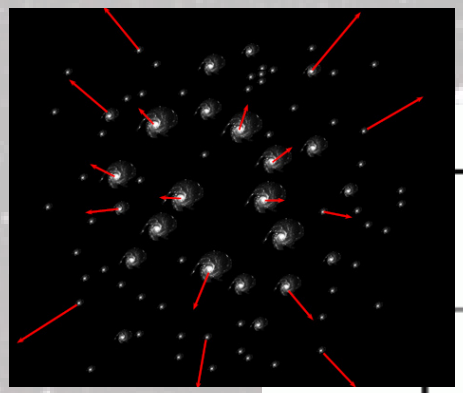
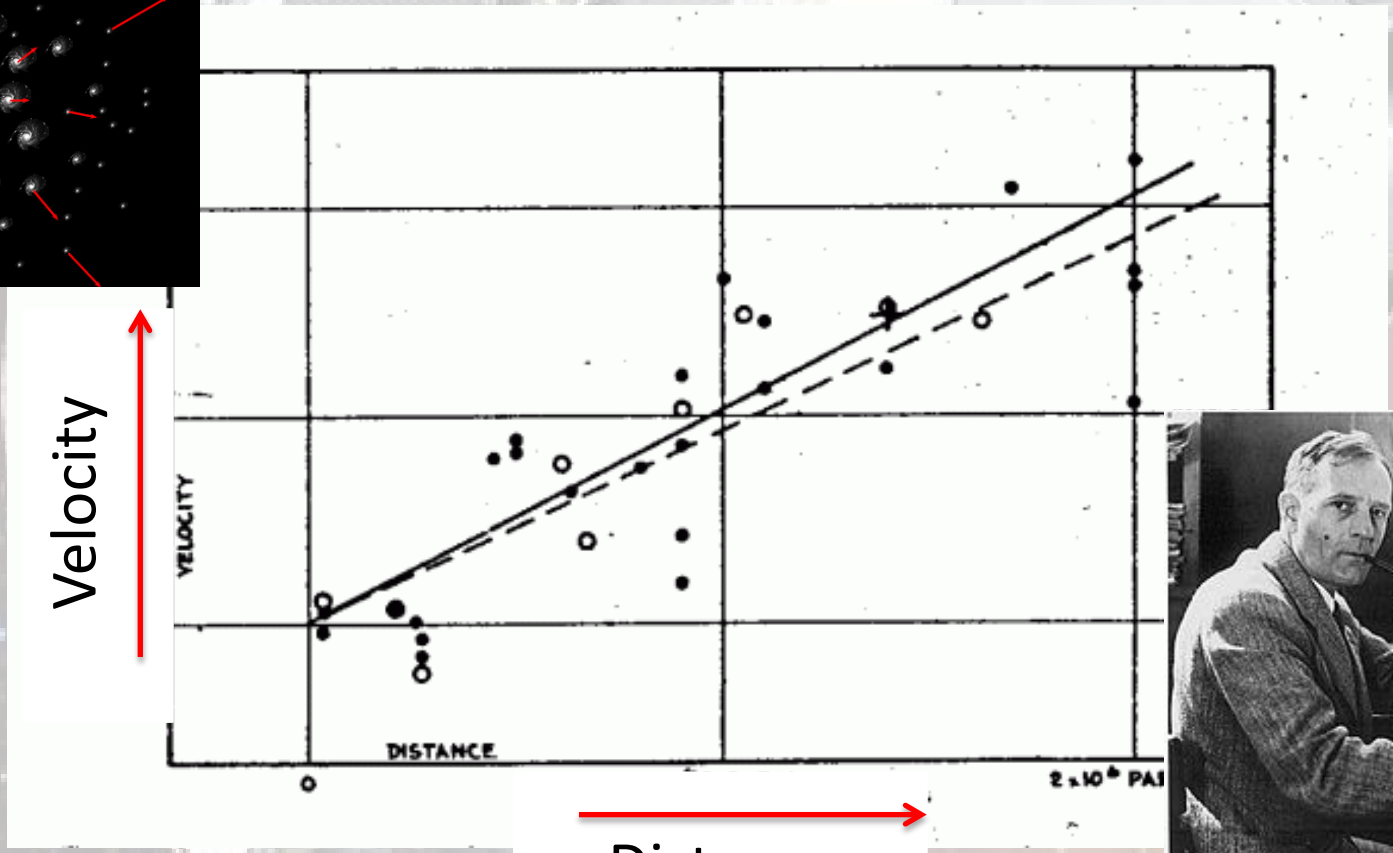
Monster Footprints in the Invisible Universe

James Allison

University of Sydney

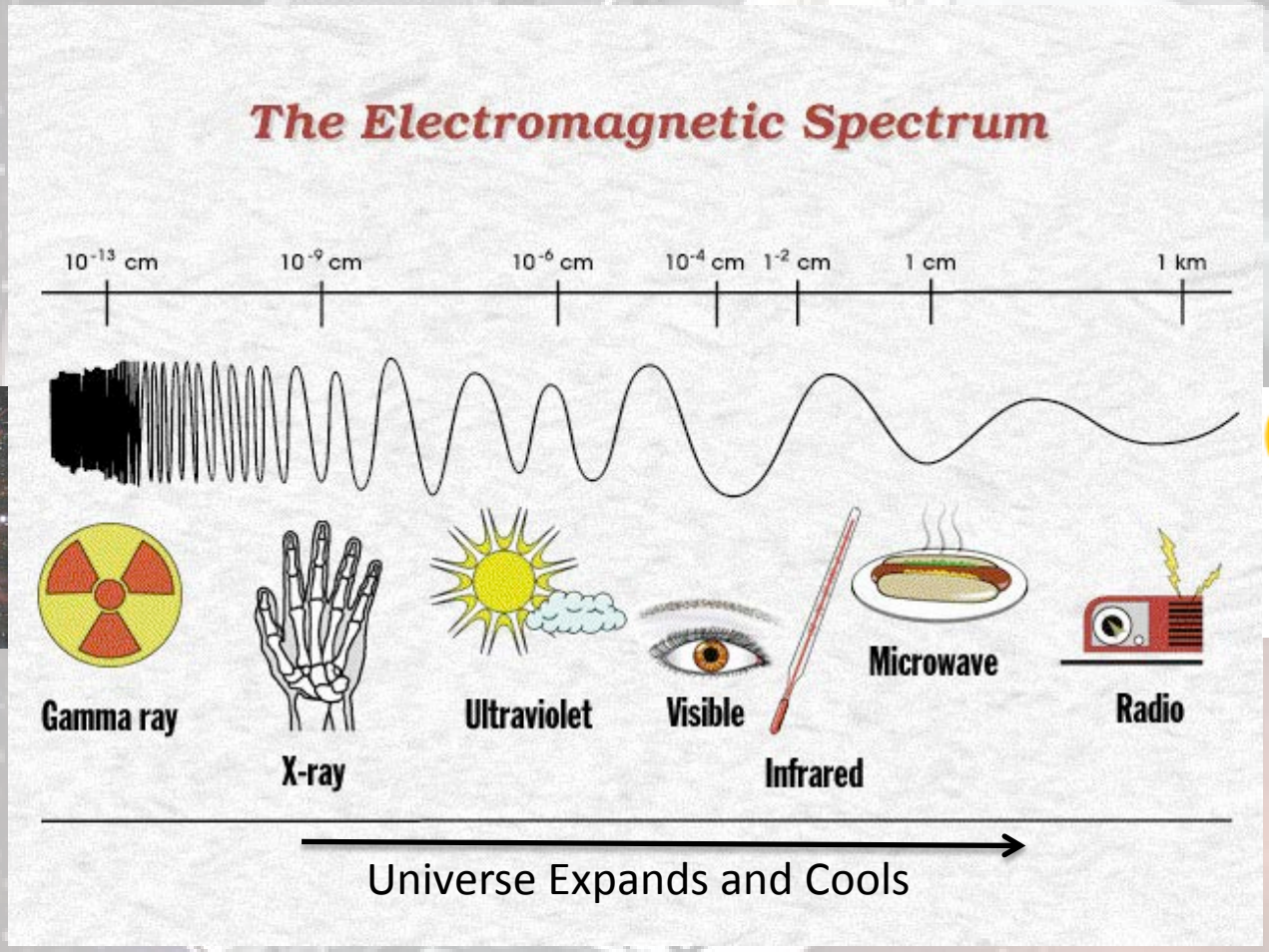
The Expanding Universe (1930s)





The Big Bang Prediction 1930s-1960s

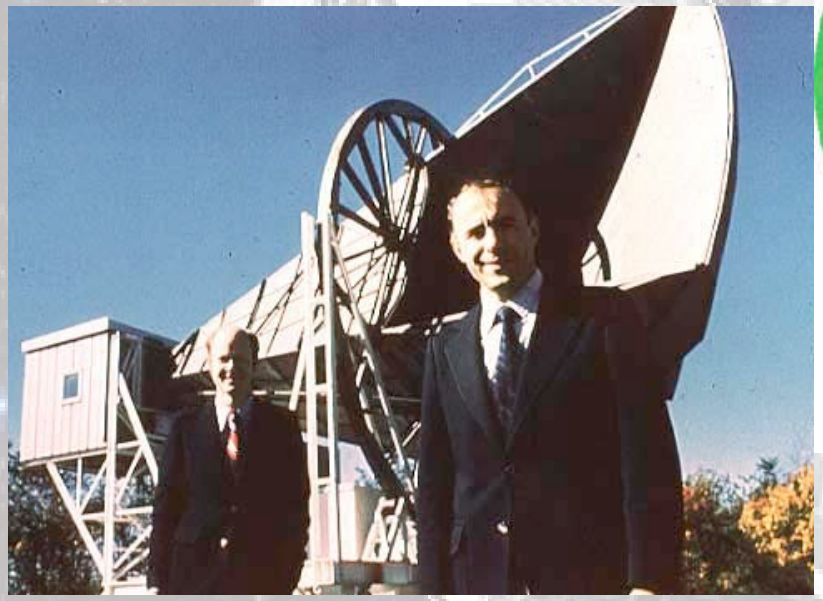
Big Bang



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"

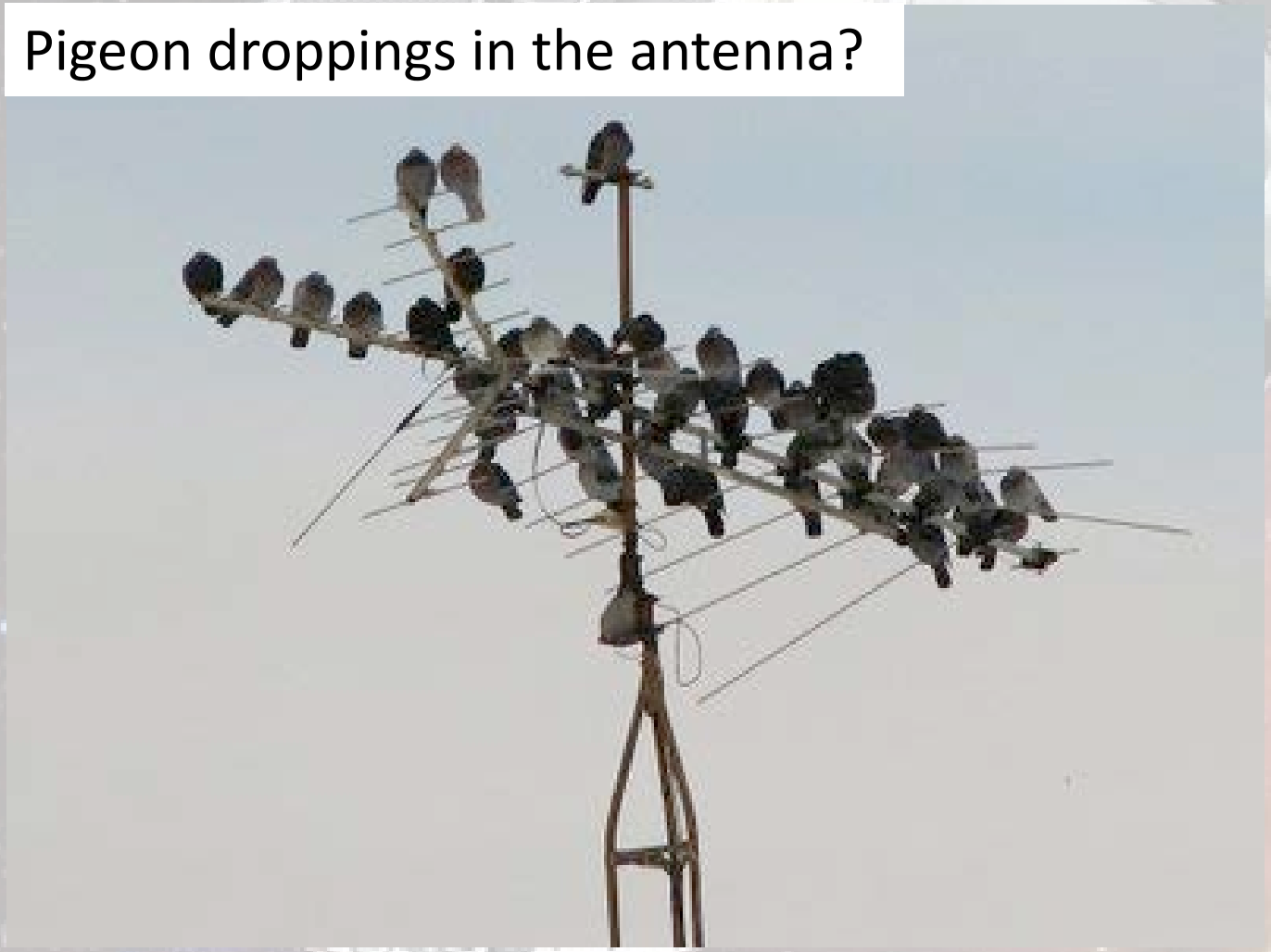
What was this -270°C microwave radiation?

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!

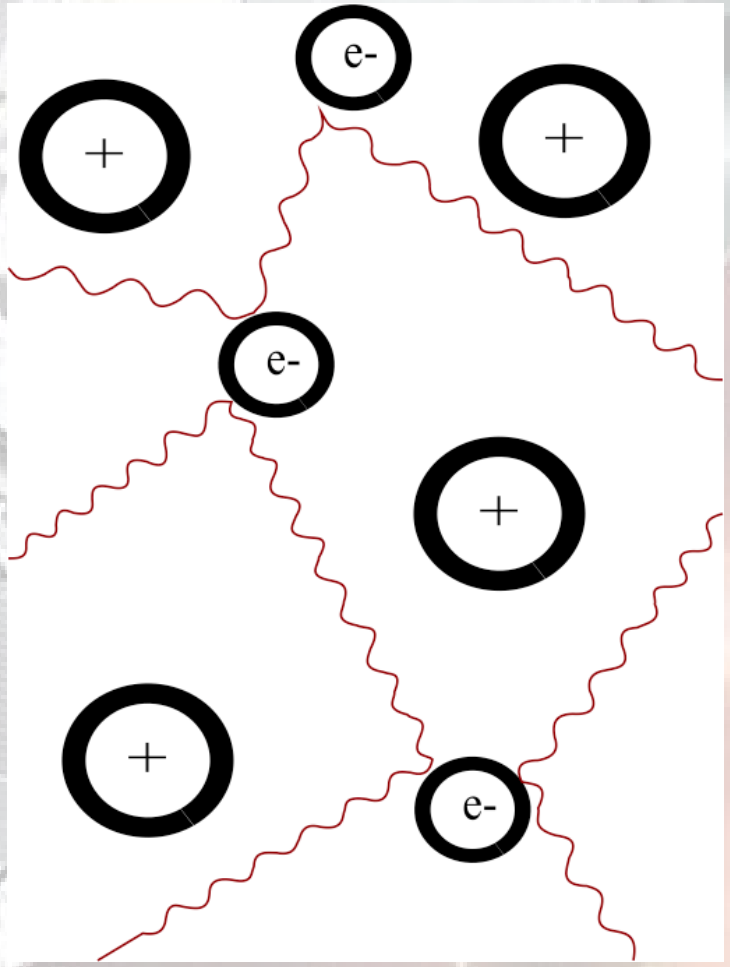
Credit :Jean-Charles Cuillandre (CFHT)

Discovery of the Cosmic Microwave Background in 1965

NOBEL PRIZE!

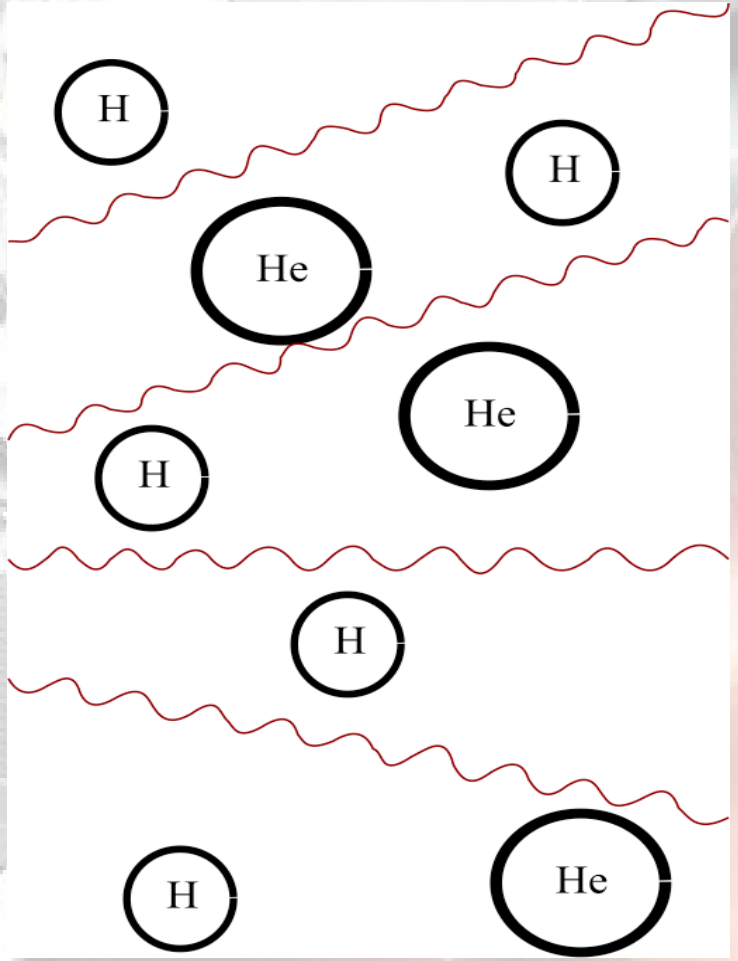
What is the CMB?

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

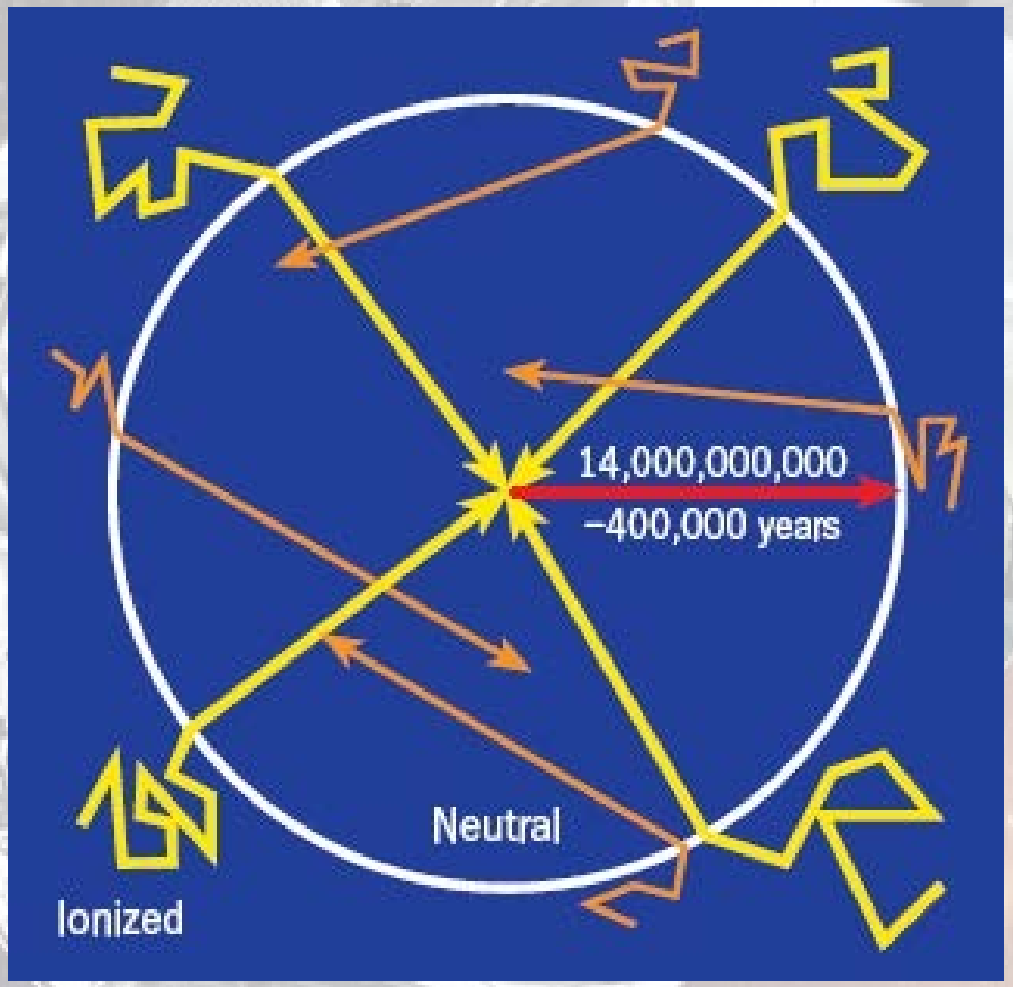


What is the CMB?

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



What is the CMB?

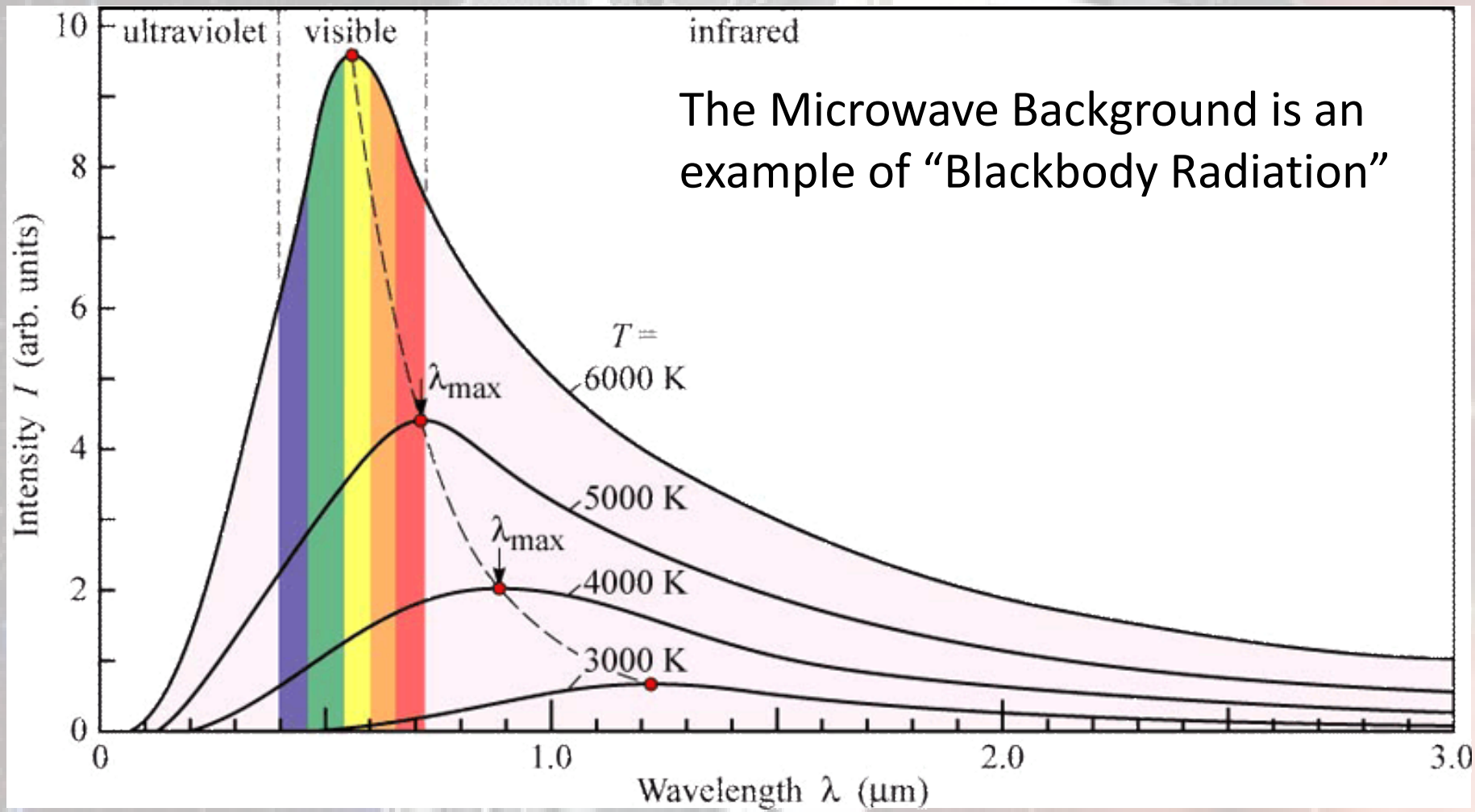


We see an all-sky image of the early hot Universe

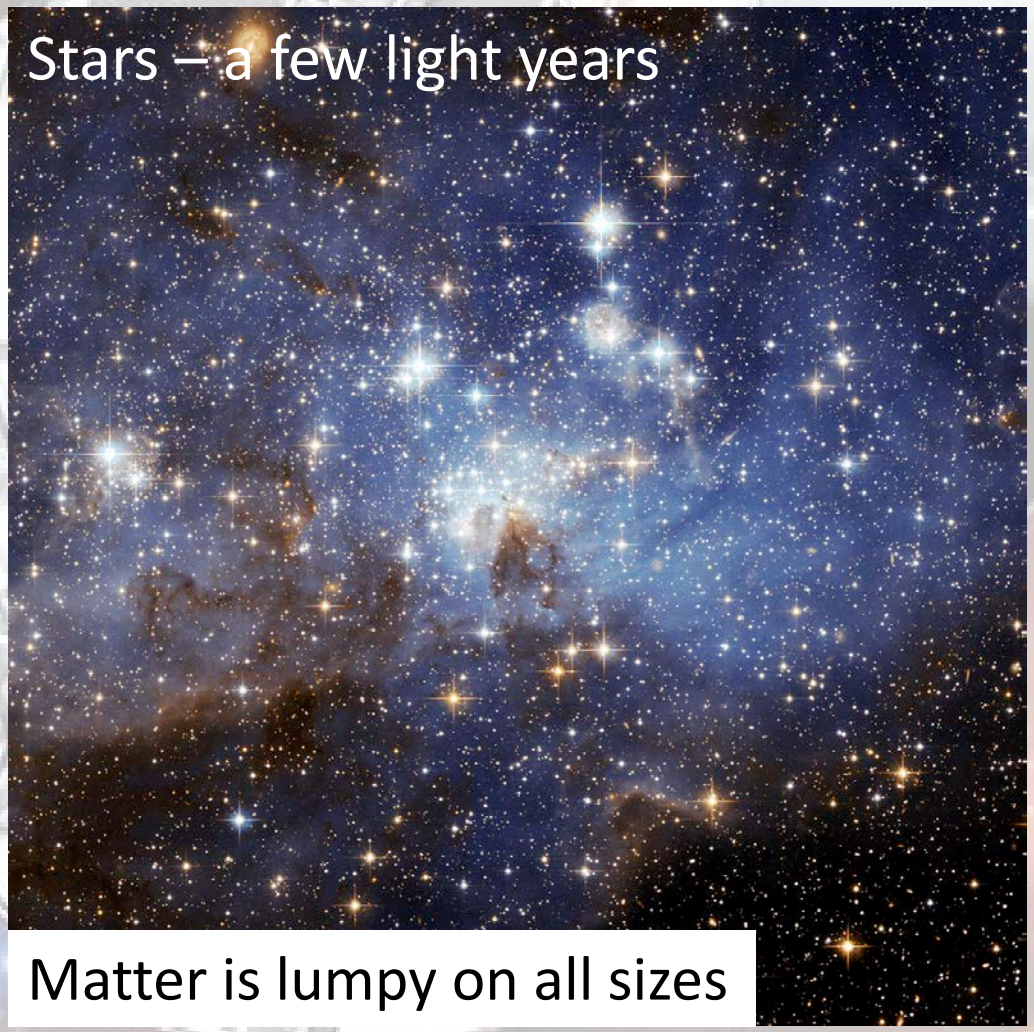
What is the CMB?

A small percentage (~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?



Matter is lumpy on all sizes

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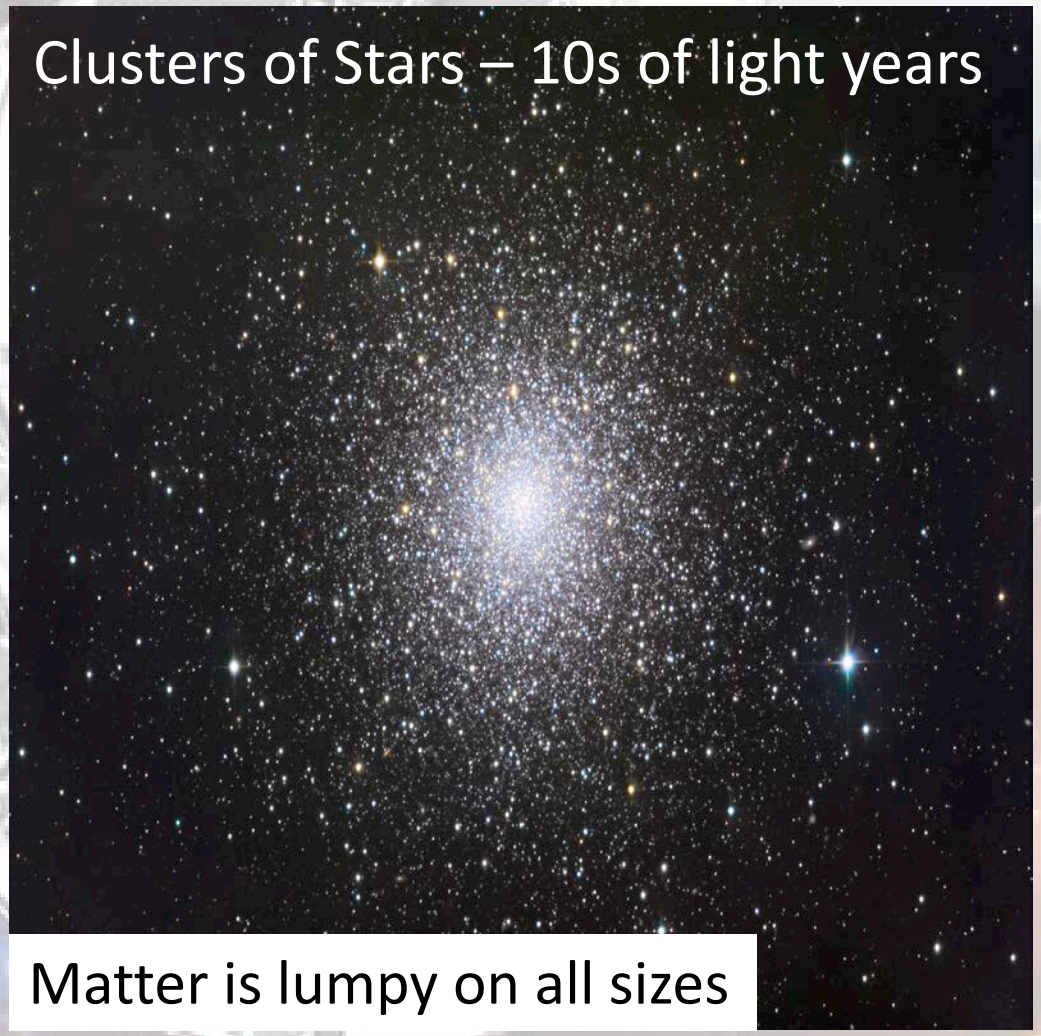

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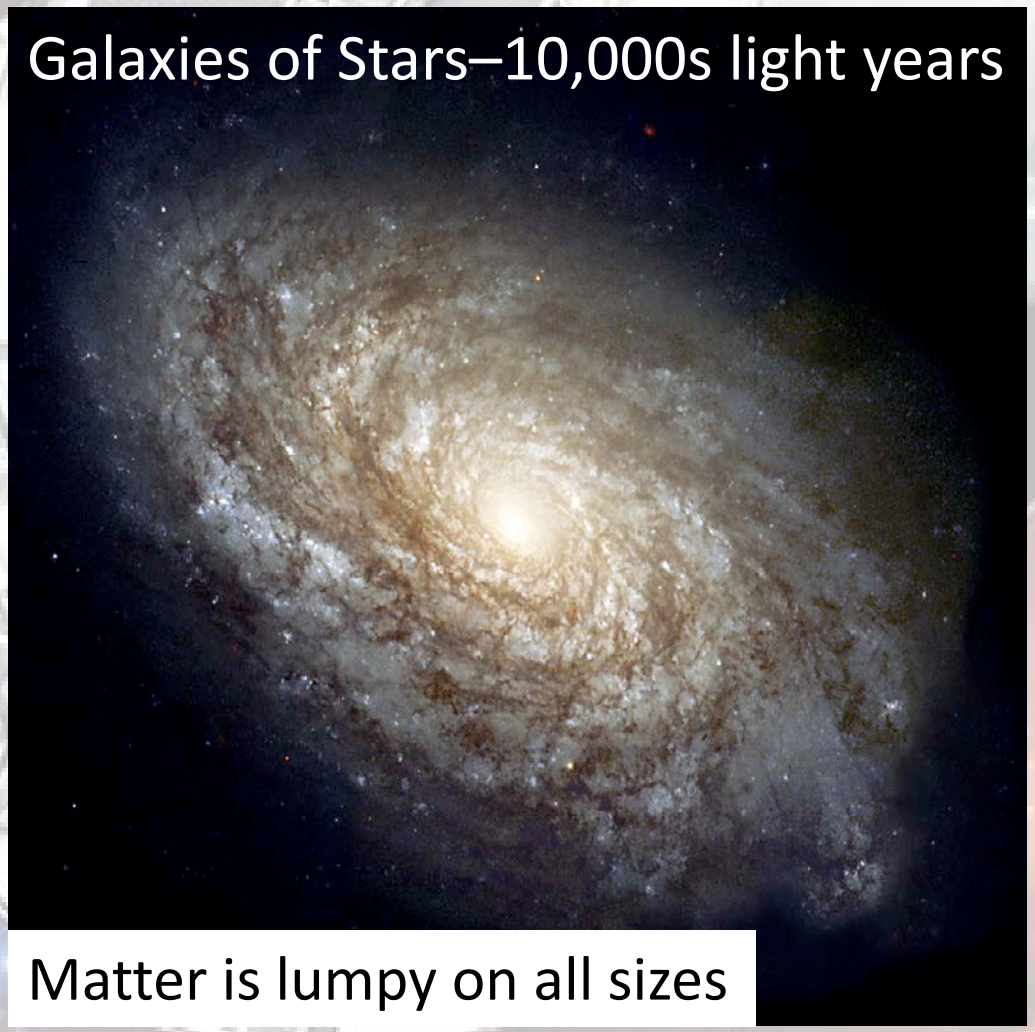

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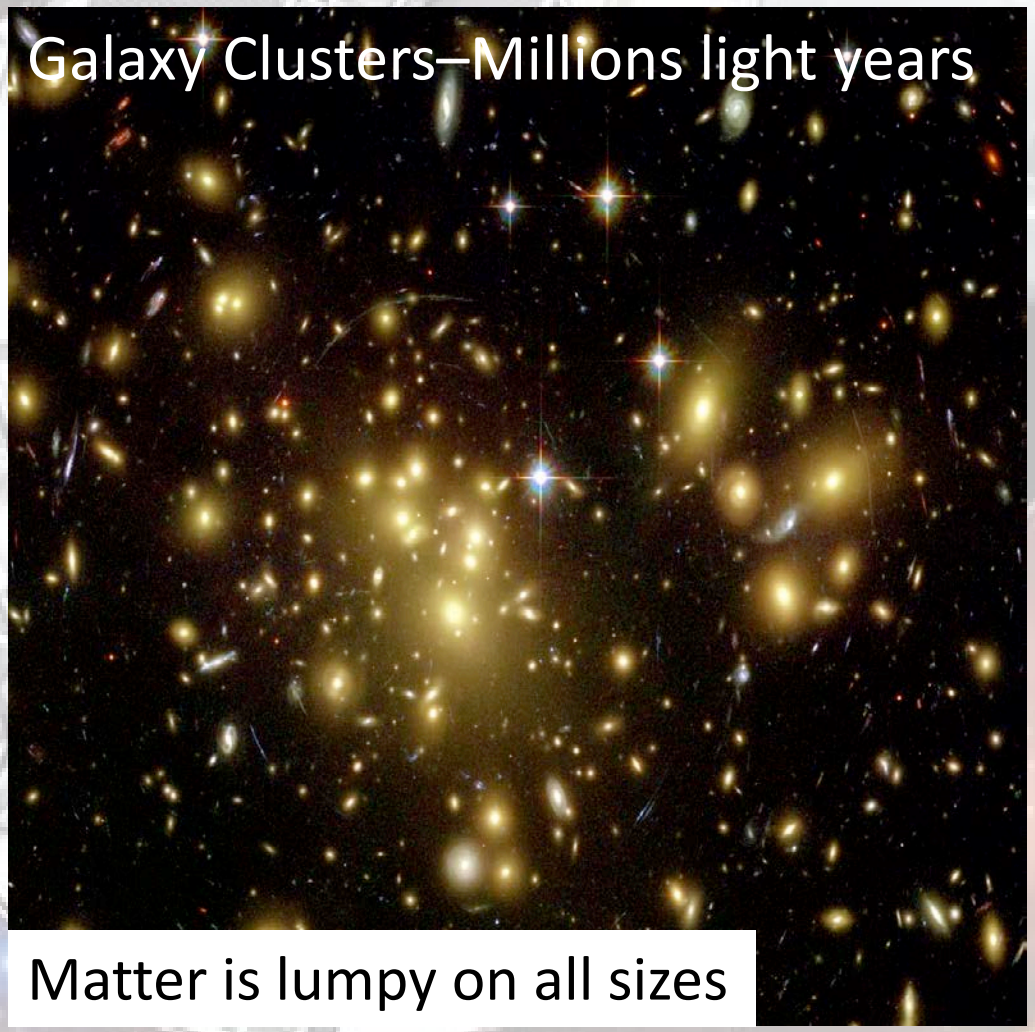

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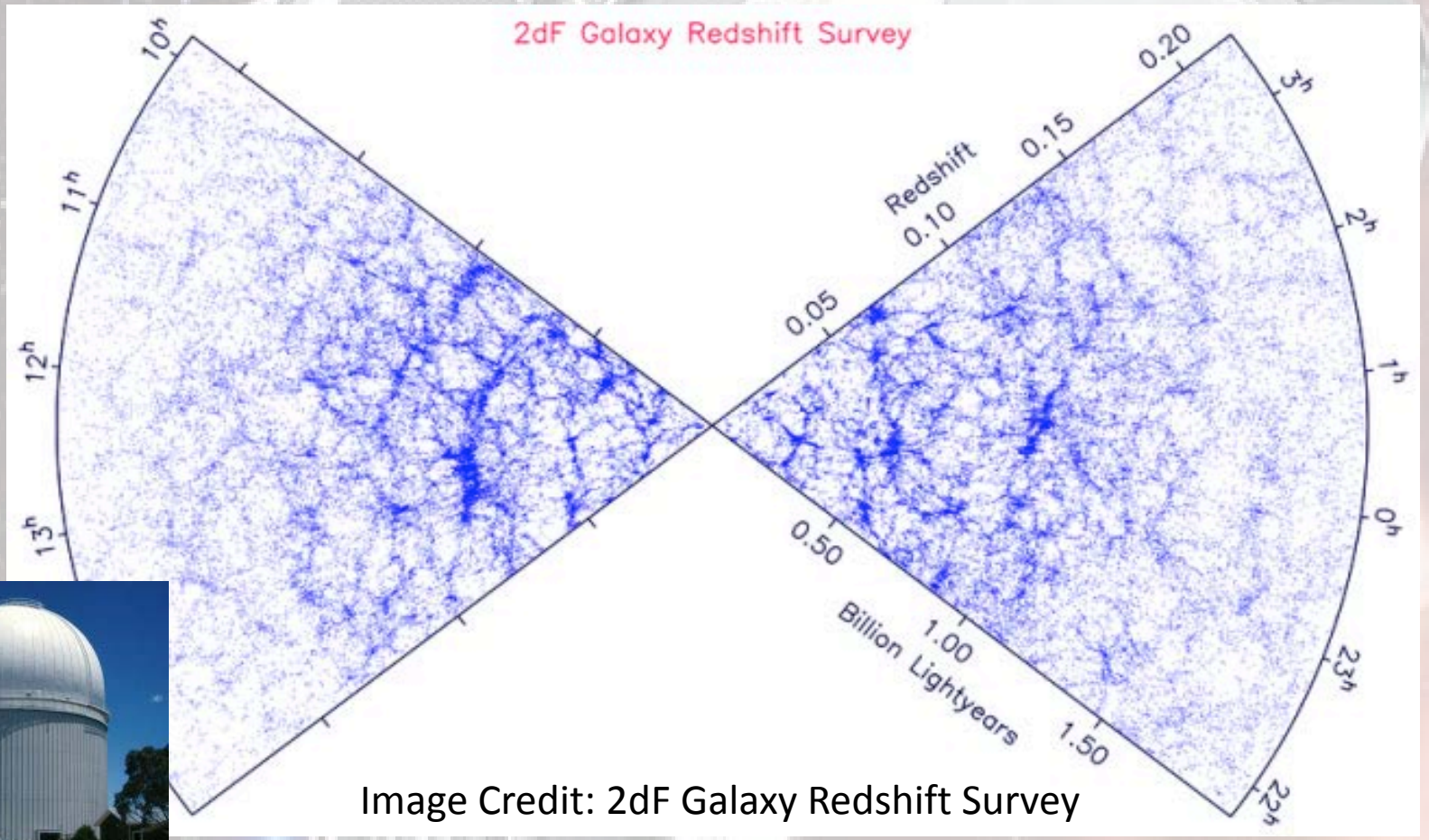
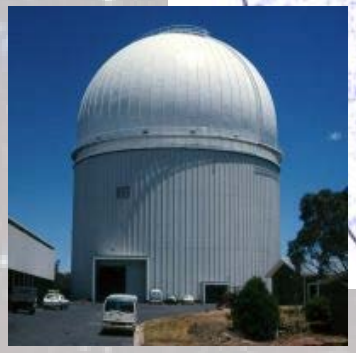
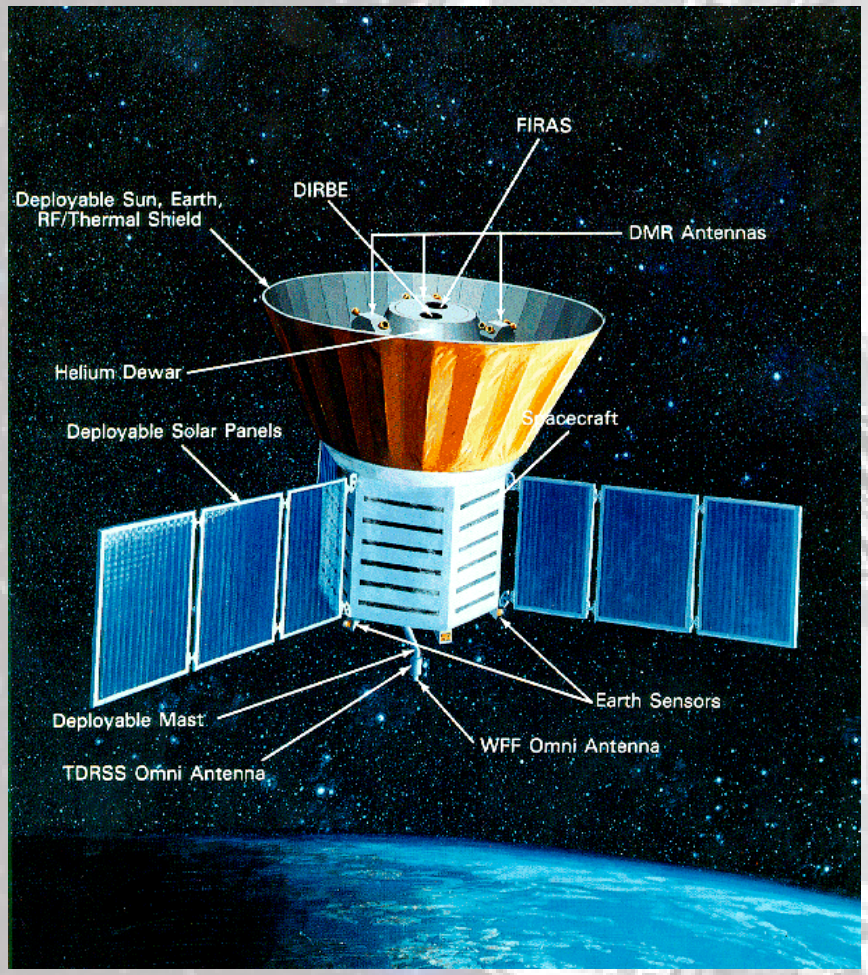


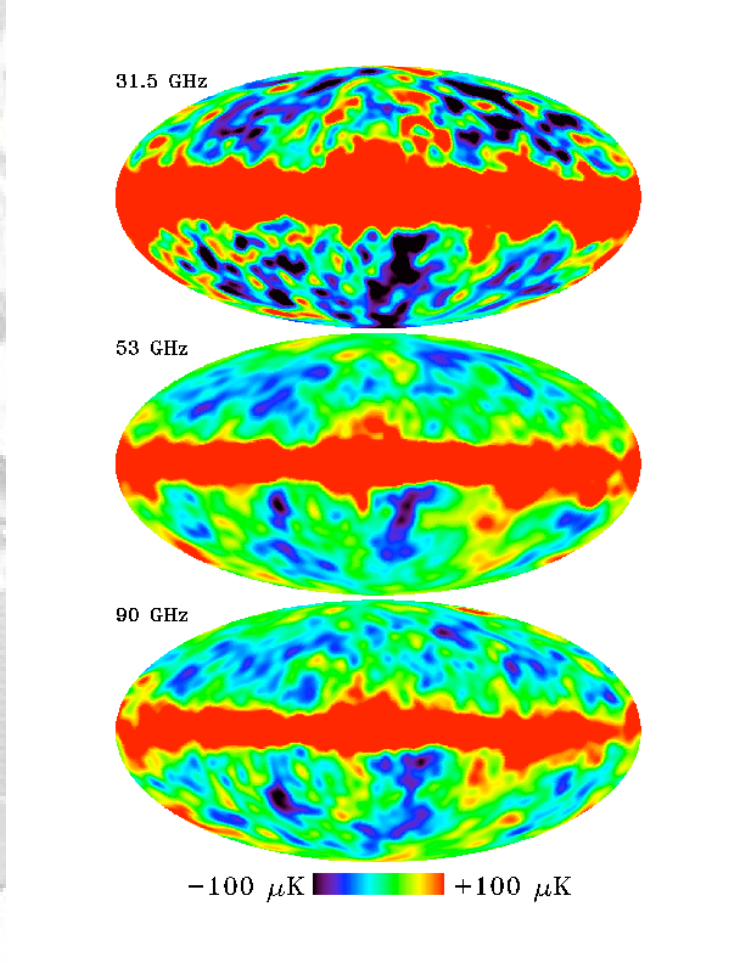
Image Credit: 2dF Galaxy Redshift Survey



The COBE Satellite - 1990

Primordial Ripples discovered!





Detecting the ripples is hard!

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

Mapping the CMB

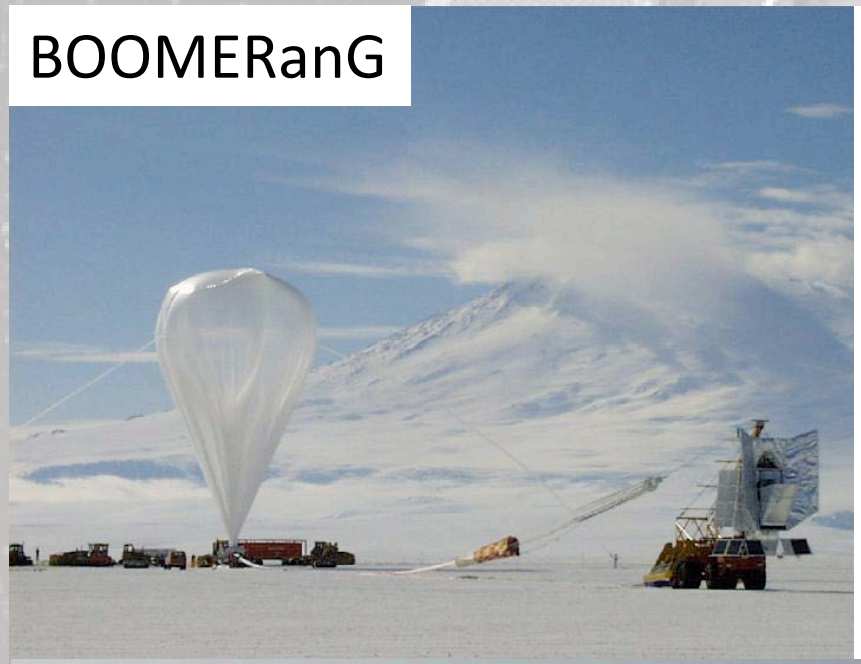
The Atacama Cosmology Telescope

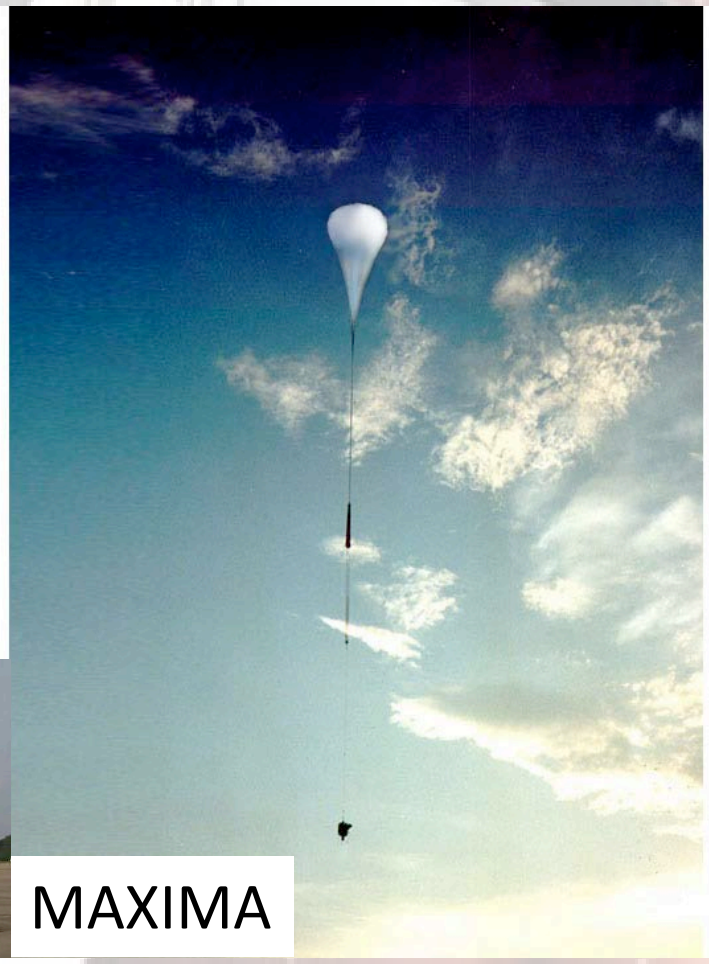
The SZ Array

The South Pole Telescope

Mapping the CMB from the Air

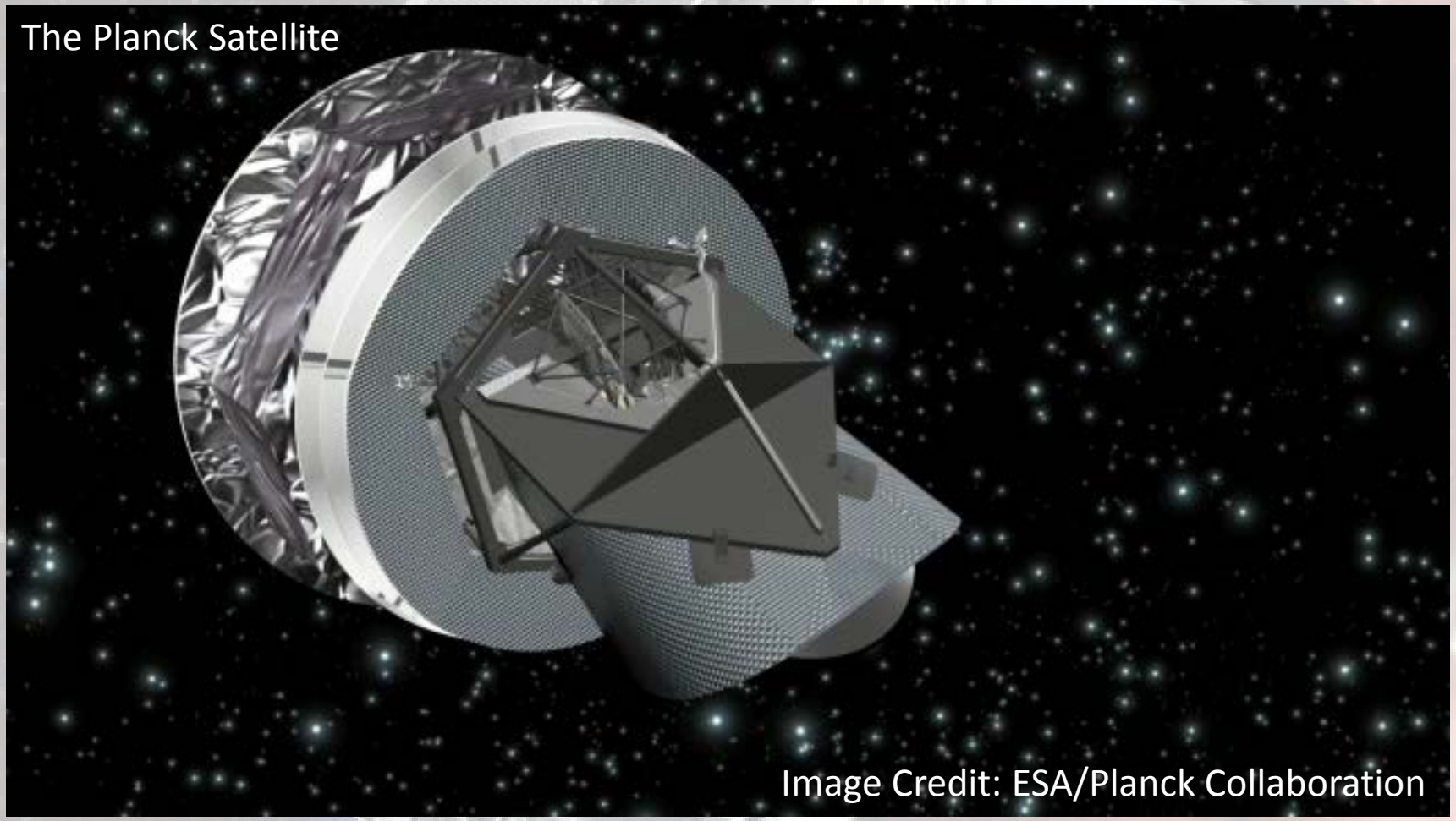
BOOMERanG





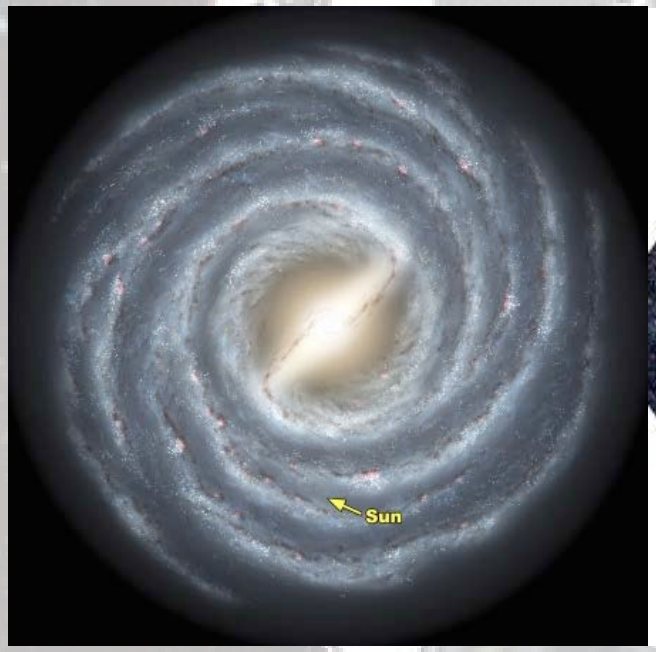
MAXIMA

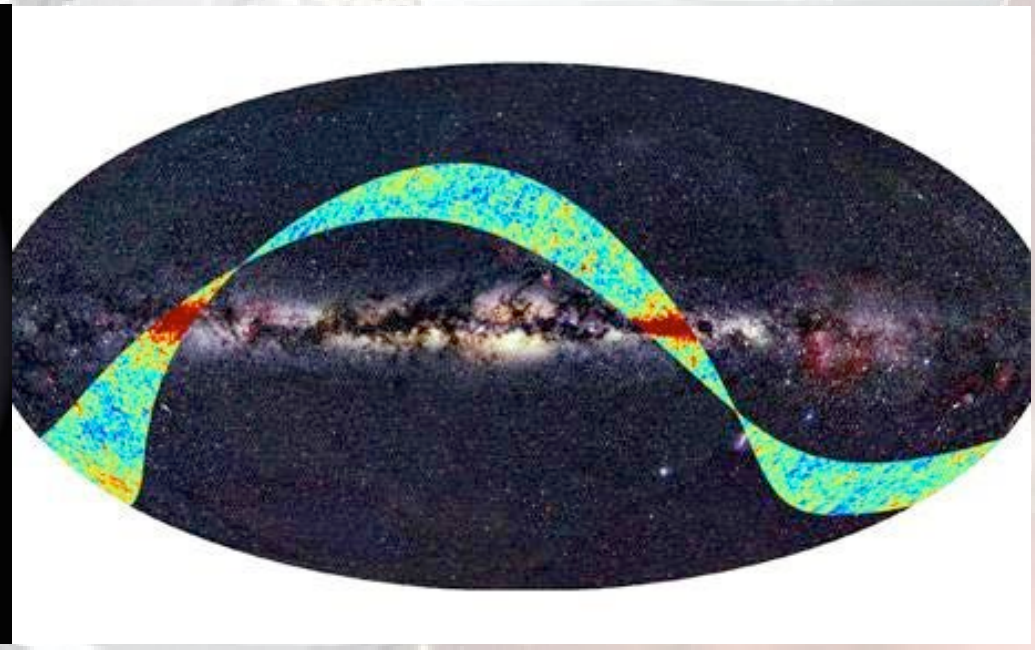
Mapping the CMB from Space



What makes up the CMB Sky?

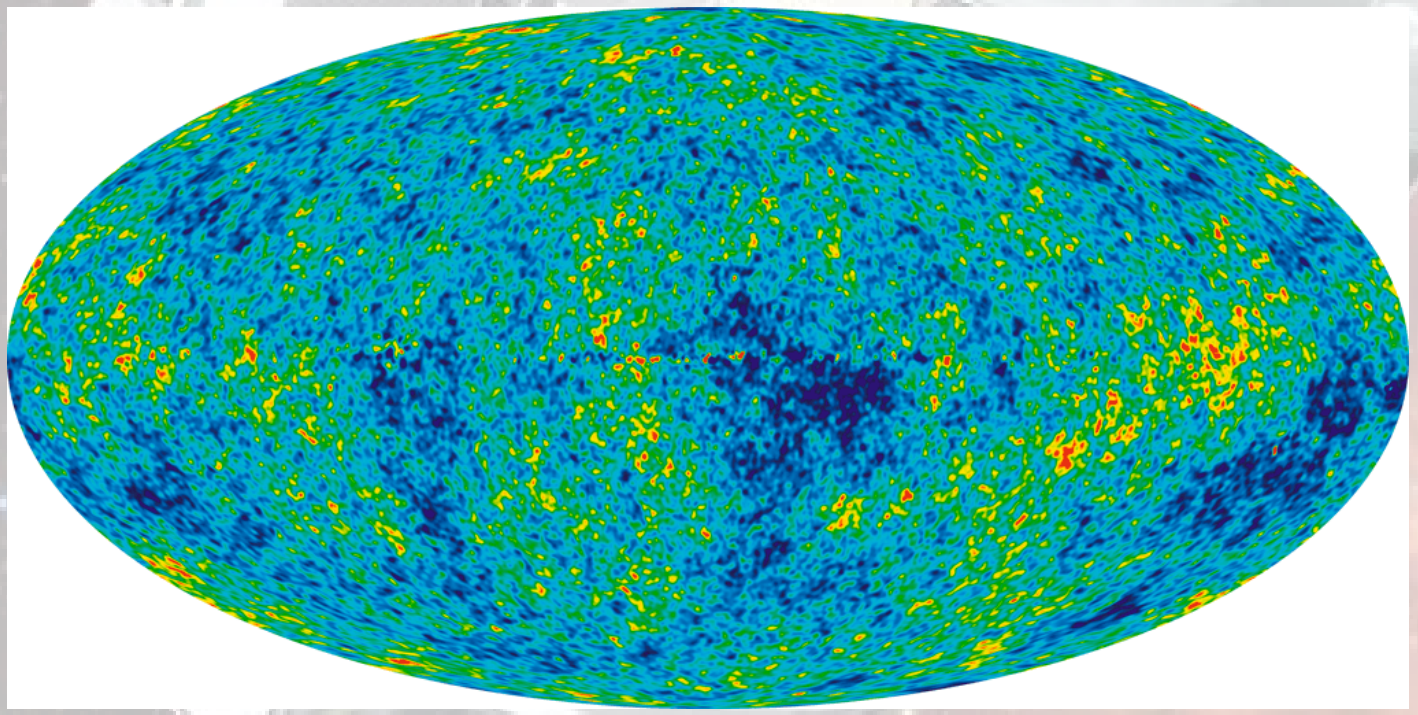
- The band in the middle is microwave emission from our own Galaxy



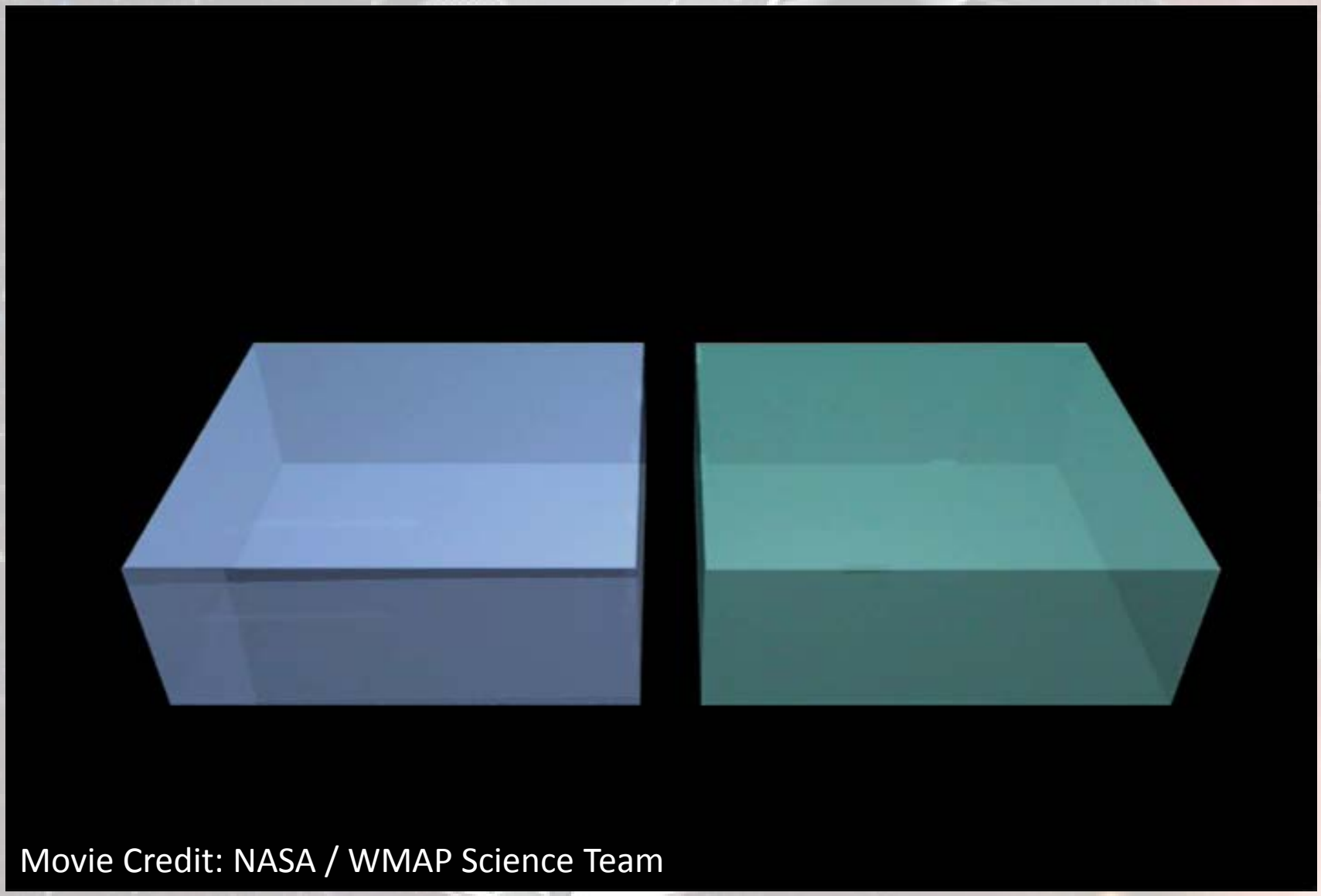


What makes up the CMB Sky?

- Everything left is an image of the Universe

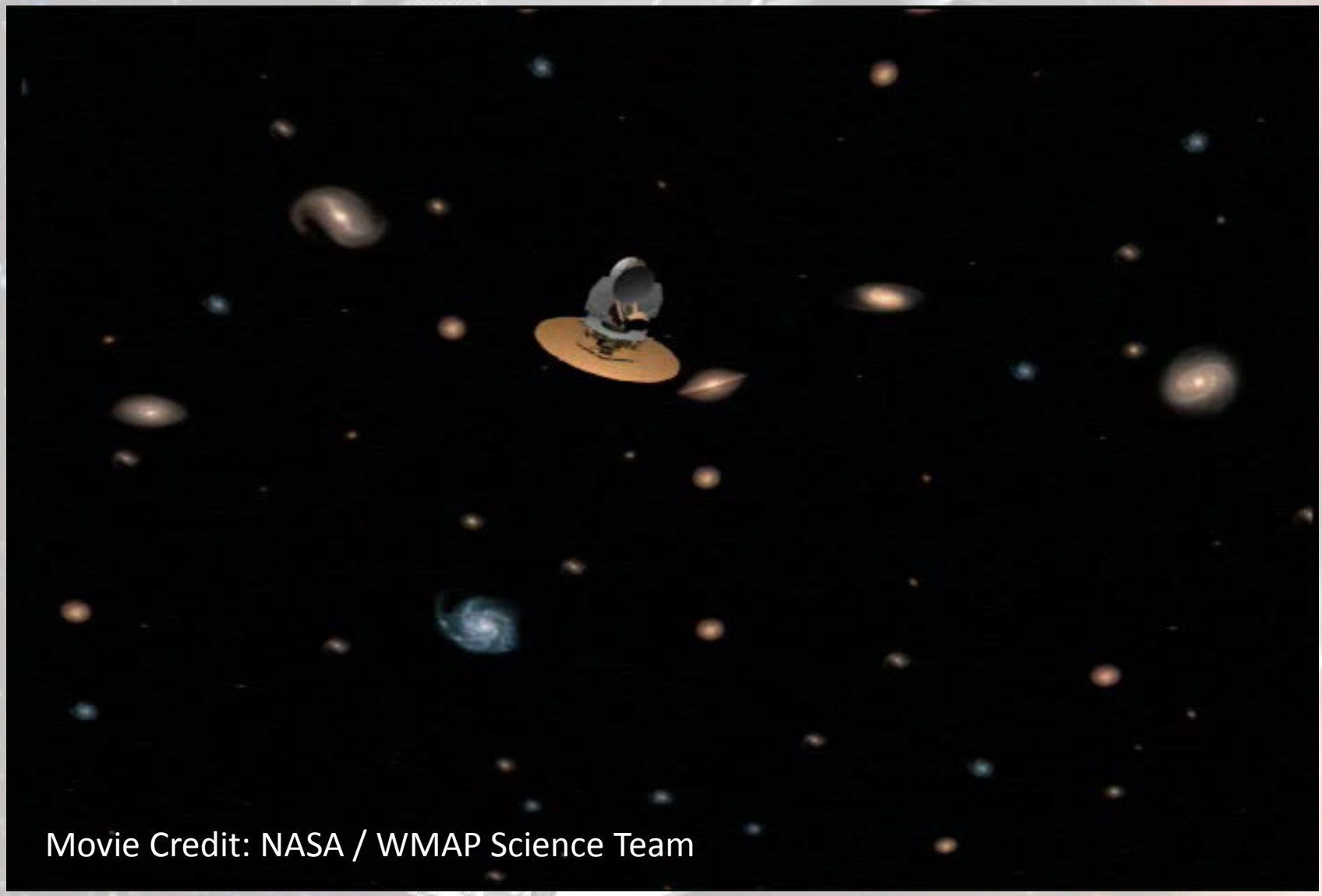


Ripples in the primordial soup



Movie Credit: NASA / WMAP Science Team

The ripples tell us about the Universe



The hot gas in Galaxy Clusters cause extra ripples

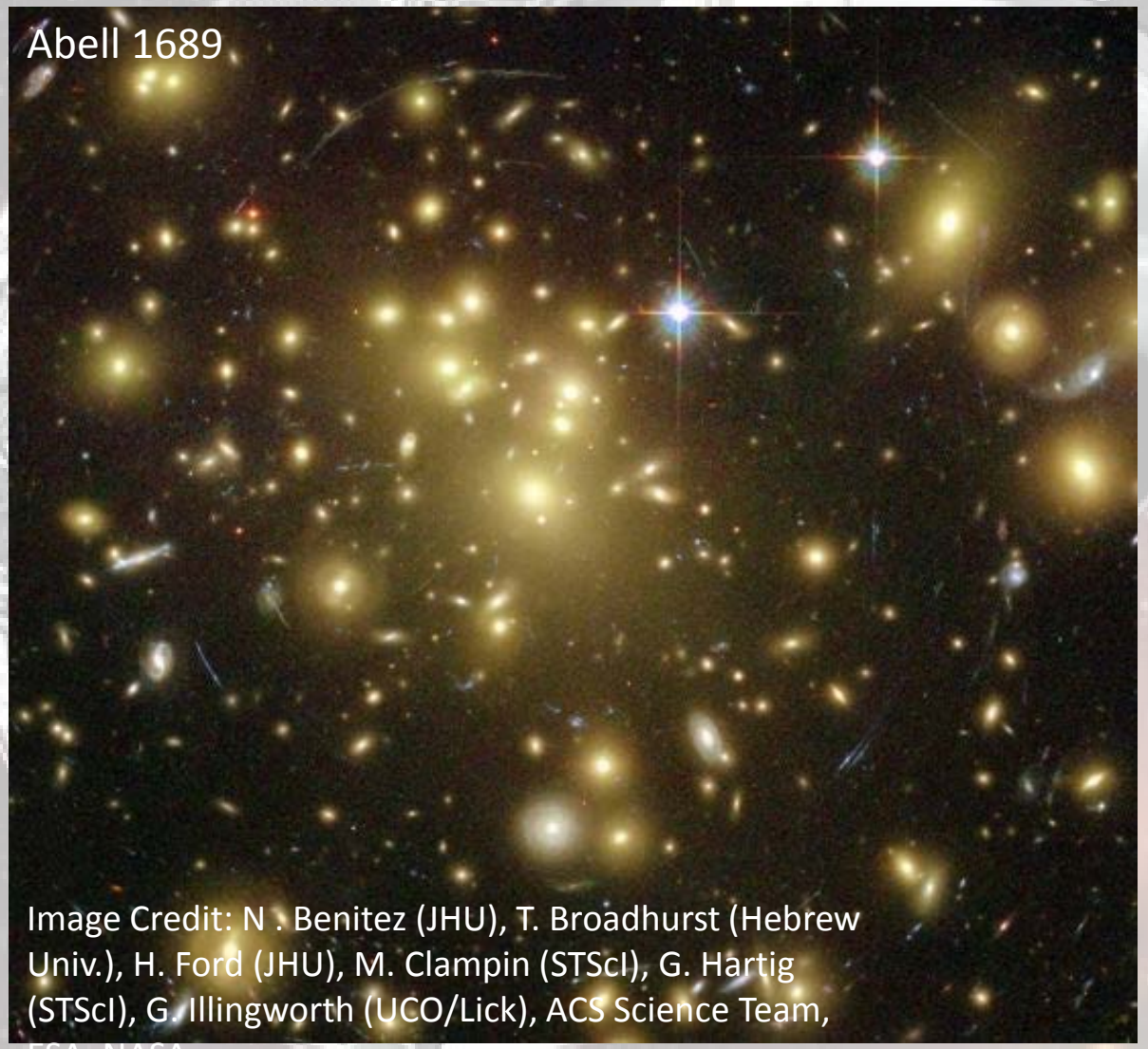


Image Credit: N . Benitez (JHU), T. Broadhurst (Hebrew Univ.), H. Ford (JHU), M. Clampin (STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick), ACS Science Team, ESA, NASA

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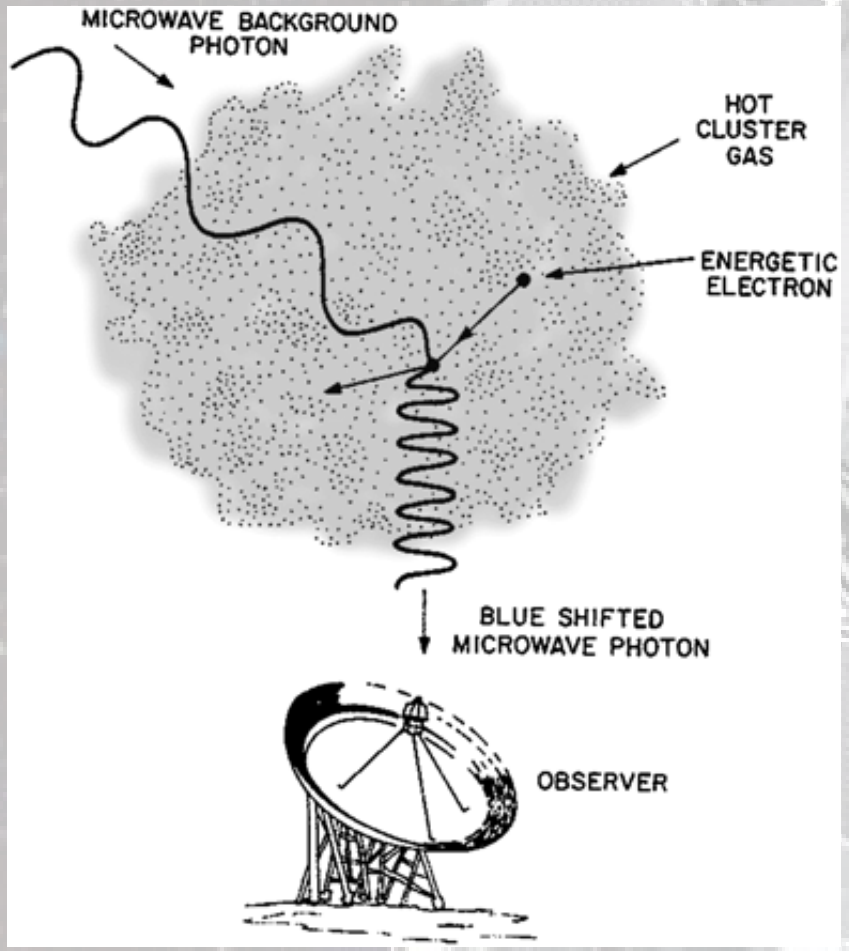


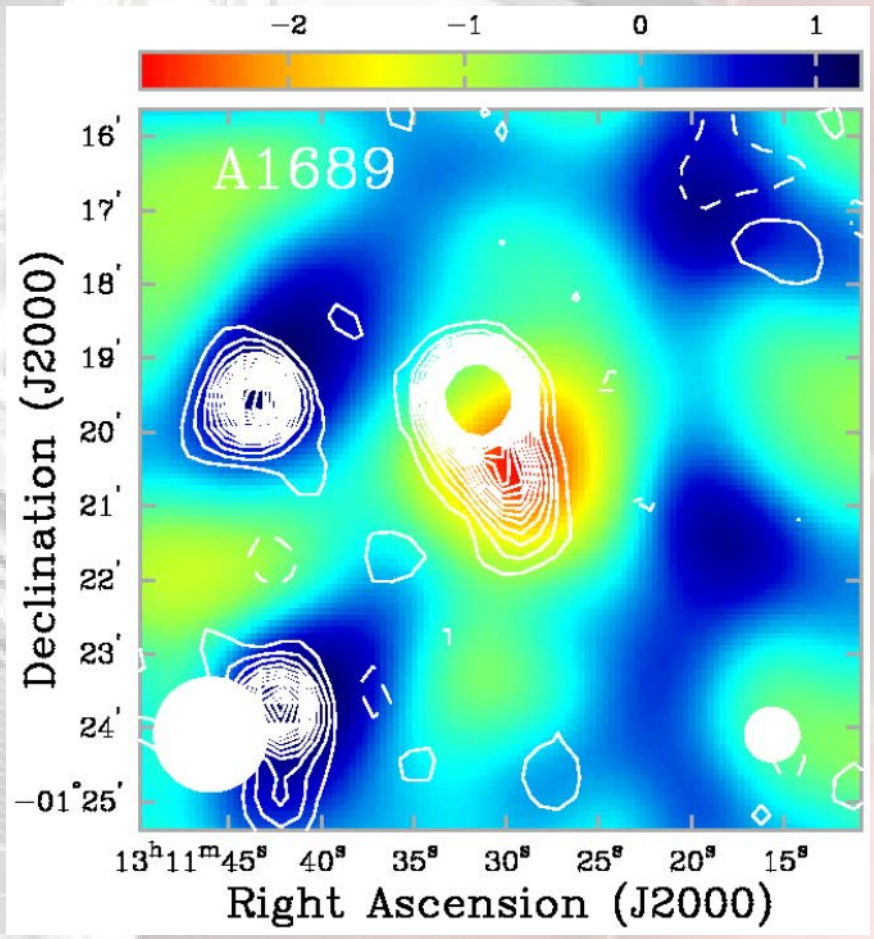


Image Credit: BIMA/OVRO Team

Clusters of Clusters of Galaxies (!)

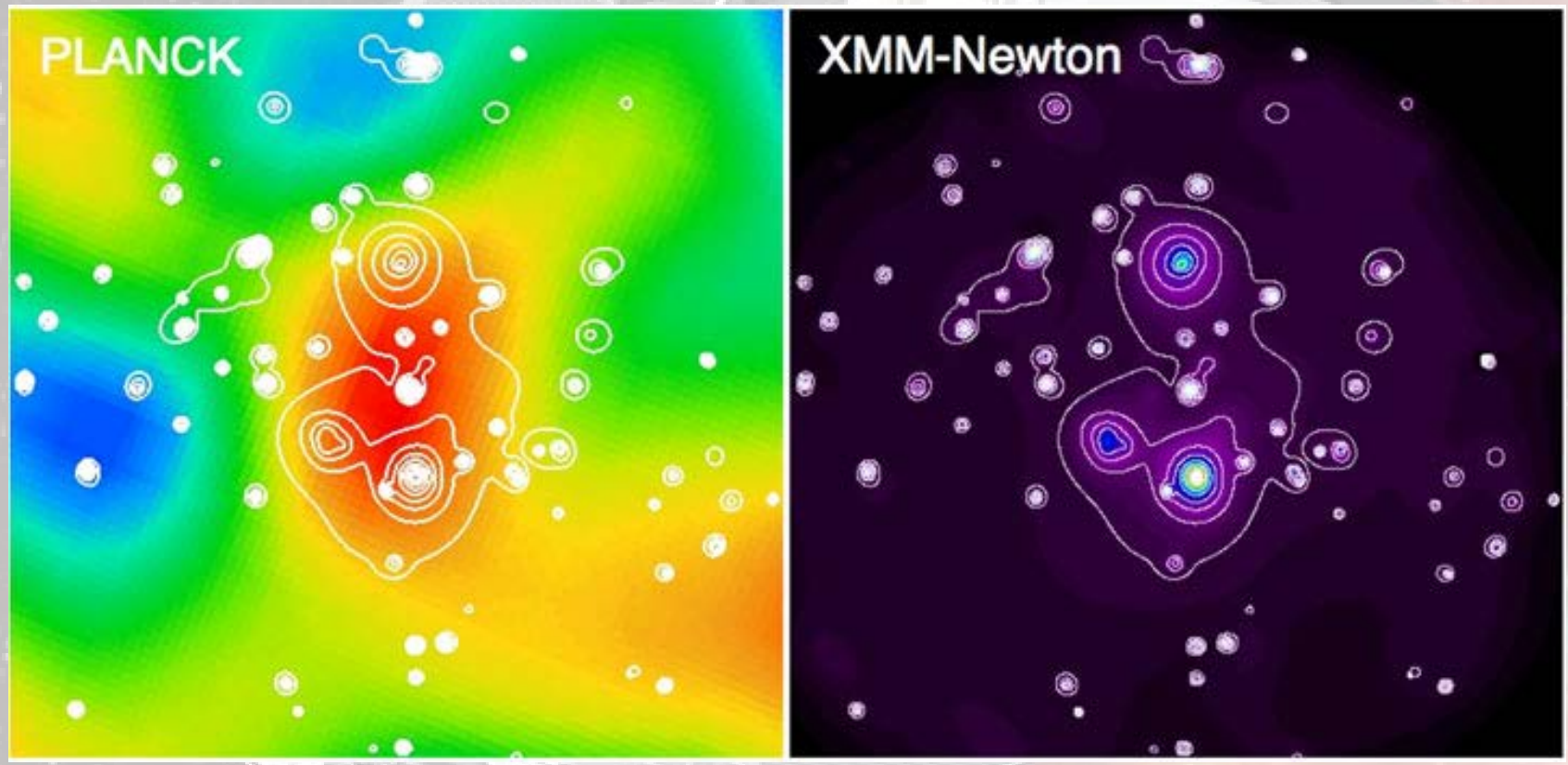
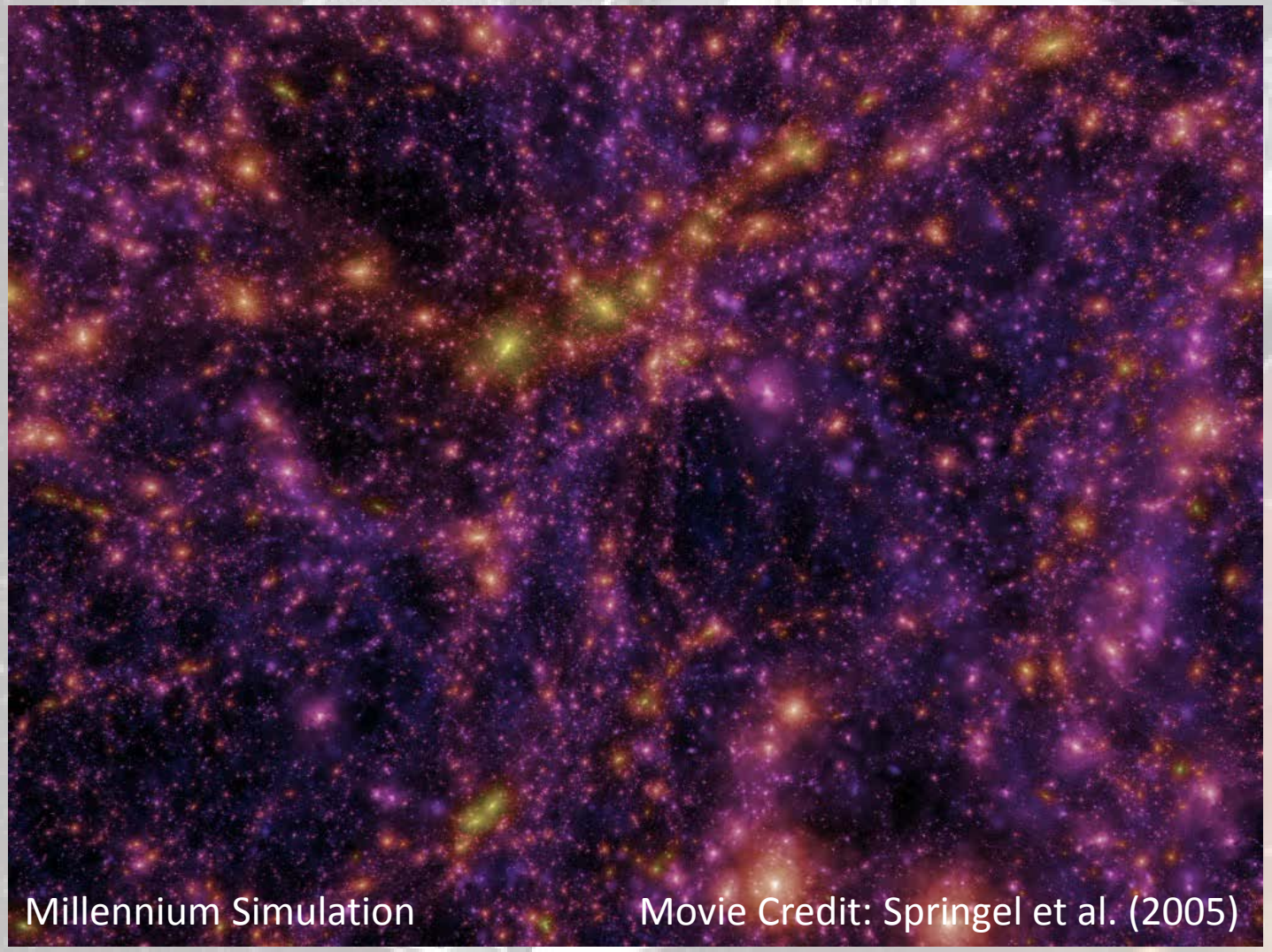


Image Credits: ESA, Planck HFI & LFI consortia, XMM-Newton.

We can build a model of our Universe



Thank you for listening!