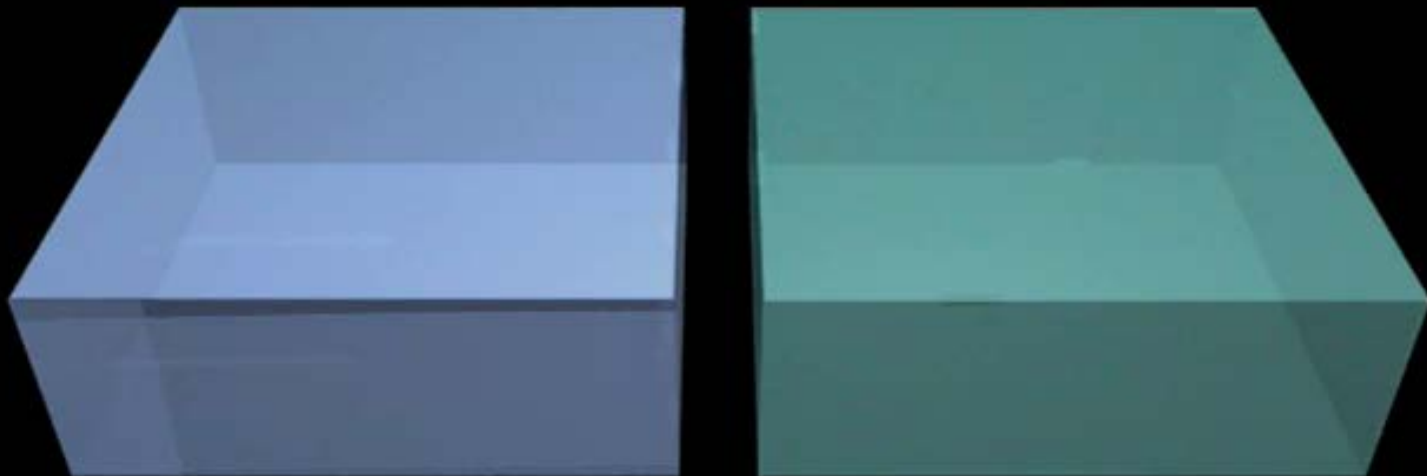


What makes up the CMB Sky?

- Everything left is an image of the Universe

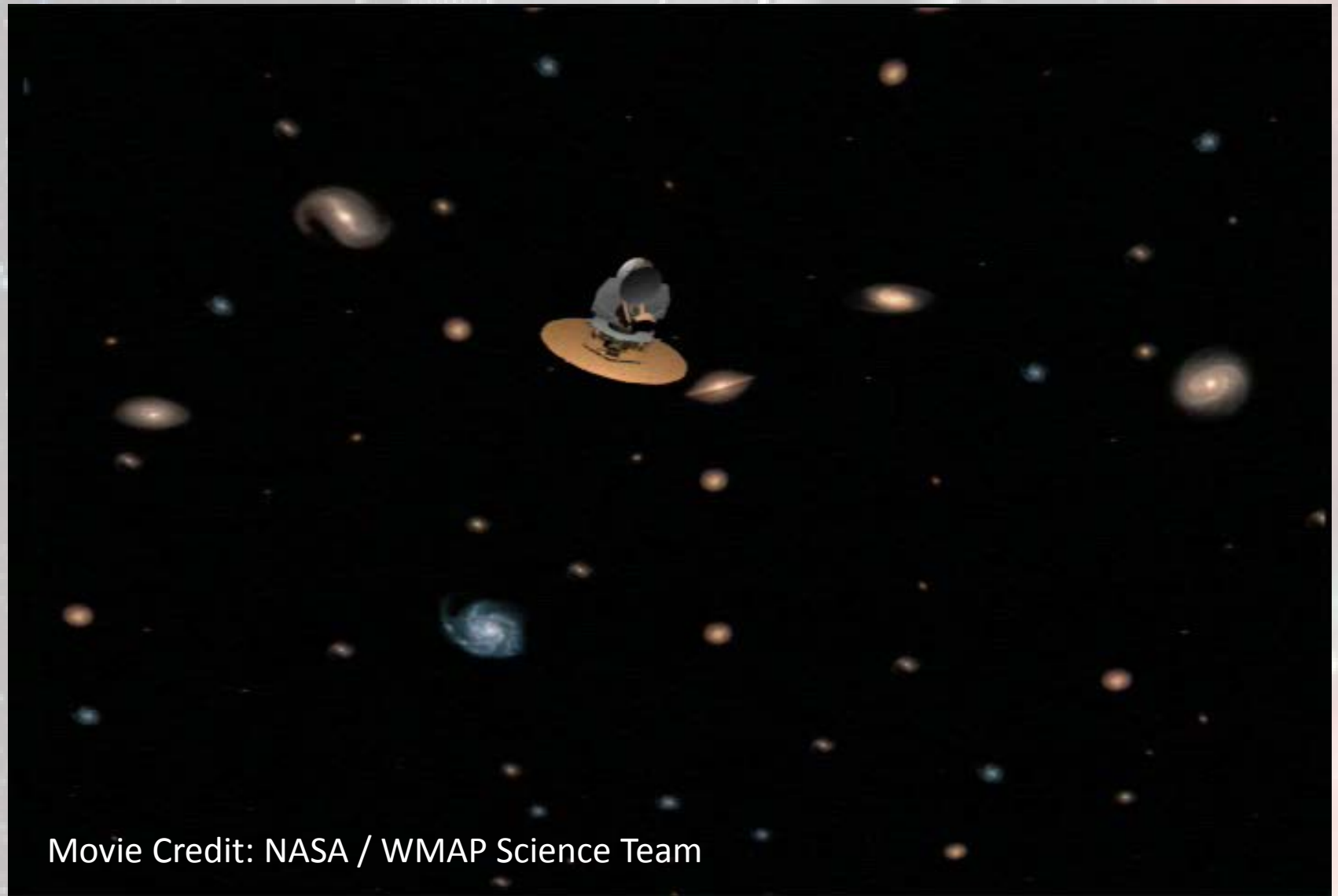


Ripples in the primordial soup



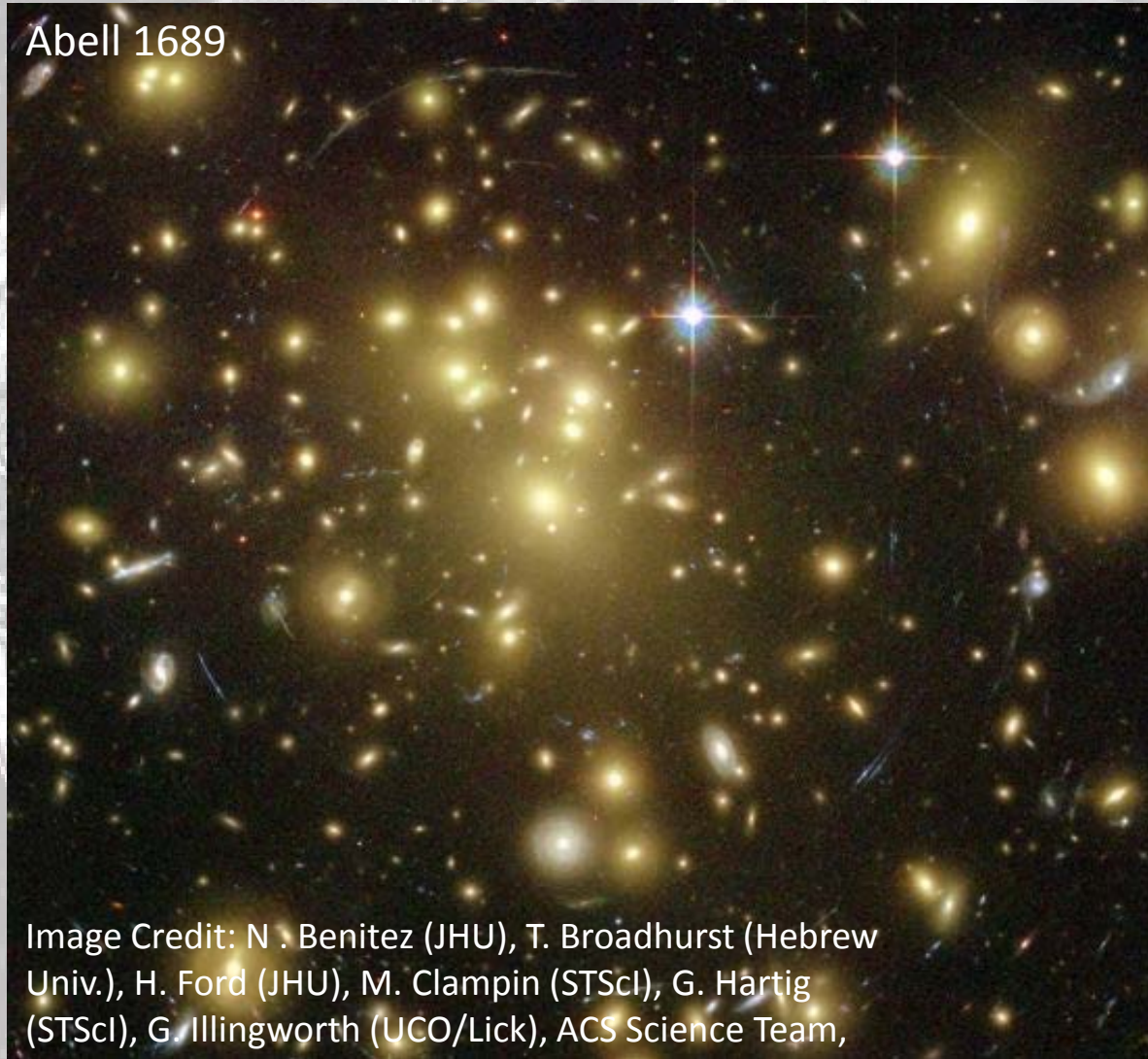
Movie Credit: NASA / WMAP Science Team

The ripples tell us about the Universe



Movie Credit: NASA / WMAP Science Team

The hot gas in Galaxy Clusters cause extra ripples



The hot gas in Galaxy Clusters cause extra ripples

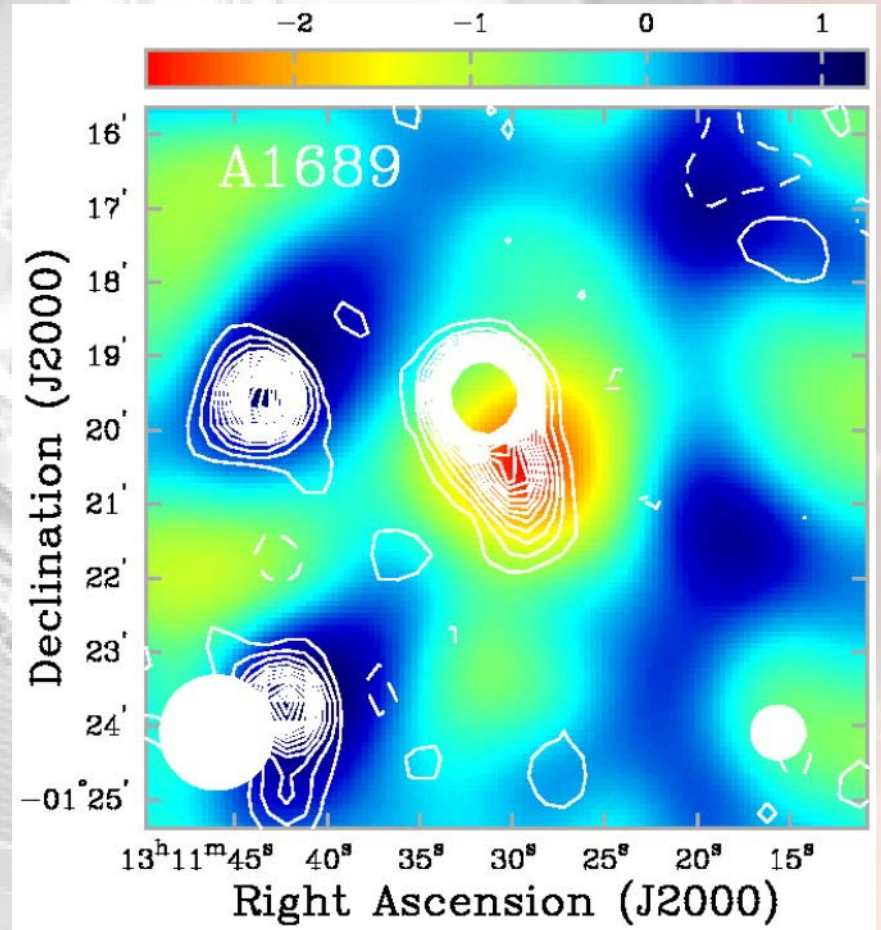
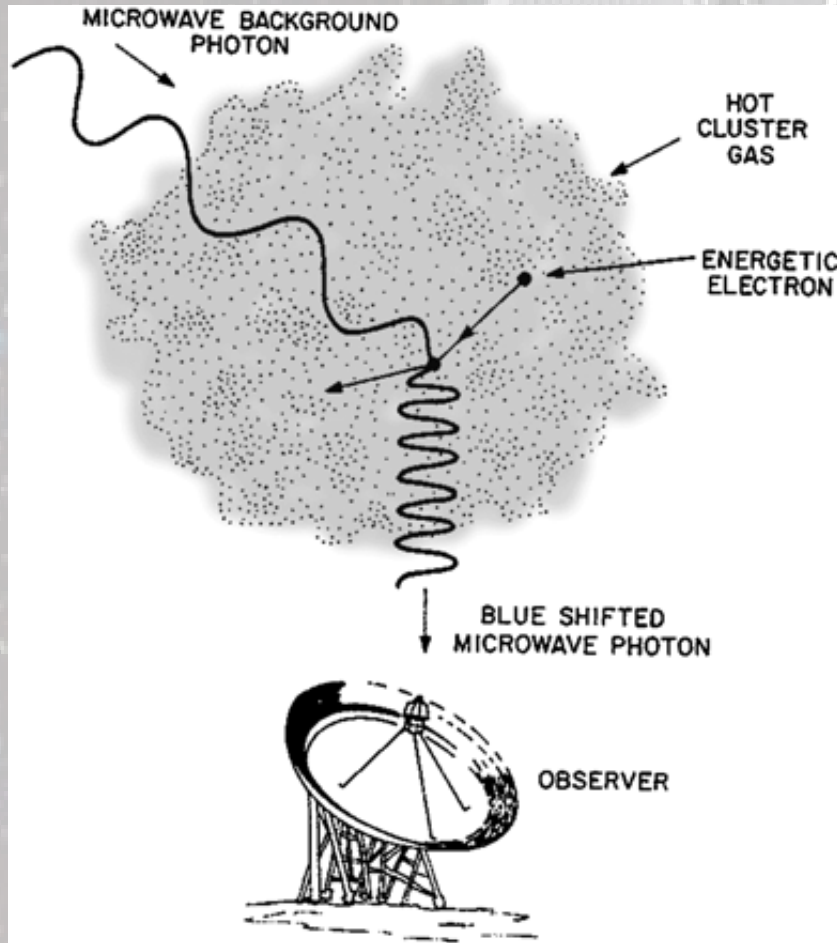


Image Credit: BIMA/OVRO Team

Clusters of Clusters of Galaxies (!)

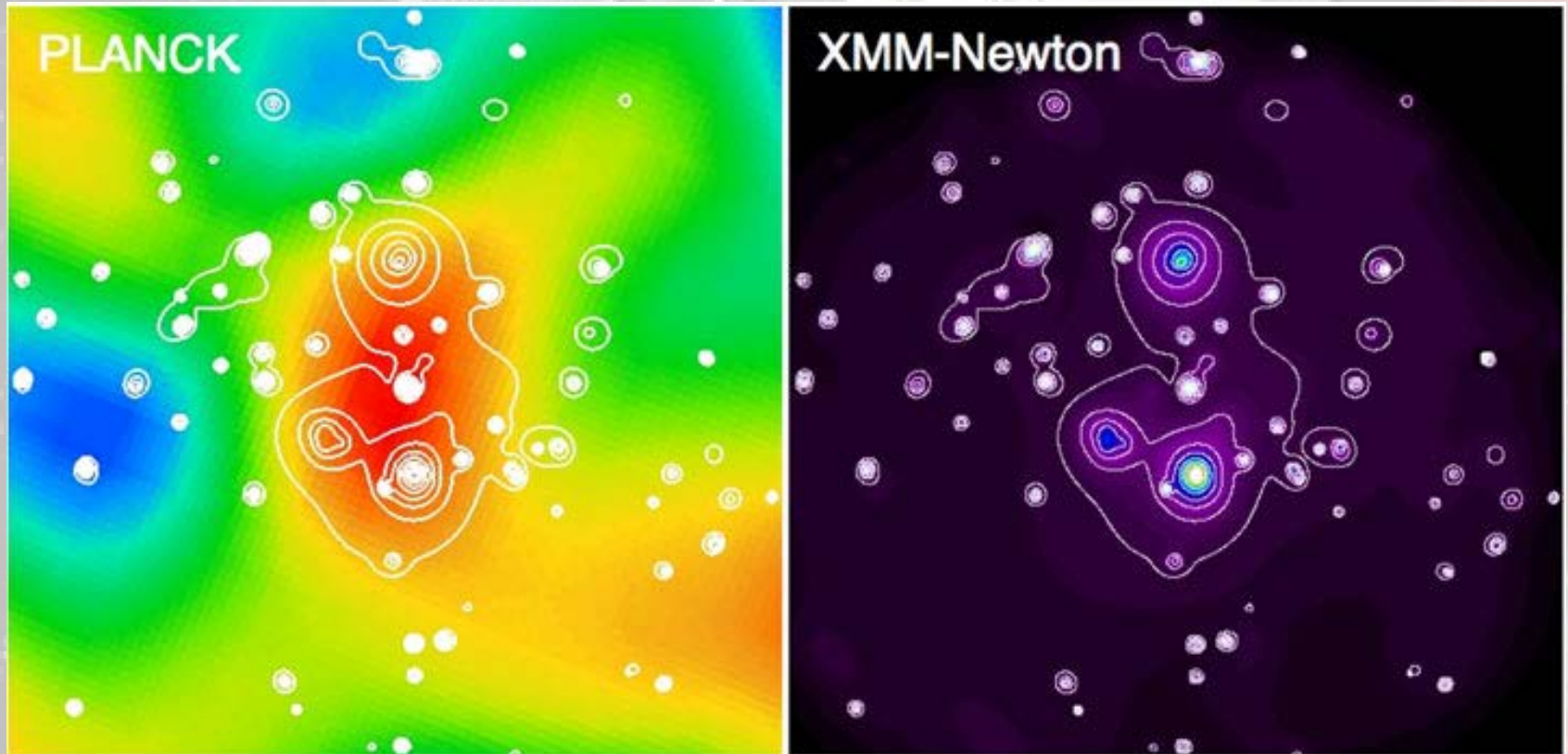
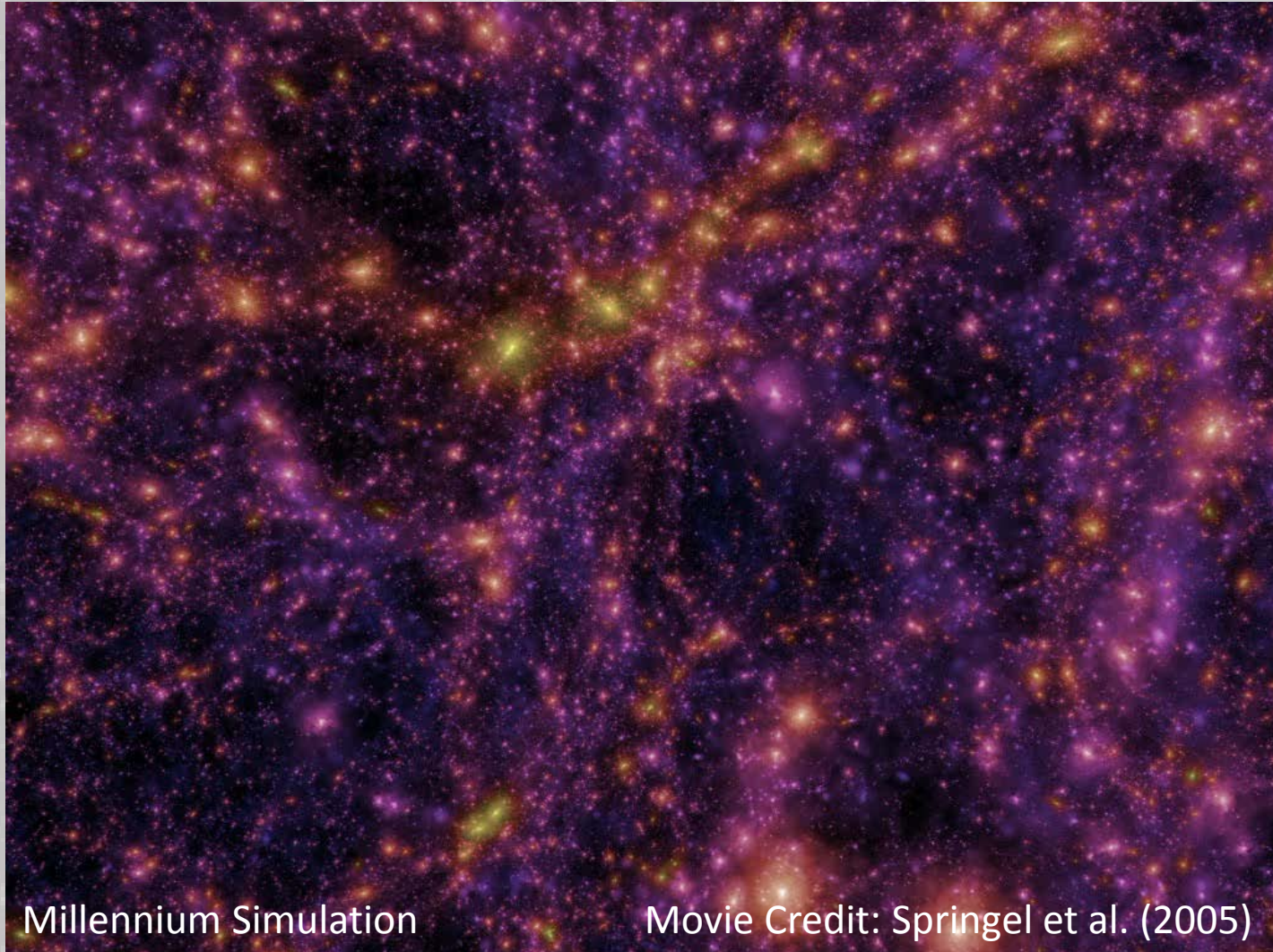


Image Credits: ESA, Planck HFI & LFI consortia, XMM-Newton.

We can build a model of our Universe



Millennium Simulation

Movie Credit: Springel et al. (2005)

Thank you for listening!

