

# EXTREME ASTROPHYSICS

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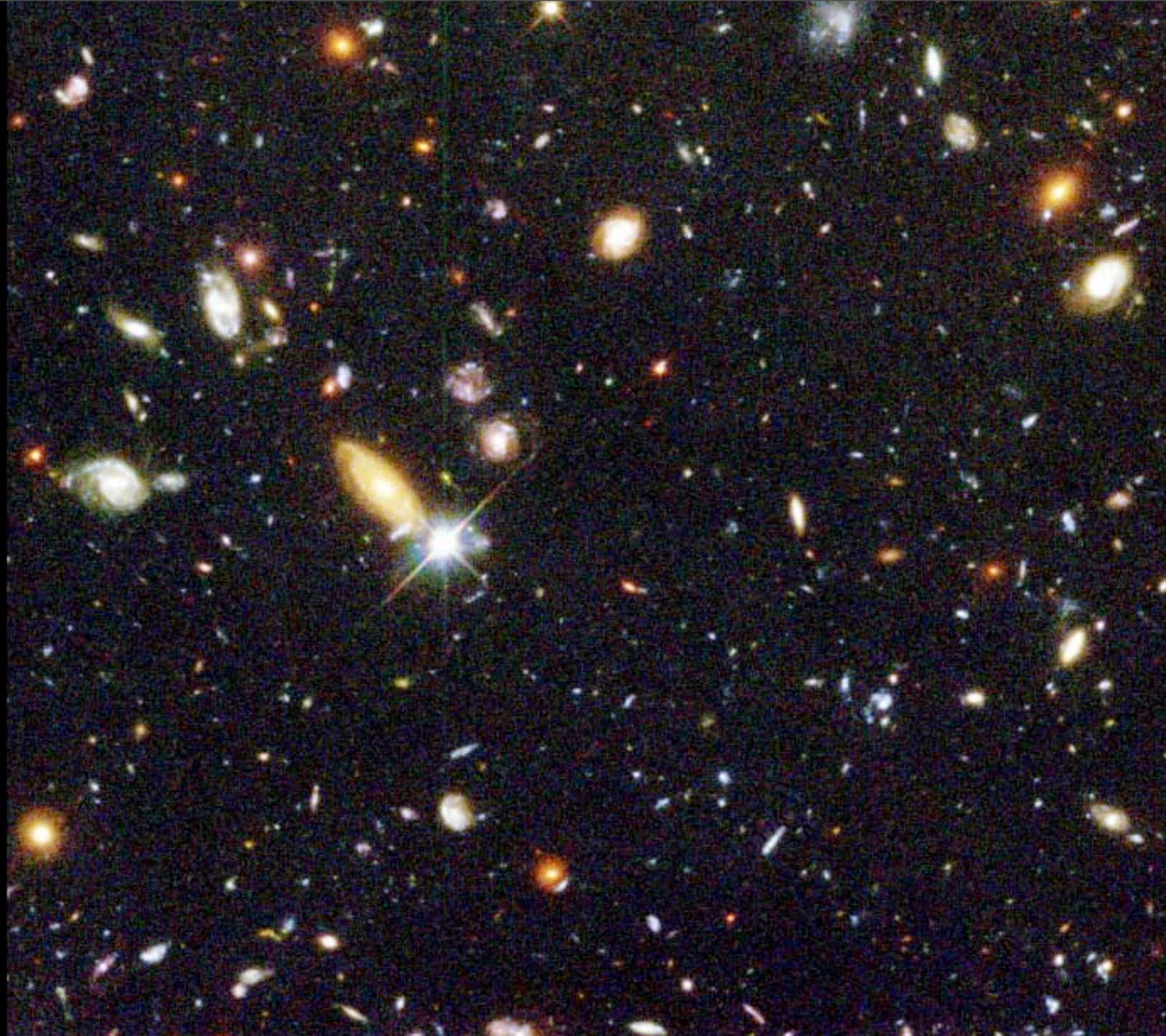
# CMB

- ✻ Canadian Mathematics Bulletin
- ✻ Capacity Management Branch
- ✻ Cosmic Microwave Background
- ✻ Cash Money Boys
- ✻ Call Me Back
- ✻ Chase-Manhattan Bank







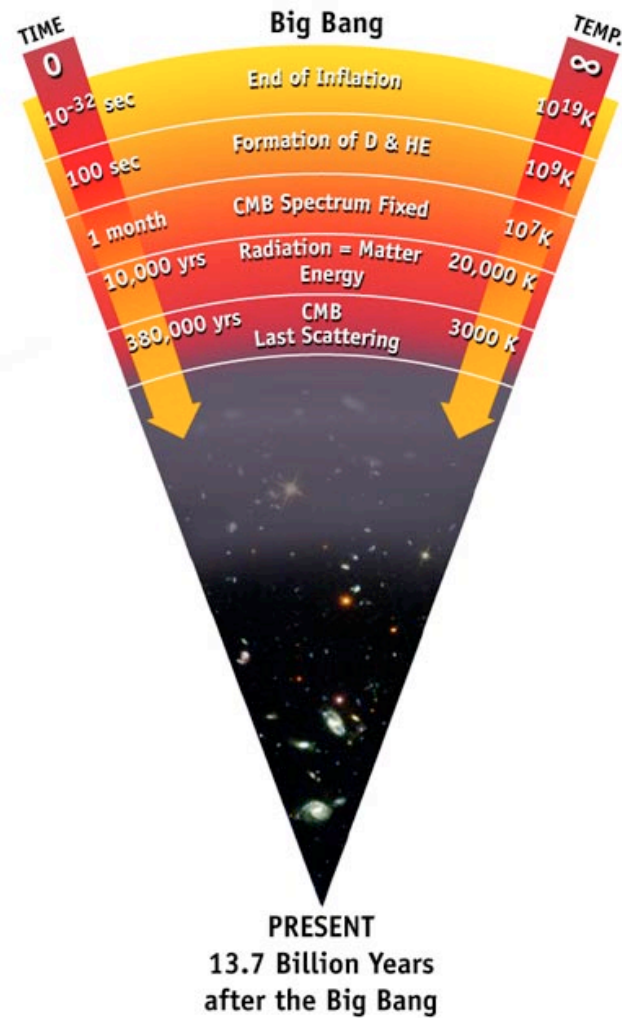


**Hubble Deep Field**

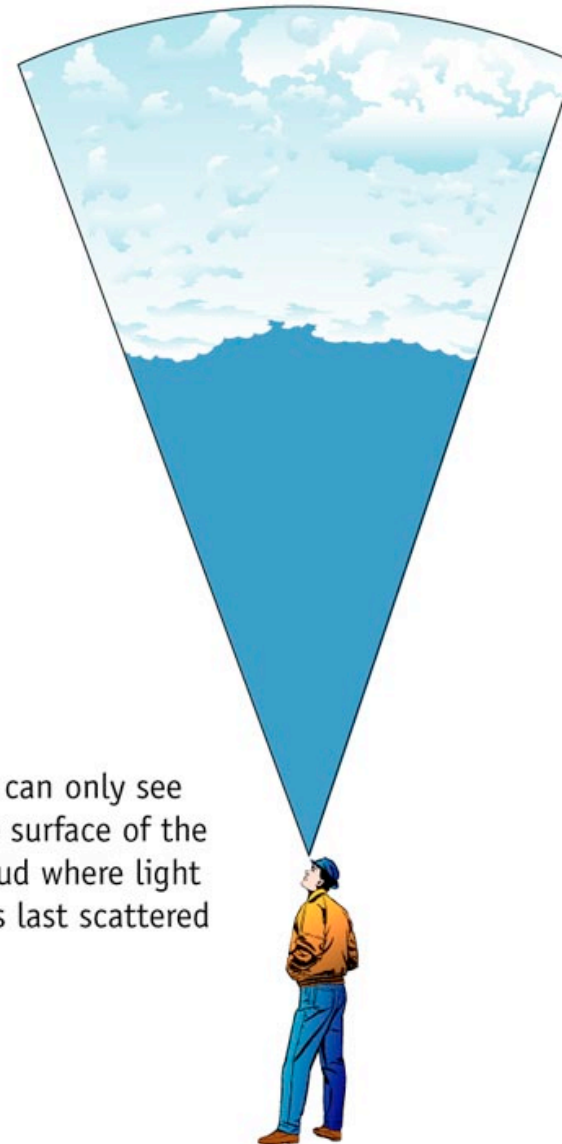
**HST • WFPC2**

PRC96-01a • ST ScI OPO • January 15, 1996 • R. Williams (ST ScI), NASA





The cosmic microwave background Radiation's "surface of last scatter" is analogous to the light coming through the clouds to our eye on a cloudy day.



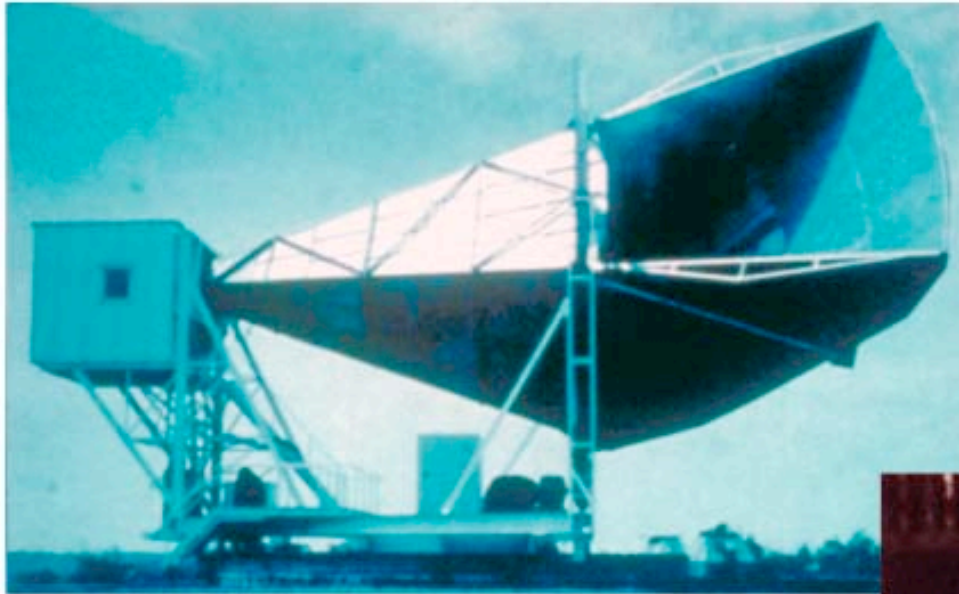
We can only see the surface of the cloud where light was last scattered

# what about at 400,000 yr?

# CMB

- [ Frequency:  $\sim$  GHz
- [ Wavelength:  $\sim$  mm
- [ Currently the best temperature is determined to be  $2.725 \pm 0.001$  kelvin ( $-270.425$  °C)
- [ **Why not in our backyard?**

# DISCOVERY OF COSMIC BACKGROUND

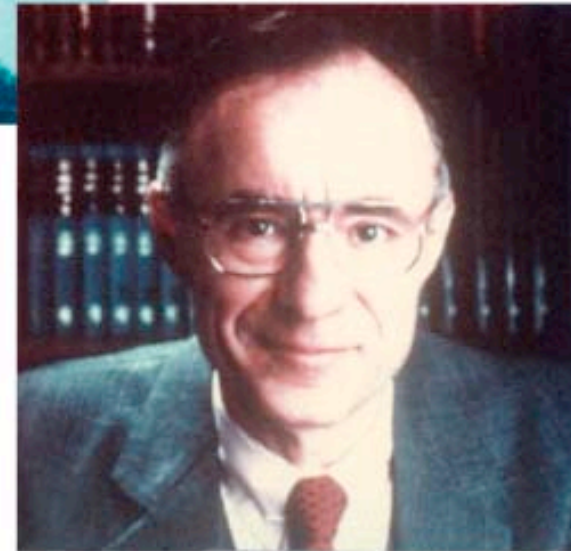


Microwave Receiver



MAP990045

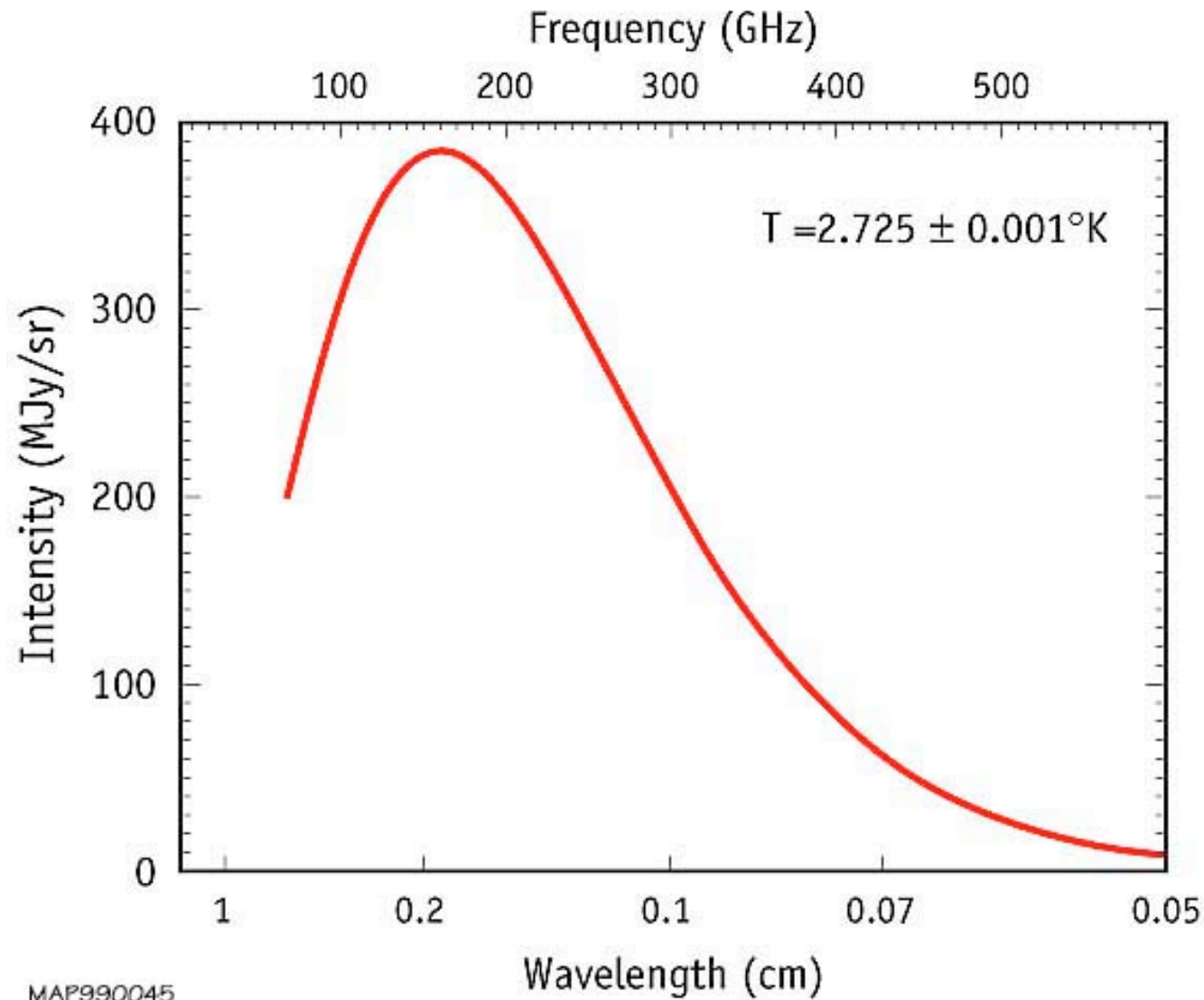
Robert Wilson



Arno Penzias

## Bell Labs 1978

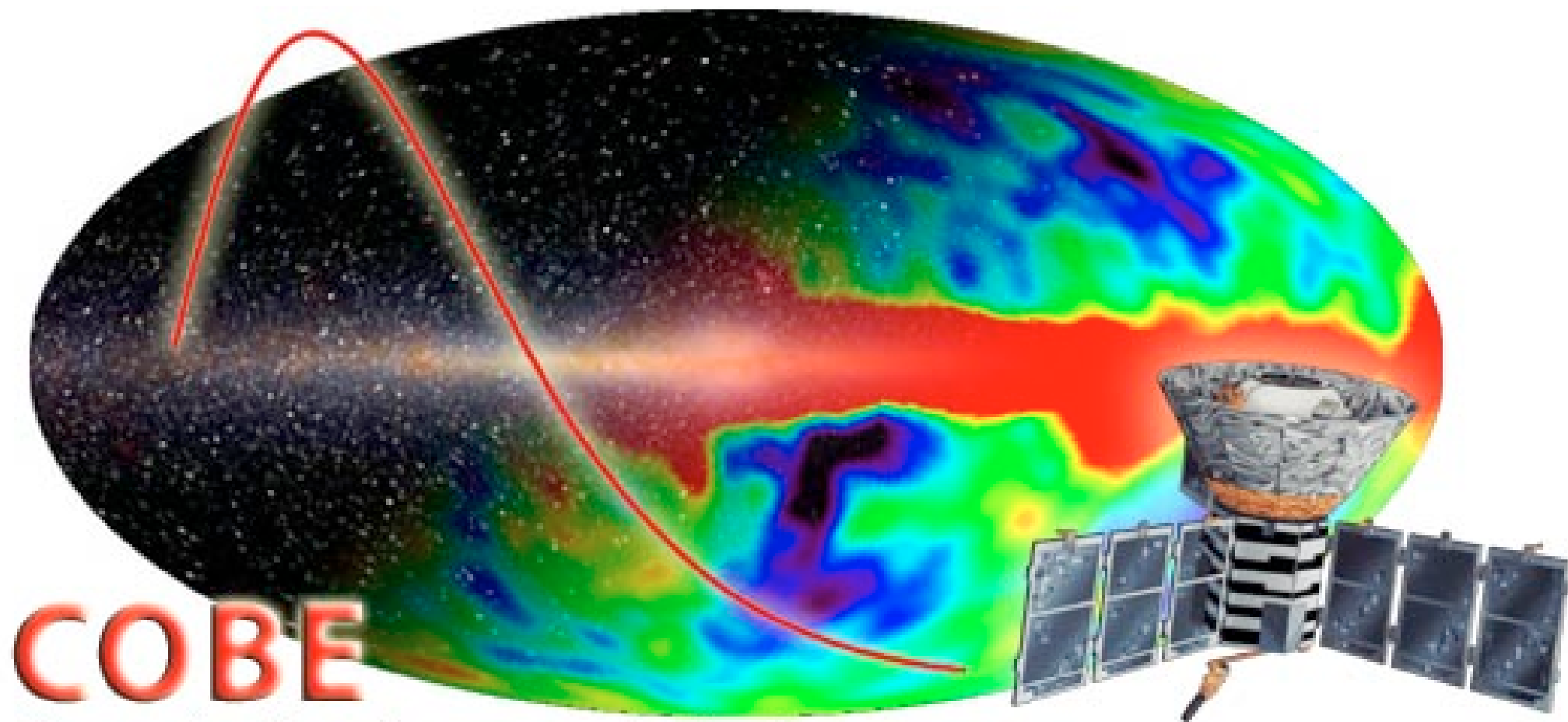
# SPECTRUM OF THE COSMIC MICROWAVE BACKGROUND



MAP990045

# FIRAS

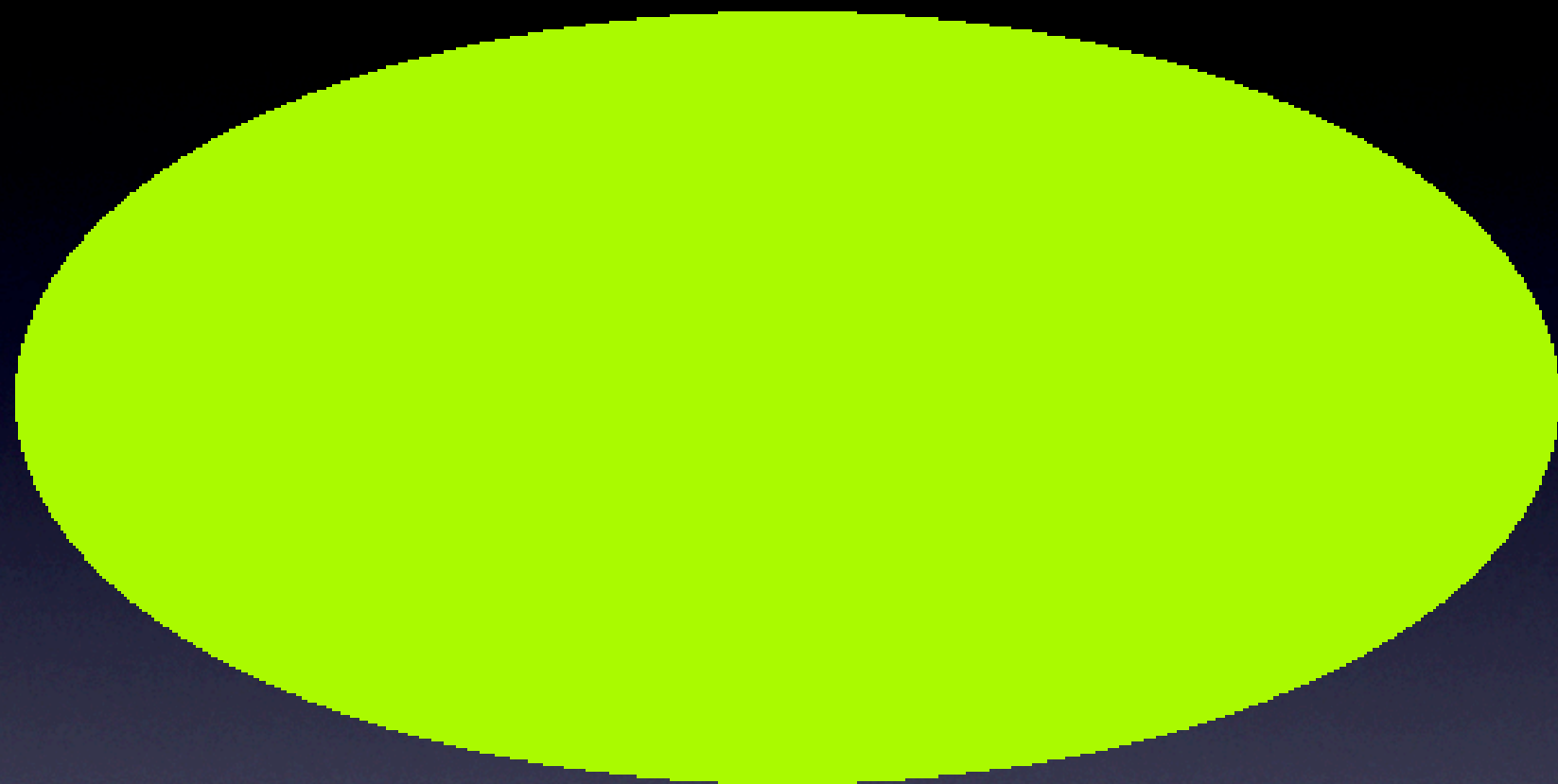




**COBE**

Cosmic Background Explorer

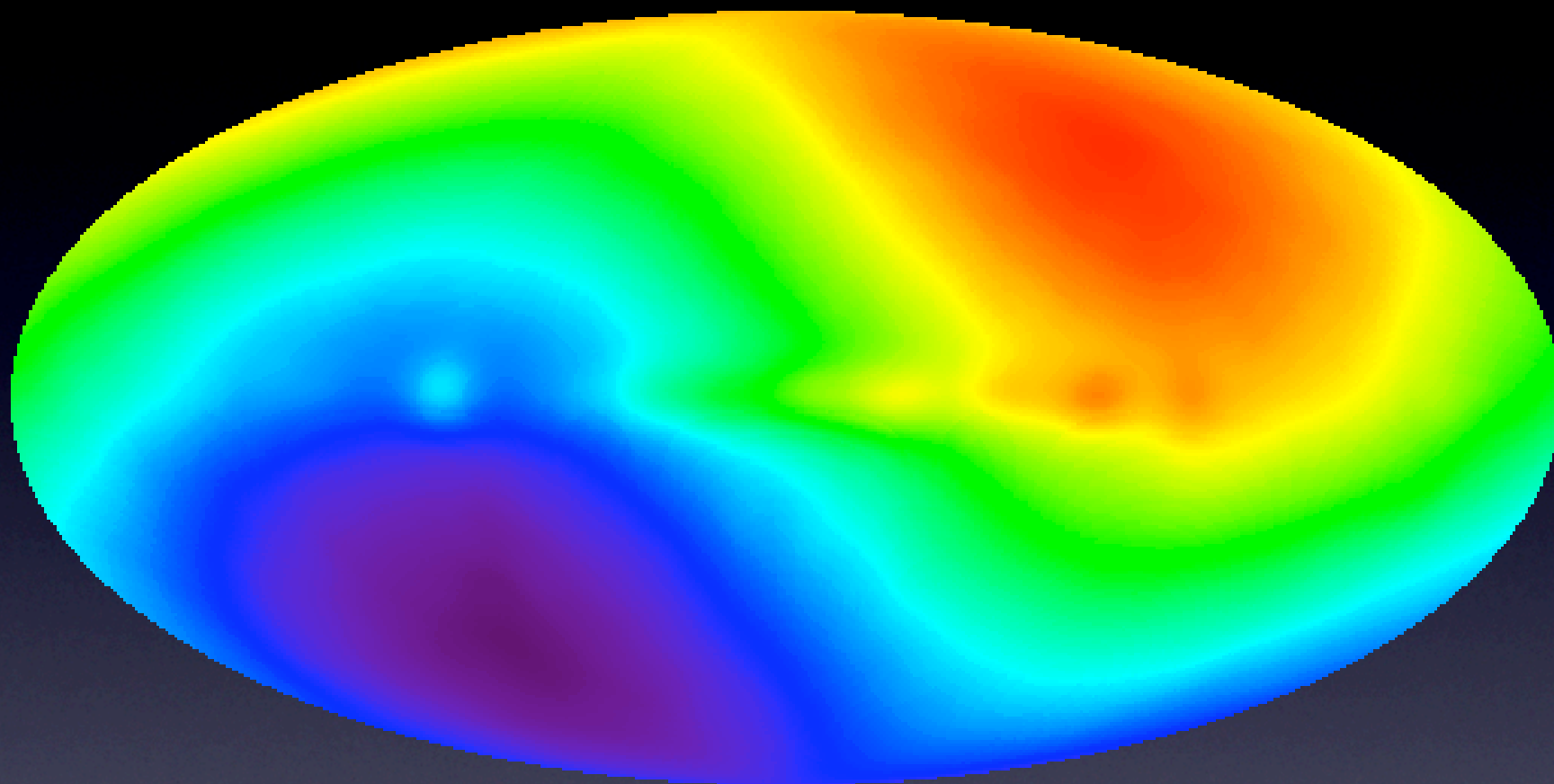




2.725 K

COBE - 1991

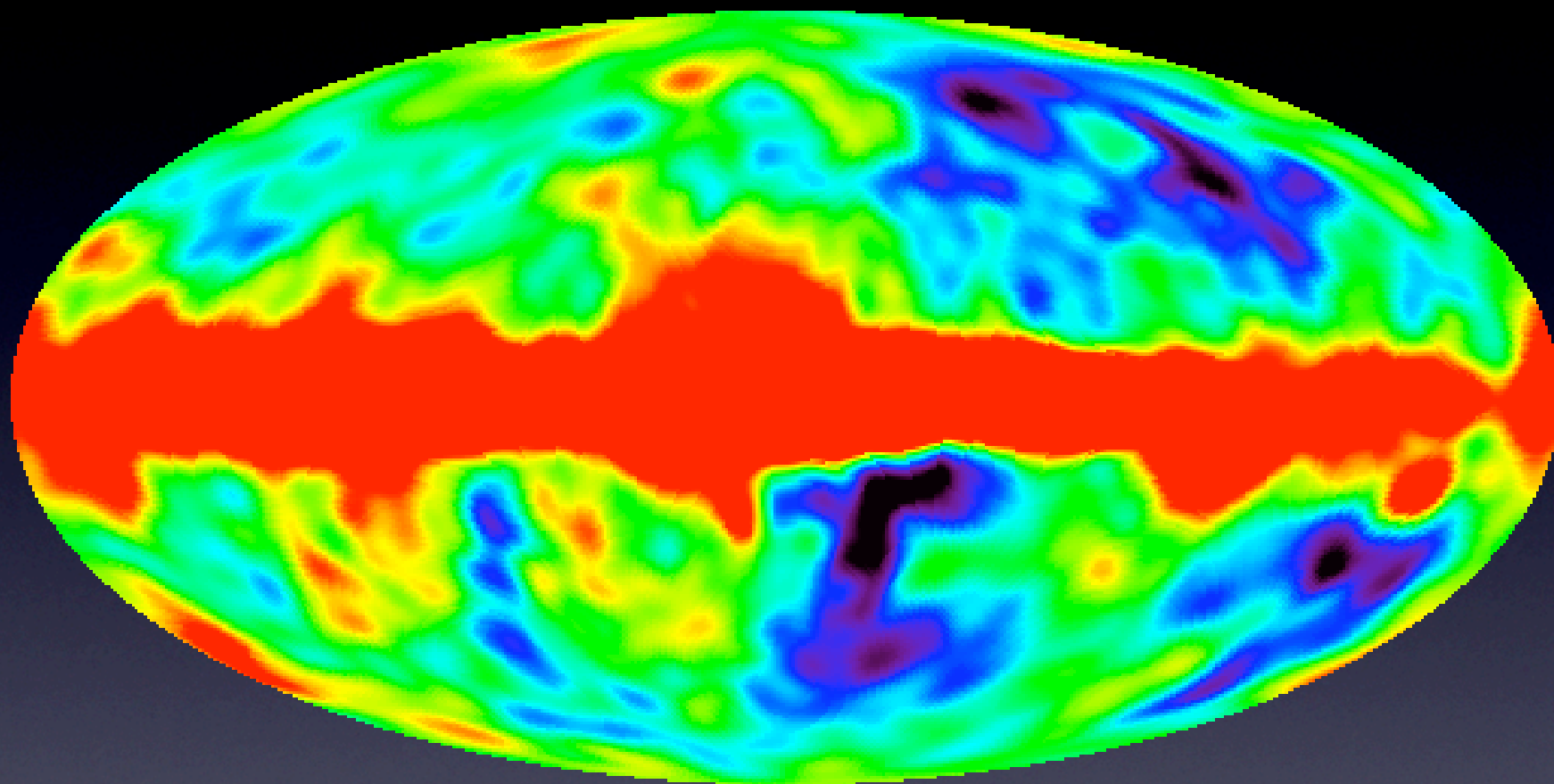




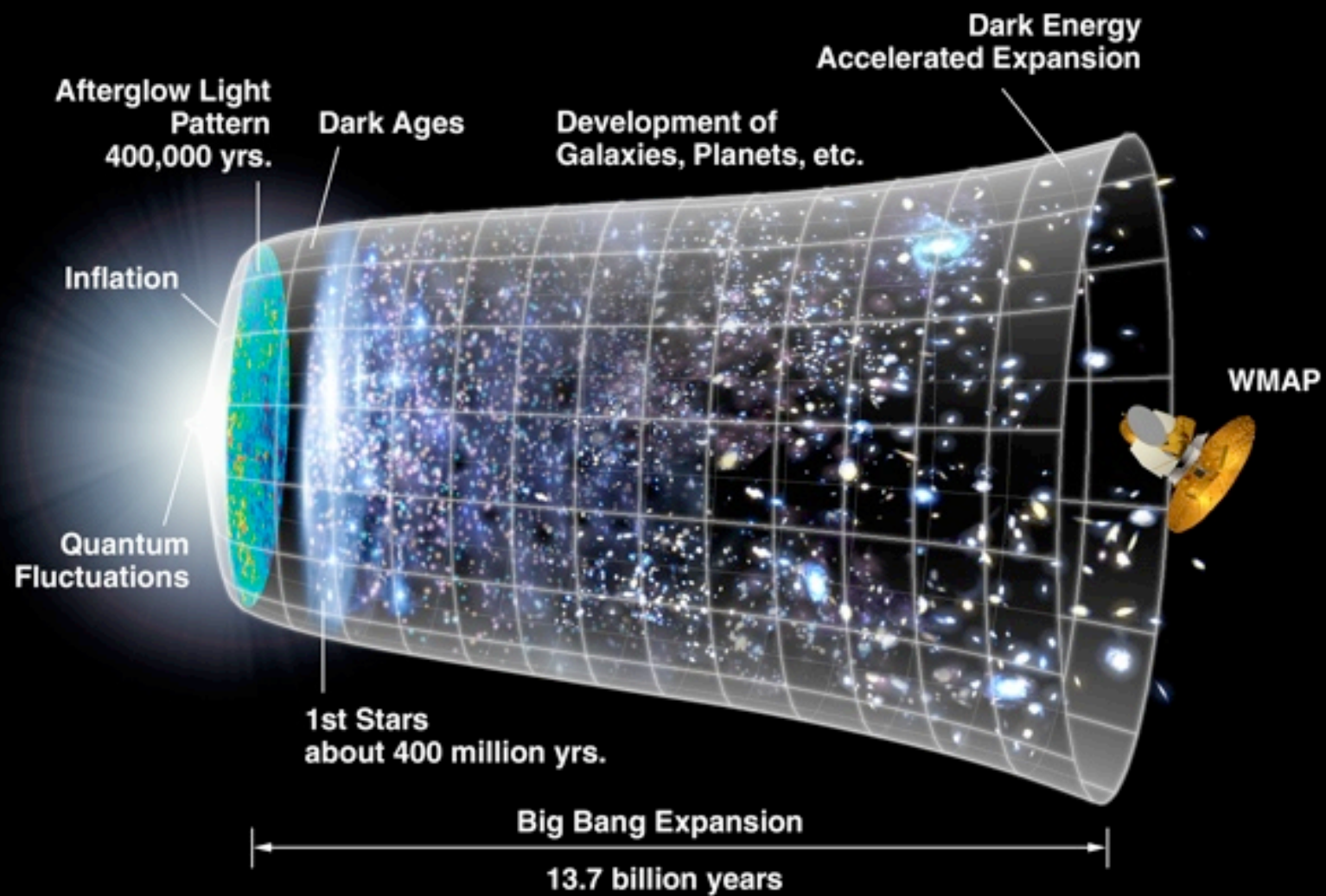
$v \sim 500 \text{ km/s}$

COBE - 1991

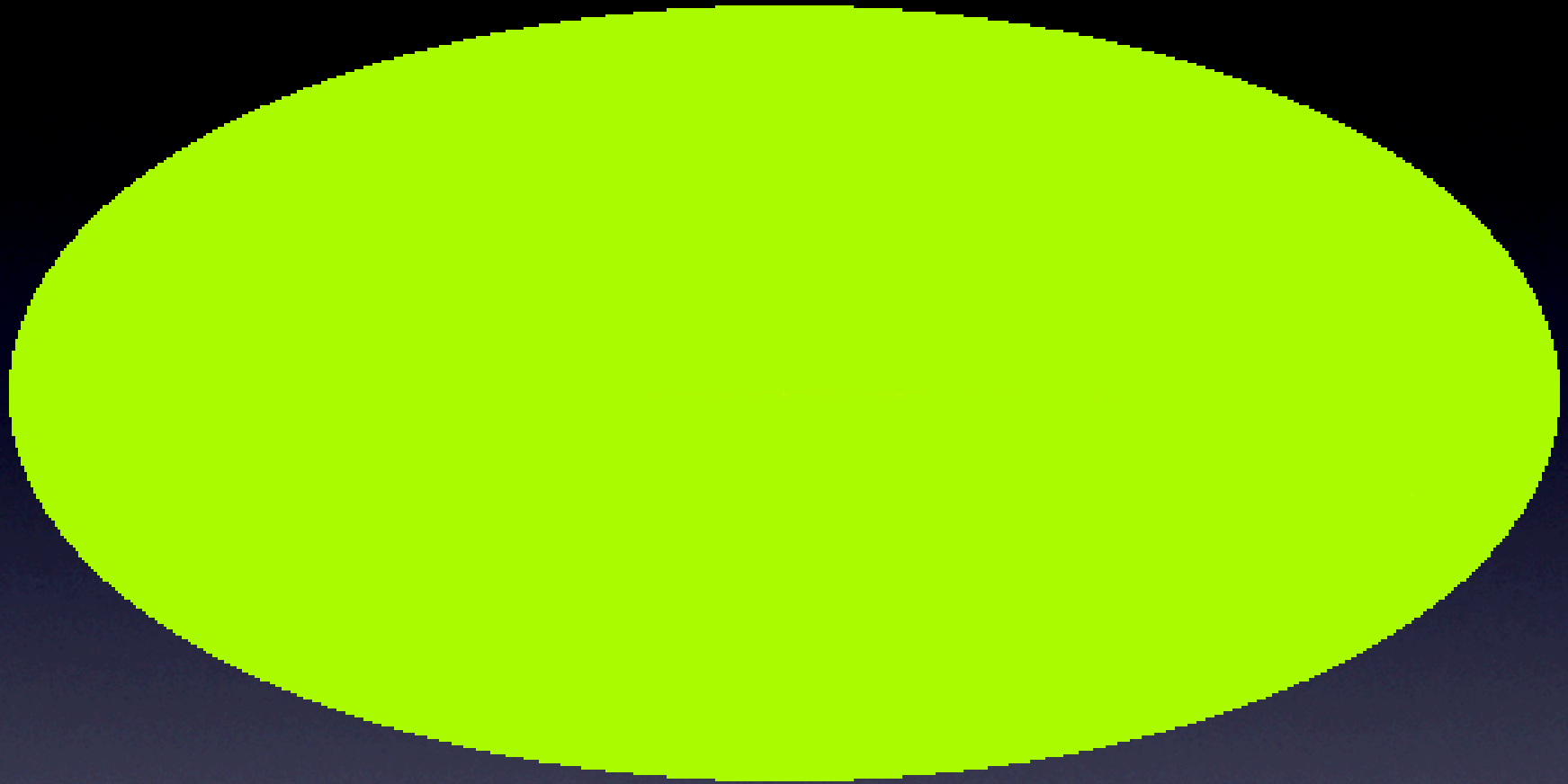




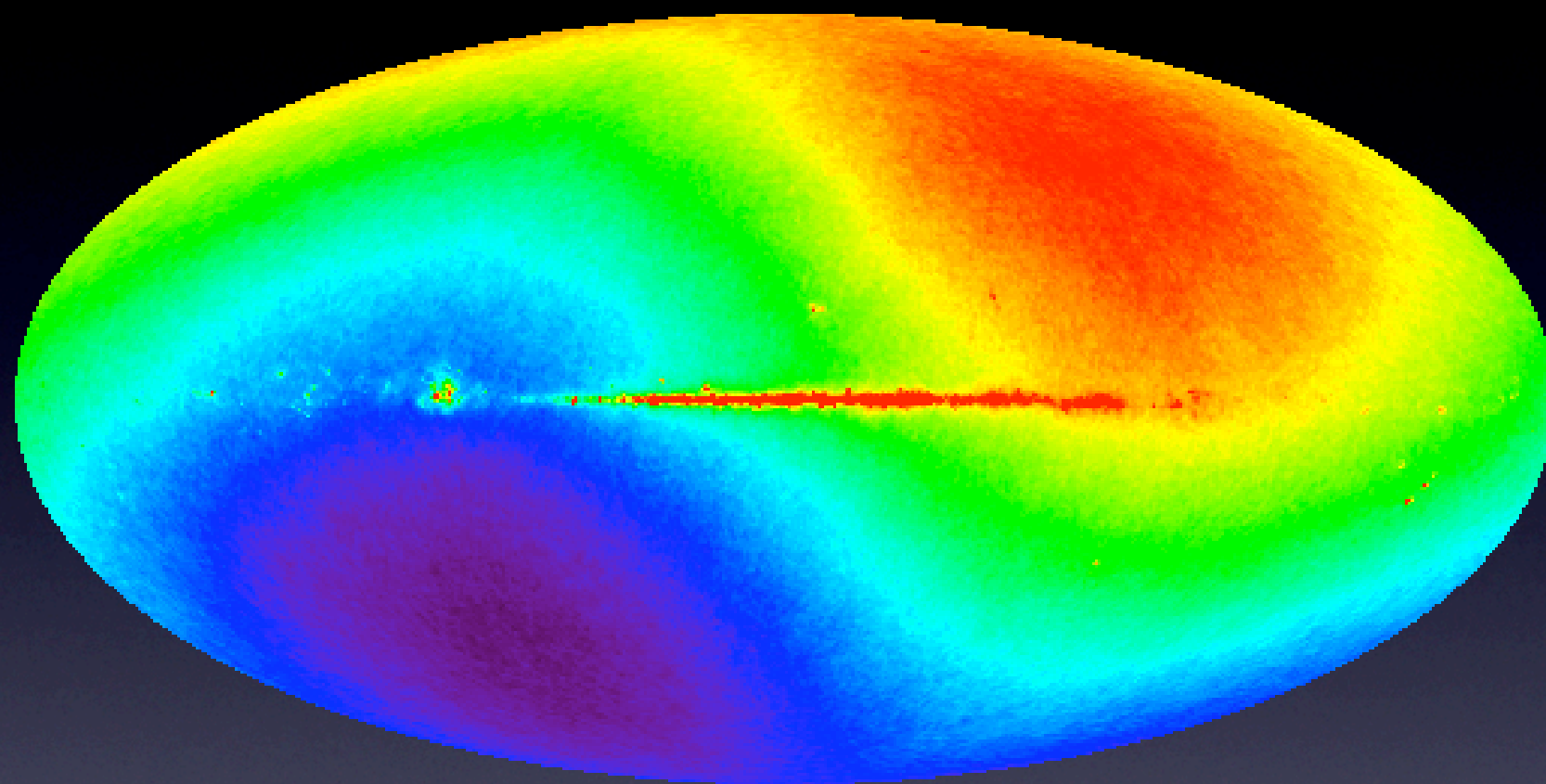
COBE - 1991







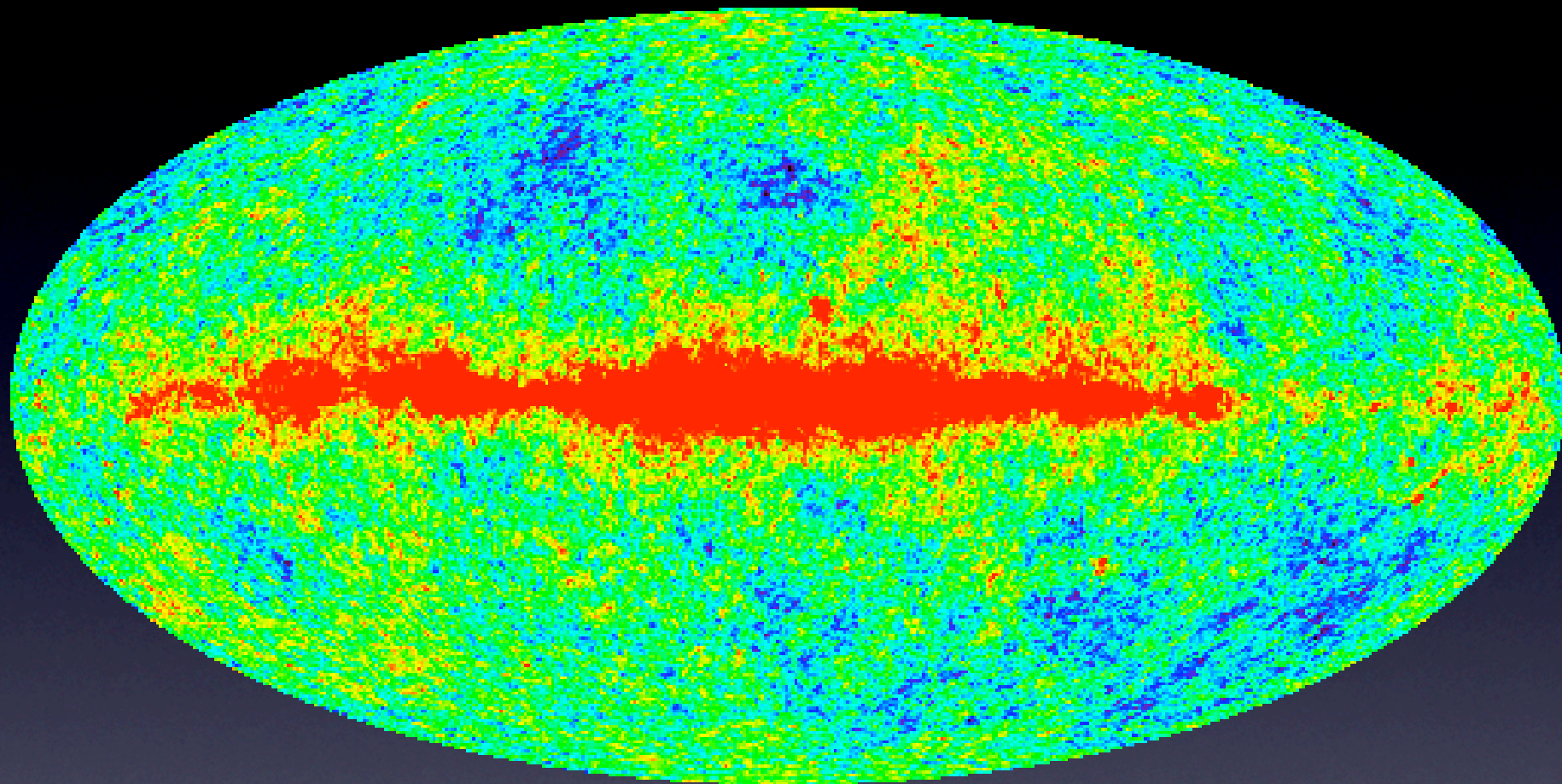
WMAP - 2003



$v \sim 500 \text{ km/s}$

WMAP - 2003





WMAP - 2003

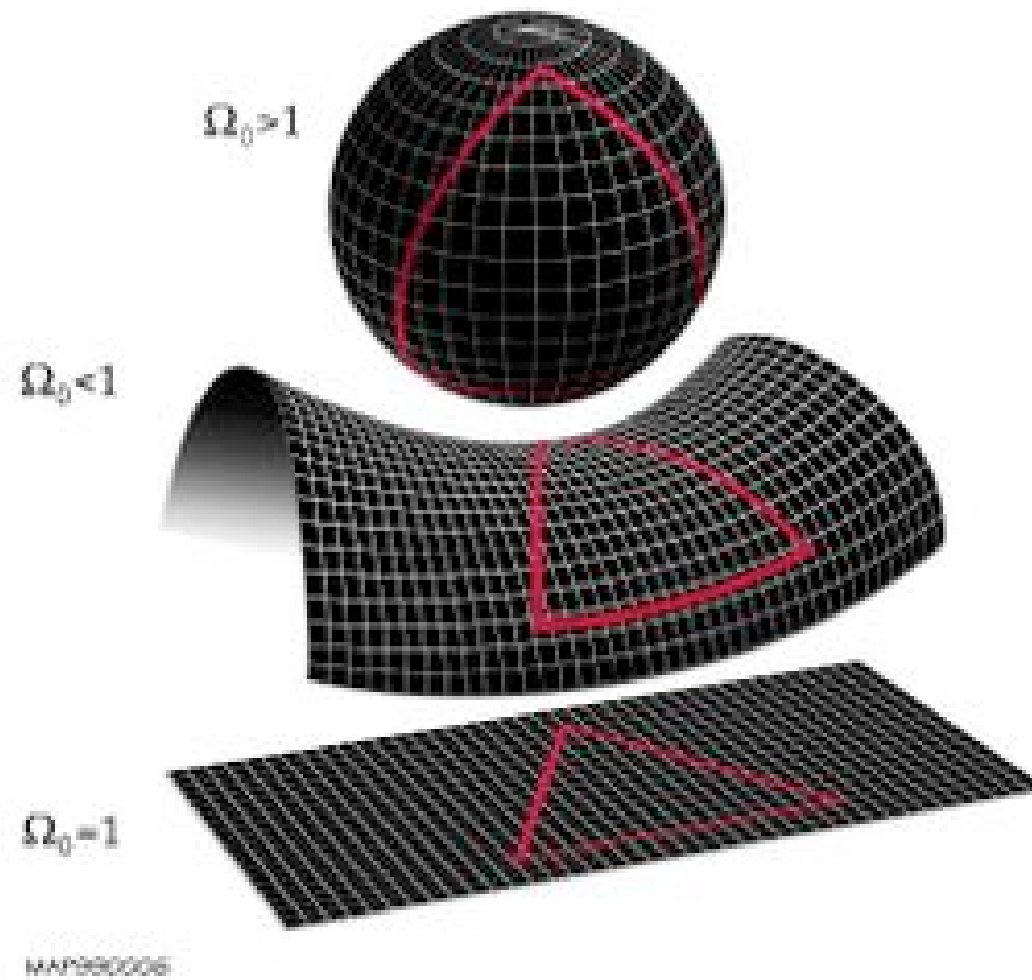
# WMAP (2003 - now)

- [ The additional resolution allows scientists to infer a great deal of additional information about conditions in the early universe.
- [ The density of the universe is close to critical, **this implies a flat universe**
- [ The fluctuations in the primordial density had the same amplitude on all scales





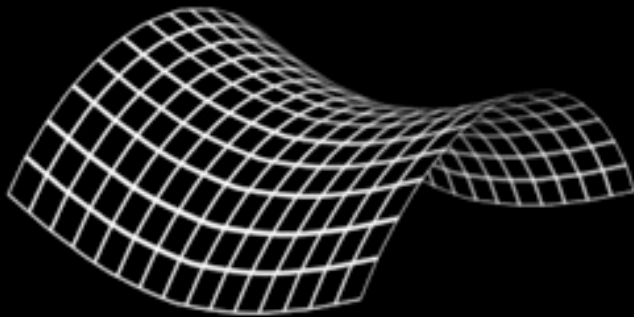
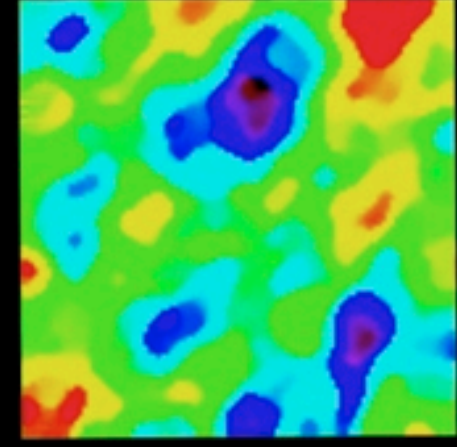
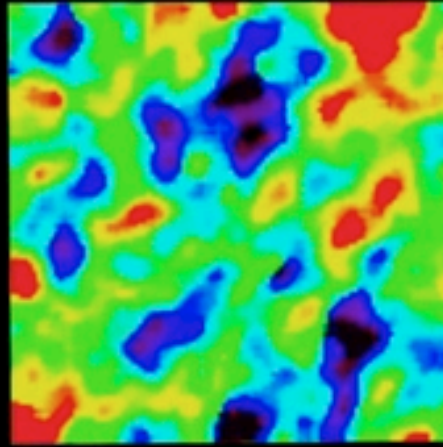
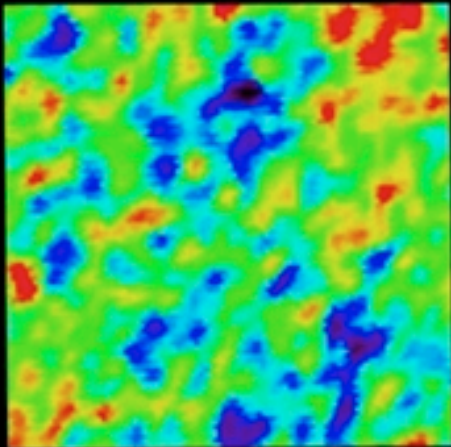
Just something pretty  
cold!



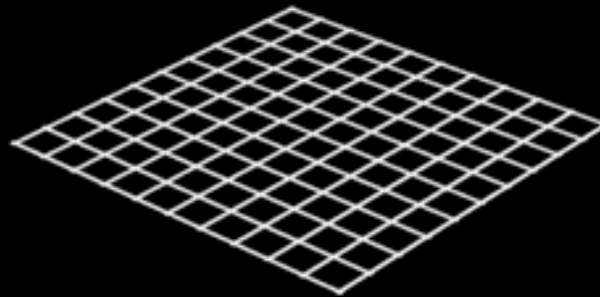
# Flatness Problem



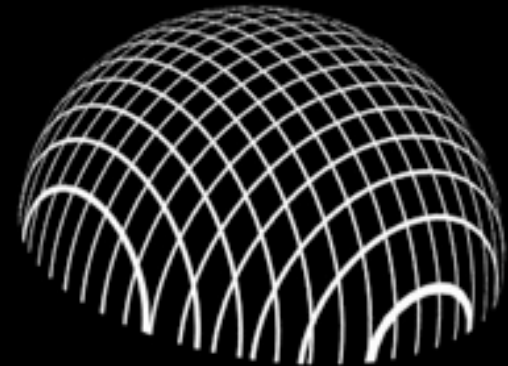
# GEOMETRY OF THE UNIVERSE



**OPEN**



**FLAT**



**CLOSED**

**Movie time!**