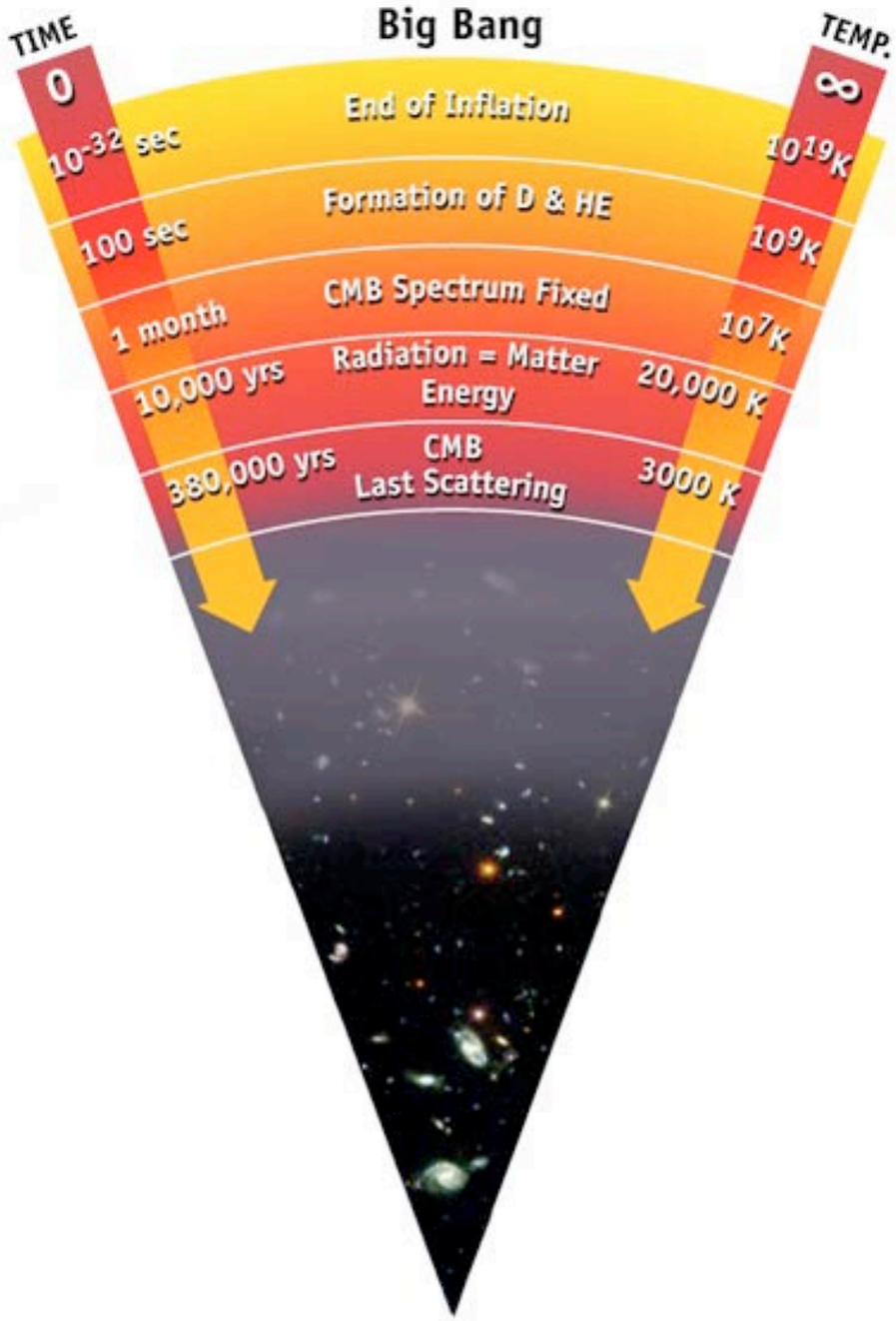
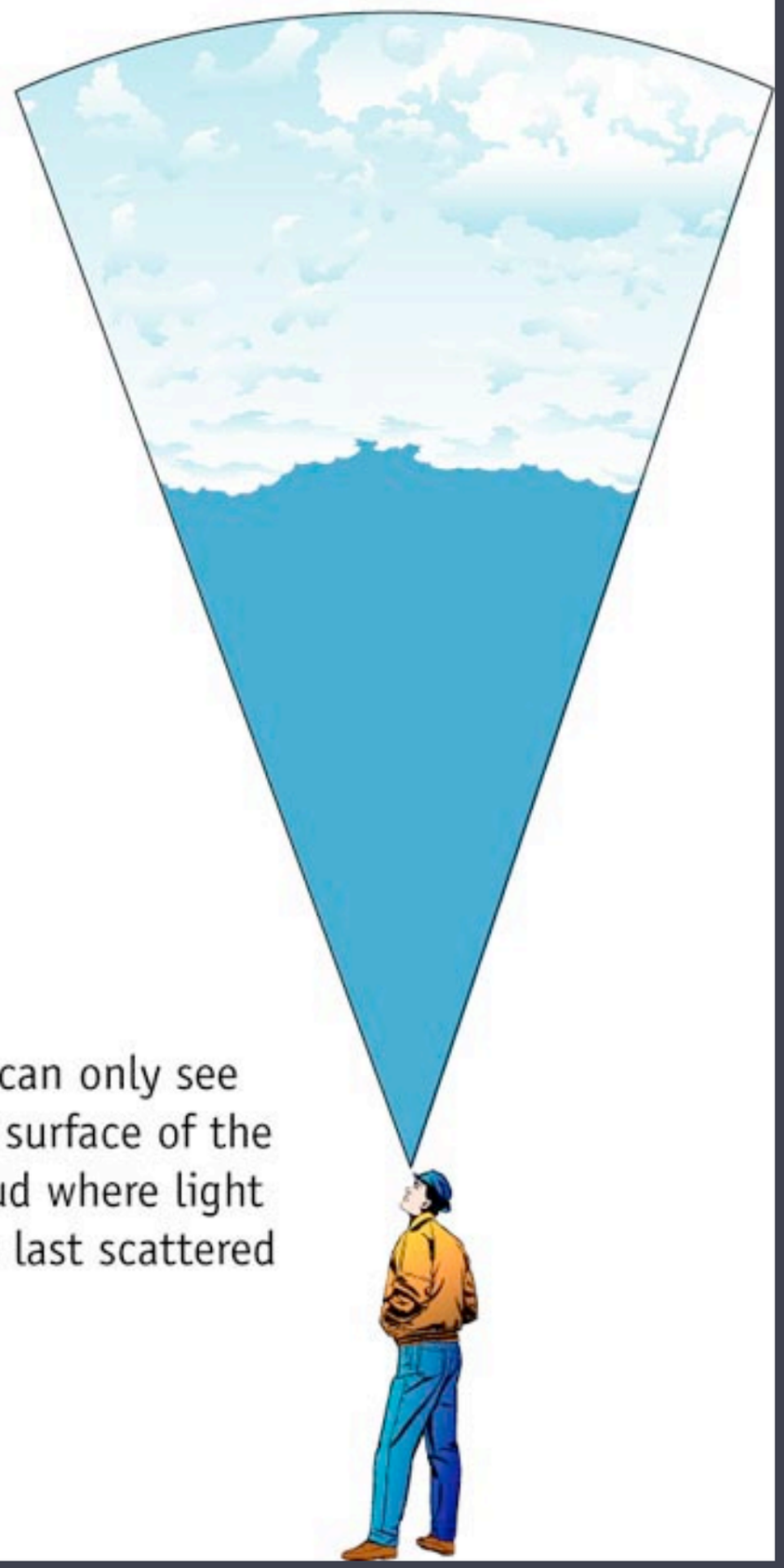
# hot things give off light: *blackbody* radiation



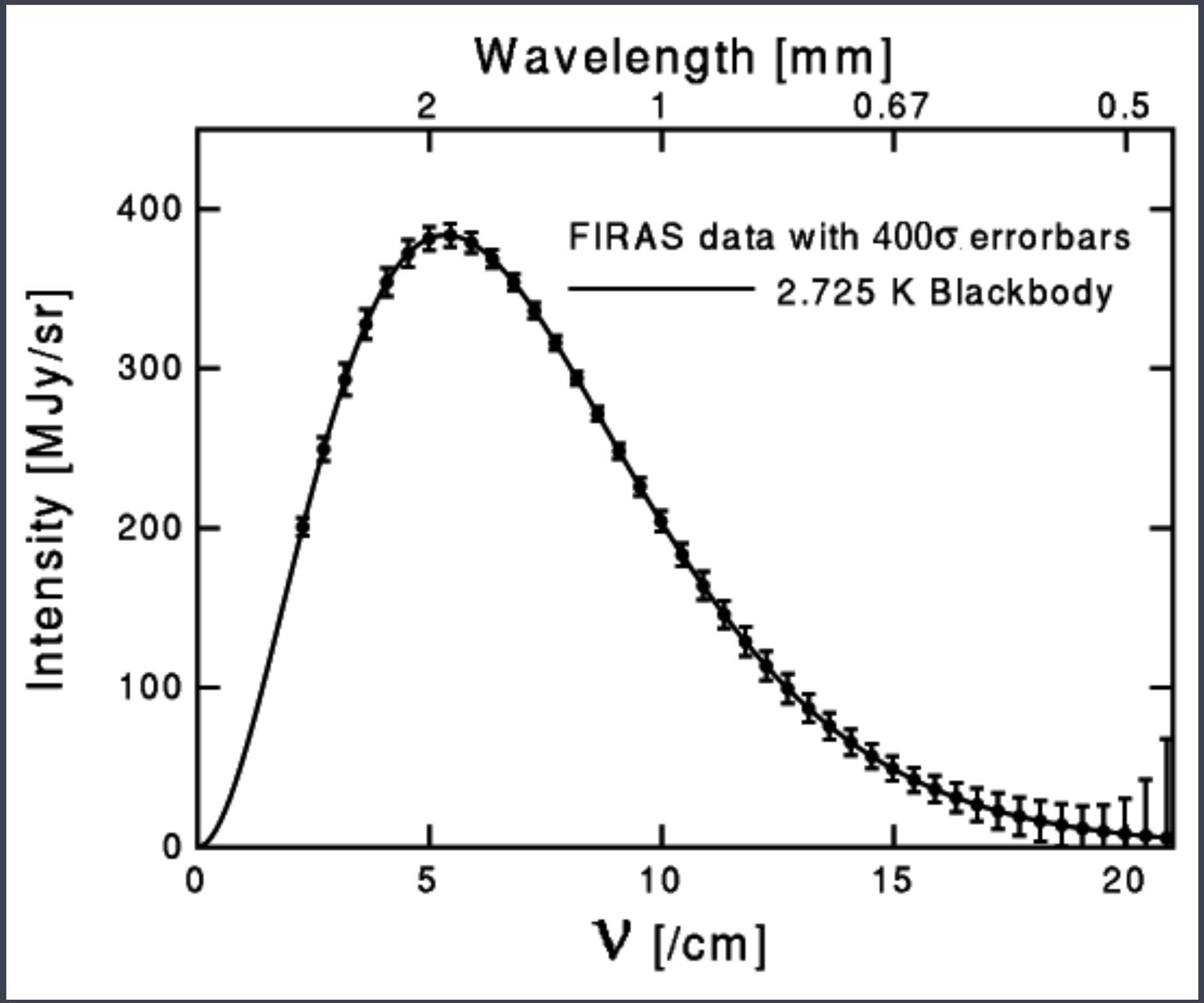

**PRESENT**
**13.7 Billion Years**
**after the Big Bang**

**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.**

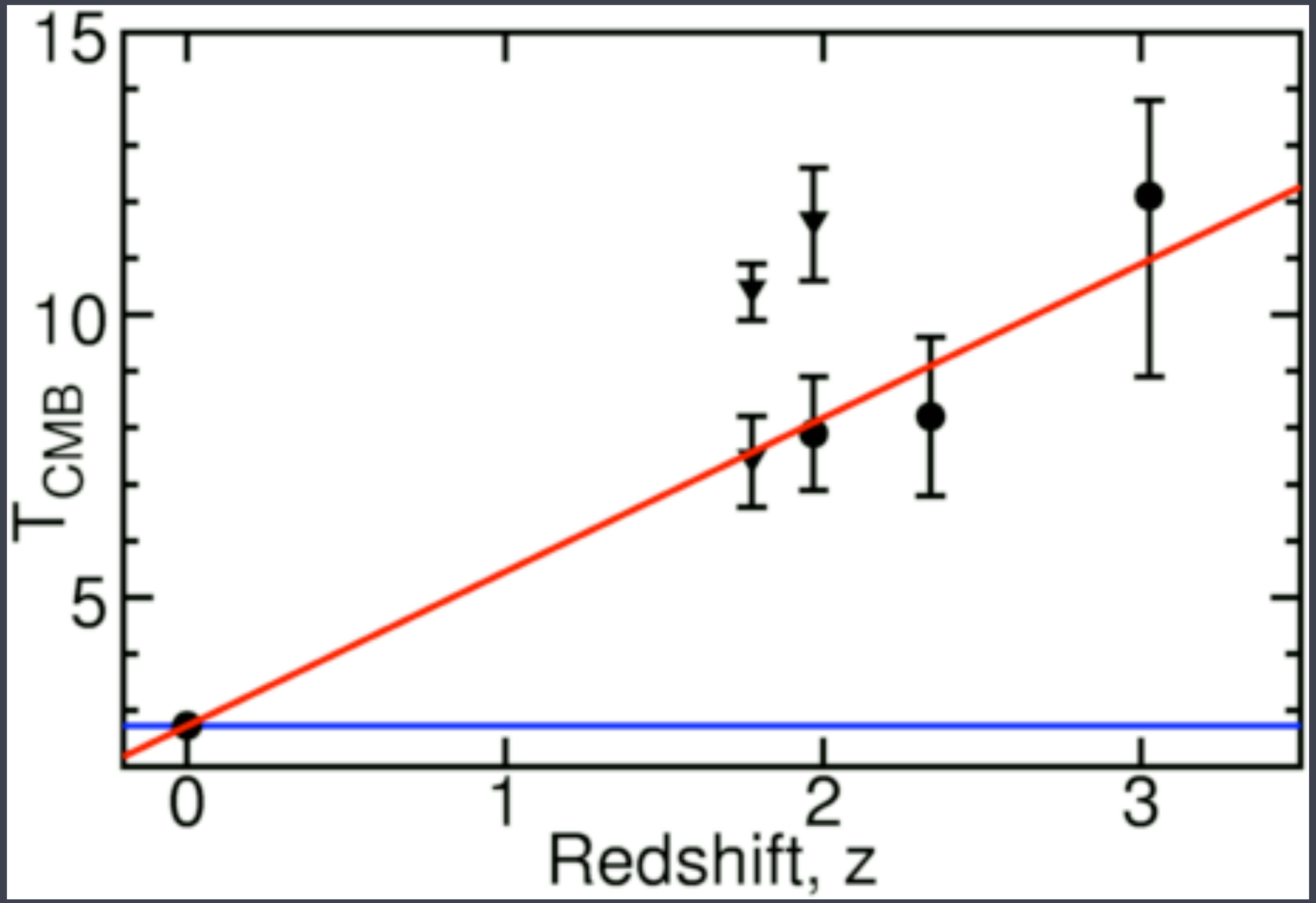


We can only see the surface of the cloud where light was last scattered

# First (1990) detailed measurement of the cosmic microwave background (CMB): COBE (J. Mather, Swarthmore '66)



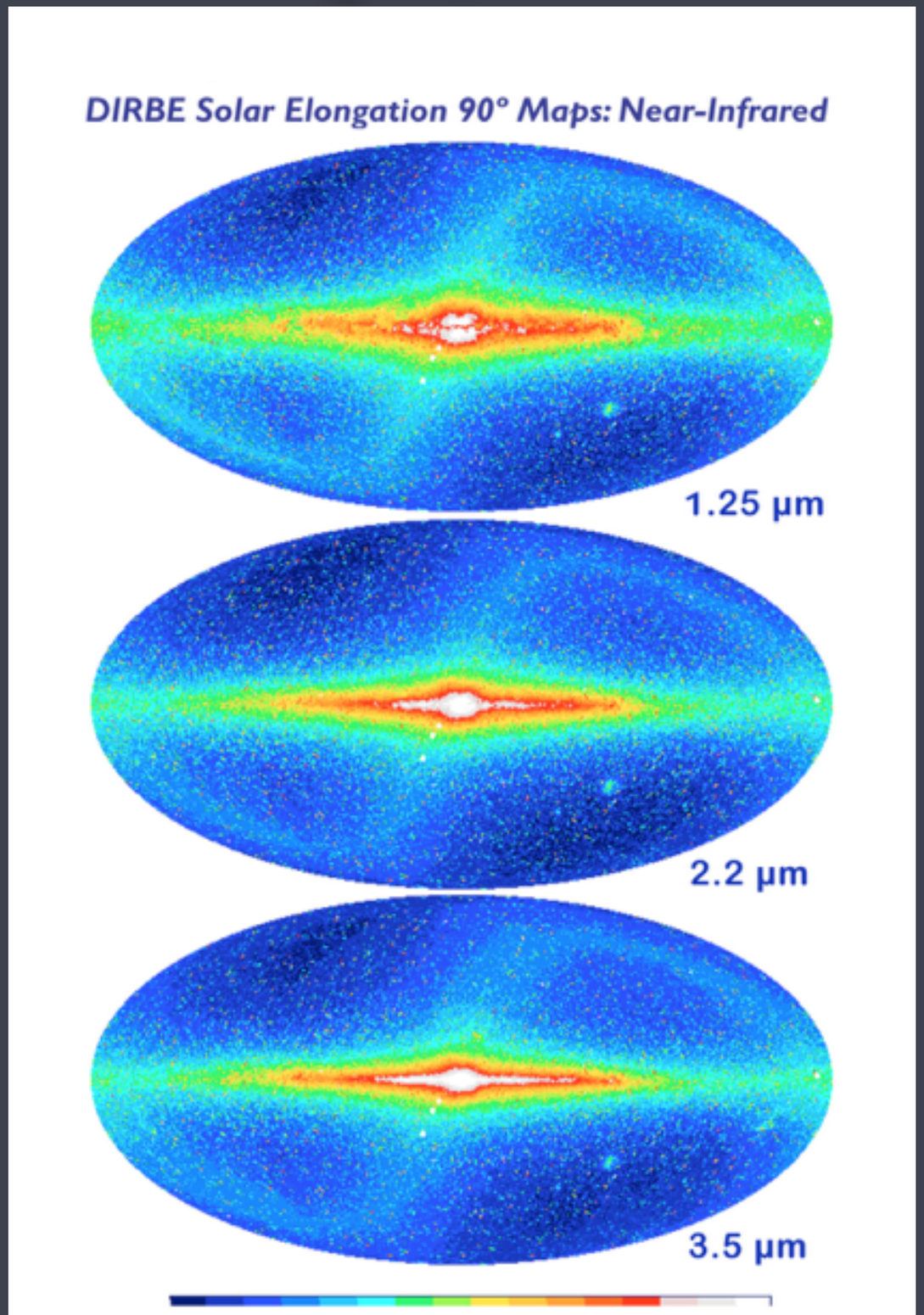
# *inferred* local $T_{CMB}$ from temperatures of gas clouds




as we look further away (and further back in time) the CMB is hotter

# COBE (early 1990s) - first detailed map of the CMB

## at several wavelengths, and over the whole sky

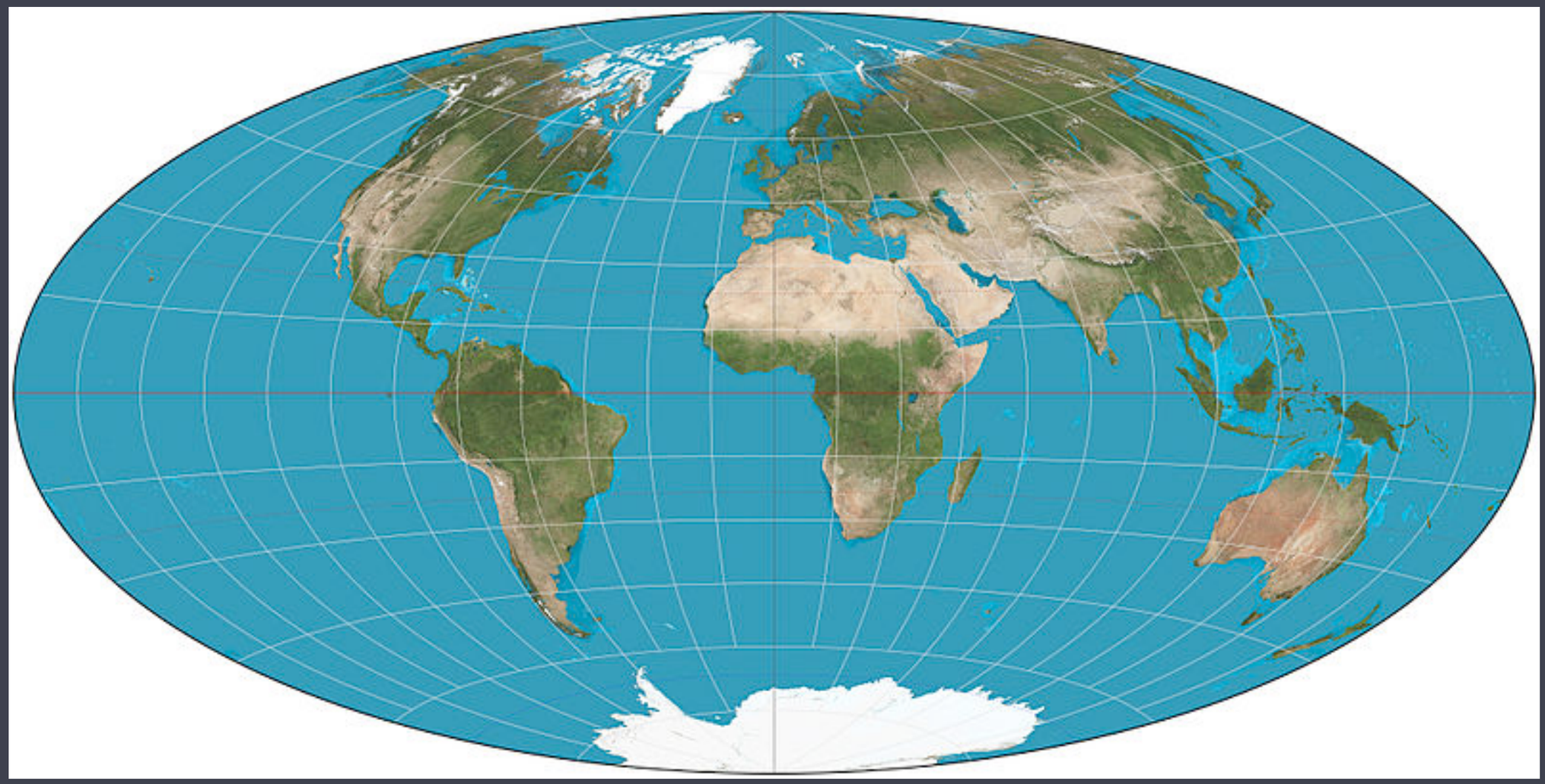


That's a coordinate system centered on the plane of the Milky Way

Here's what the Milky Way looks like in the sky, seen from the ground

# That's a coordinate system centered on the plane of the Milky Way

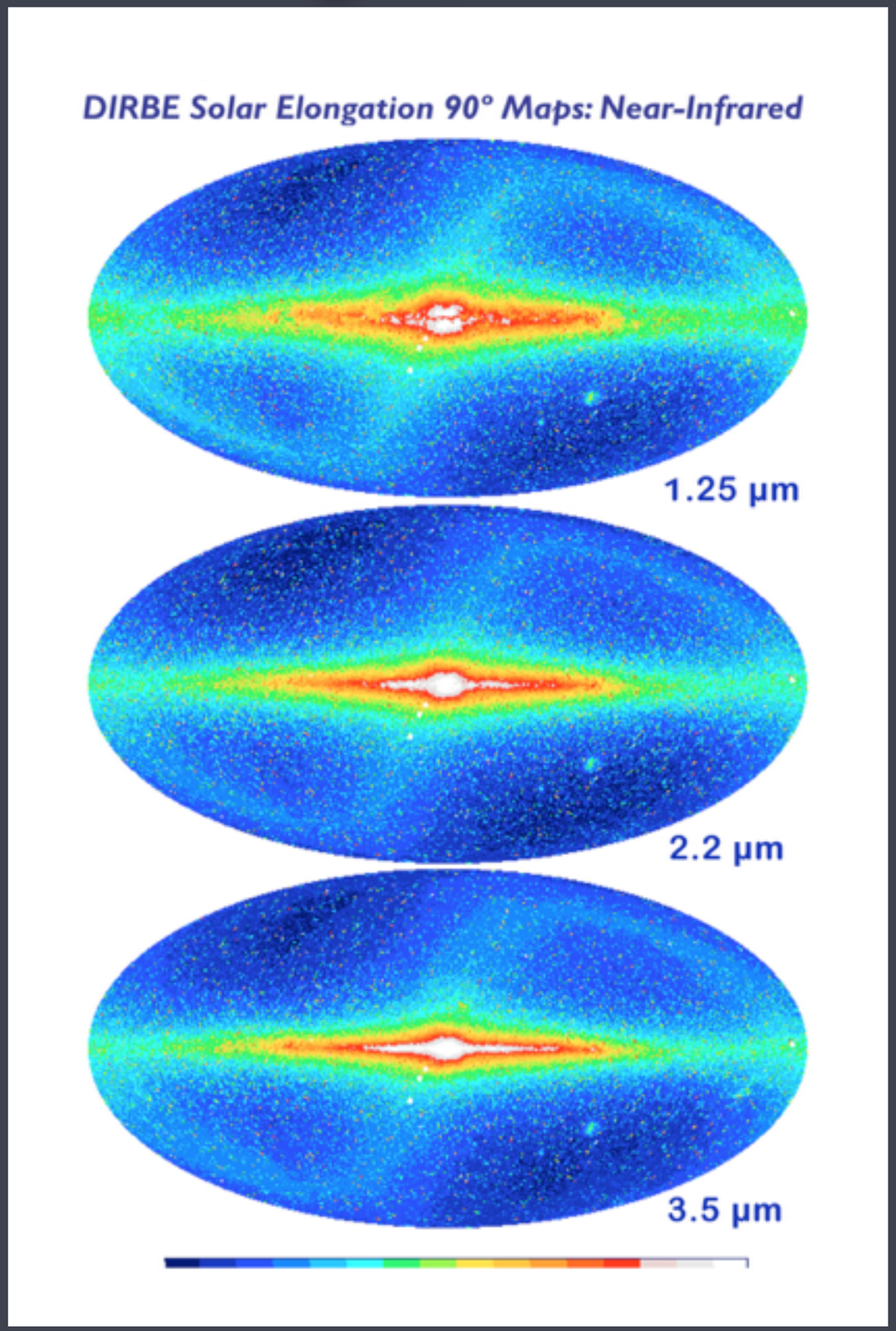
"Aitoff projection" - here applied to the Earth



# COBE (early 1990s) - first detailed map of the CMB

## at several wavelengths, and over the whole sky

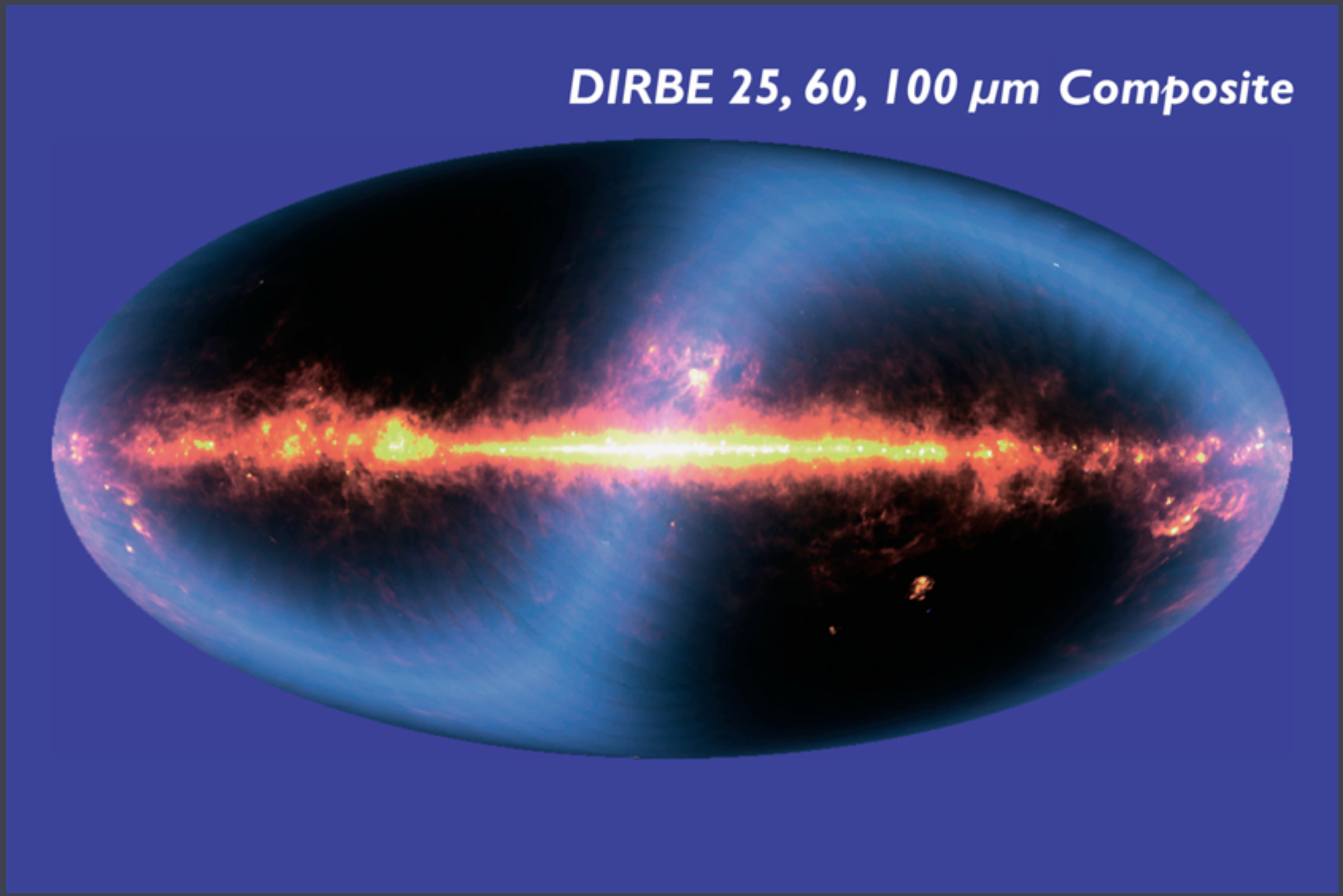
"Aitoff projection" - this is the sphere of the sky, as seen from the Earth's surface. The coordinate system is centered on the Galactic plane.




The faint, S-shaped light blue feature that spans the image is the zodiacal light — sunlight scattered off of dust in the plane of our Solar System

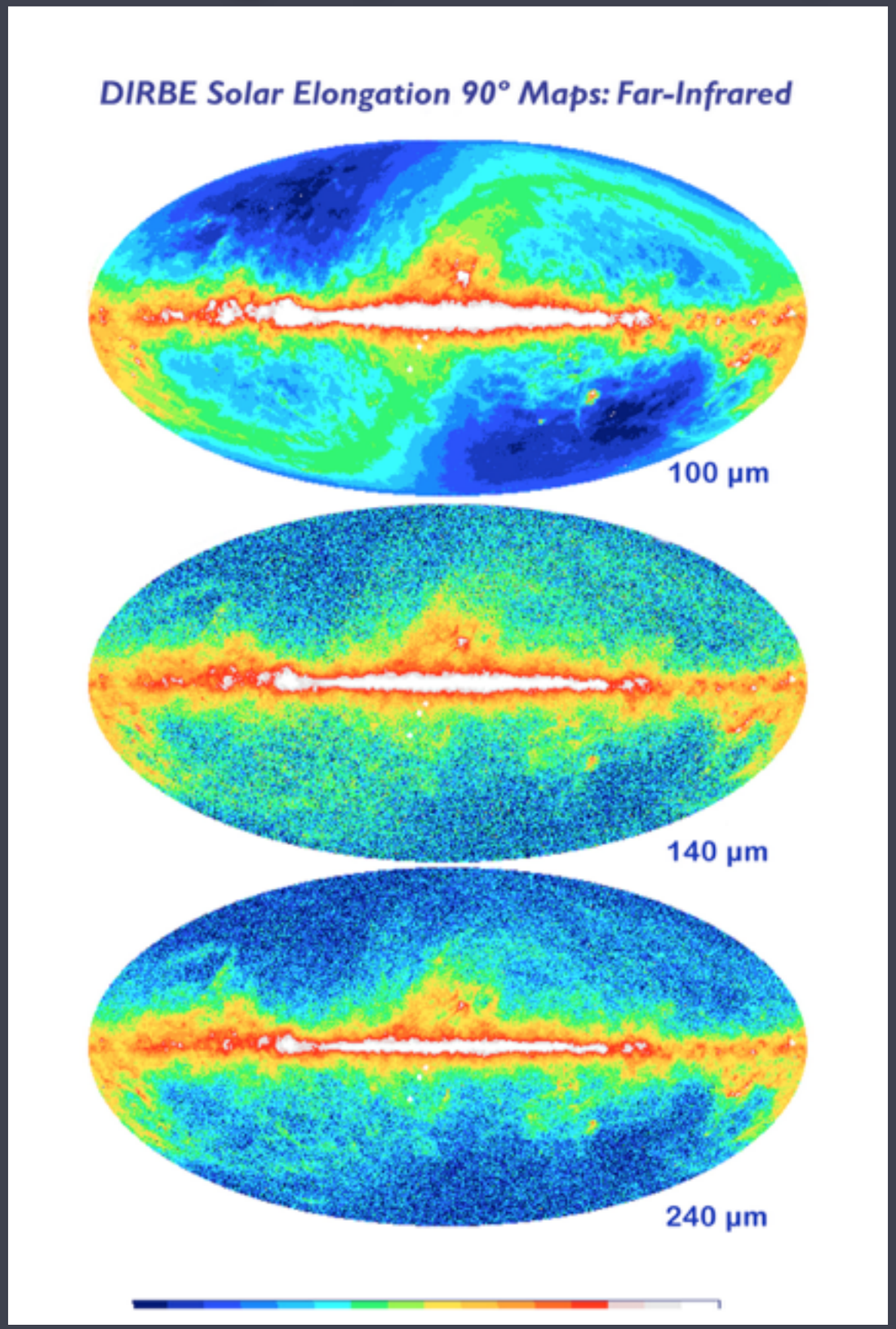
# COBE (early 1990s) - first detailed map of the CMB

## at several wavelengths, and over the whole sky



# COBE (early 1990s) - first detailed map of the CMB

## the contributions from the galaxy and the solar system can be removed



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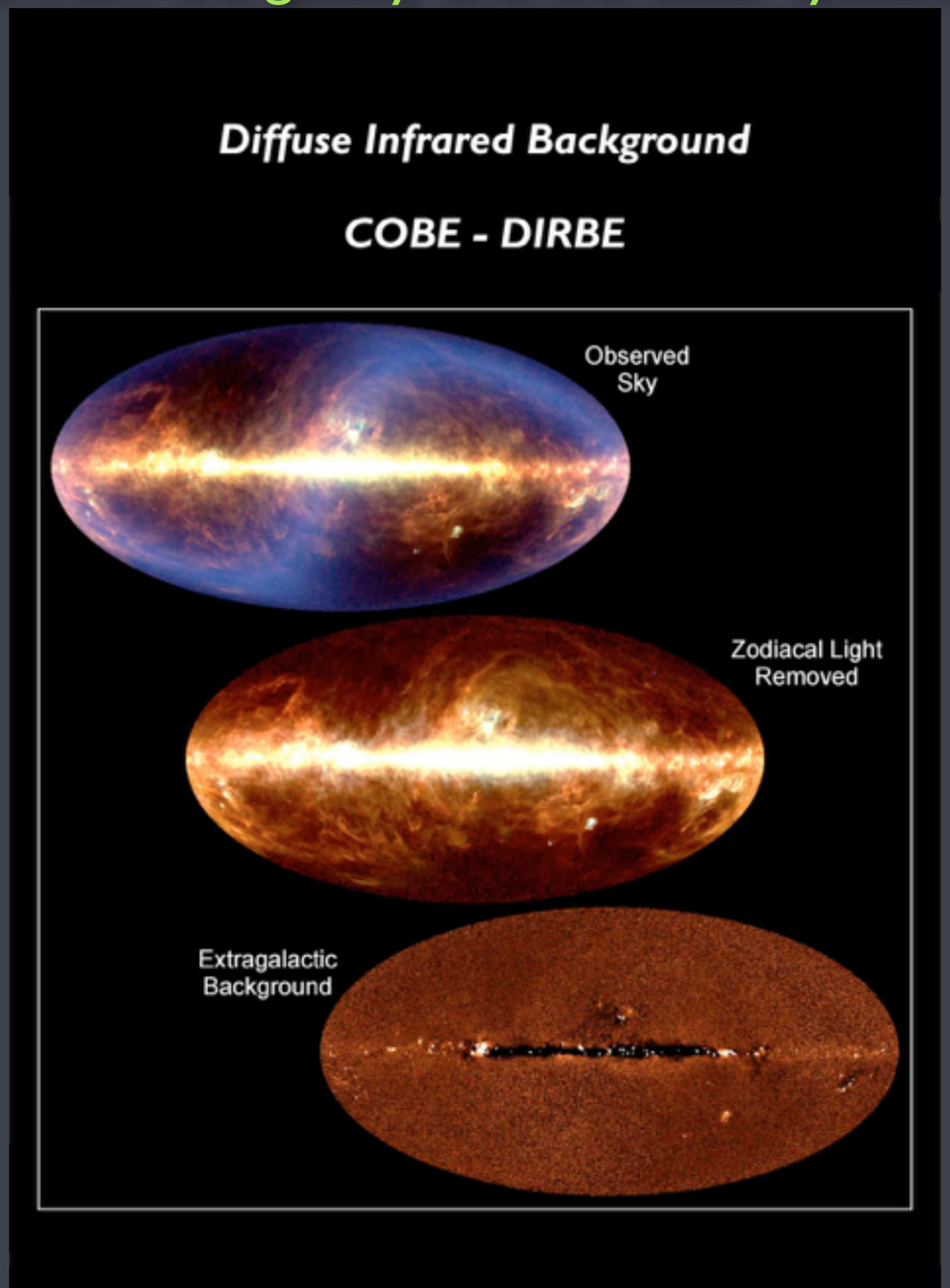
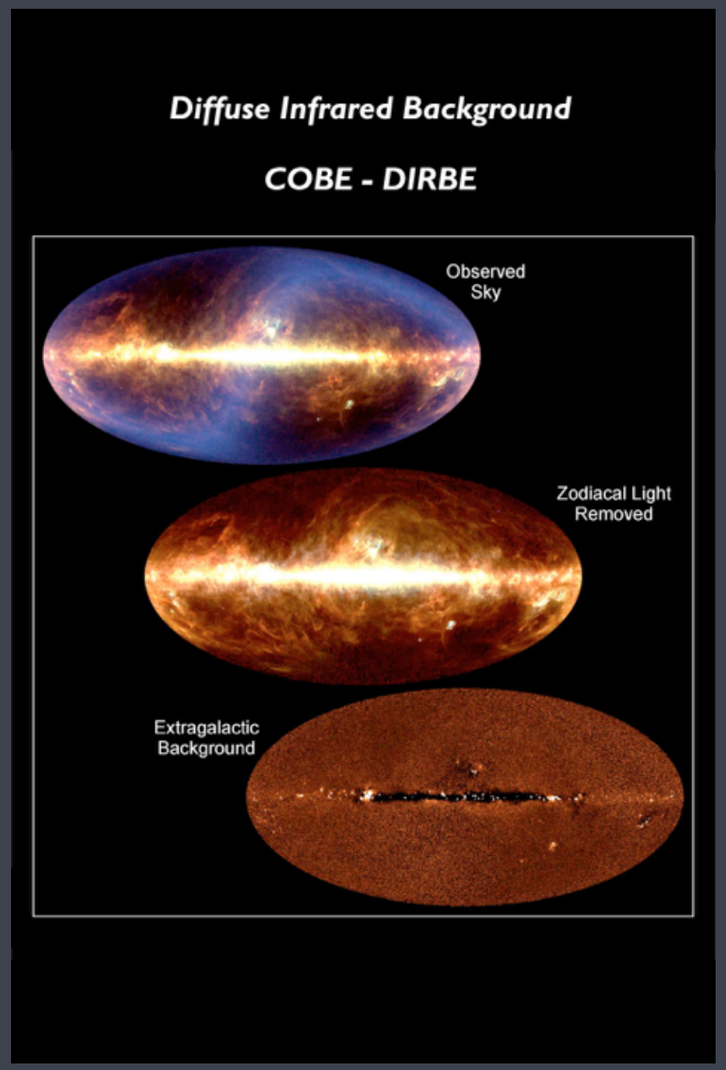
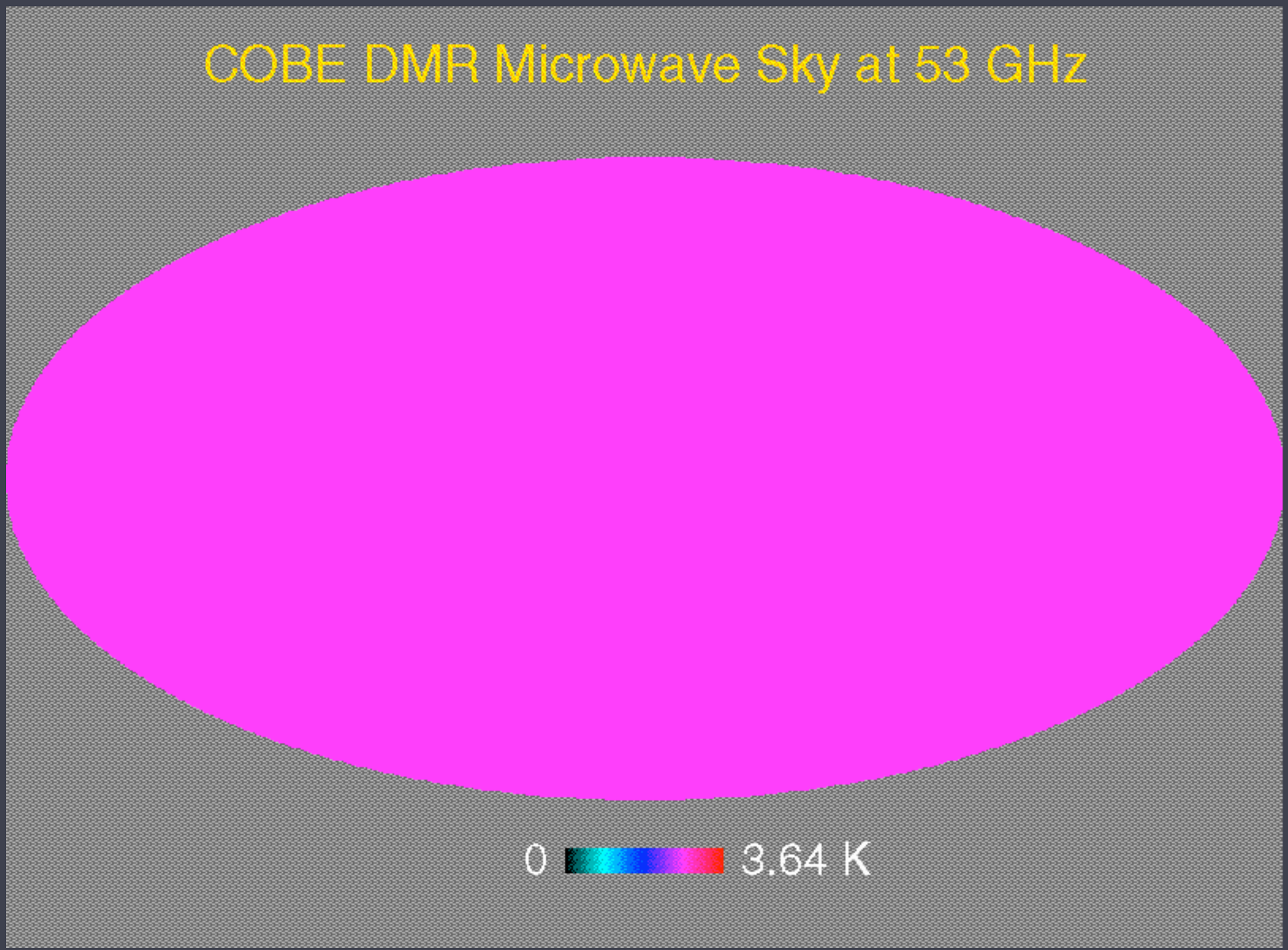


# COBE (early 1990s) - first detailed map of the CMB

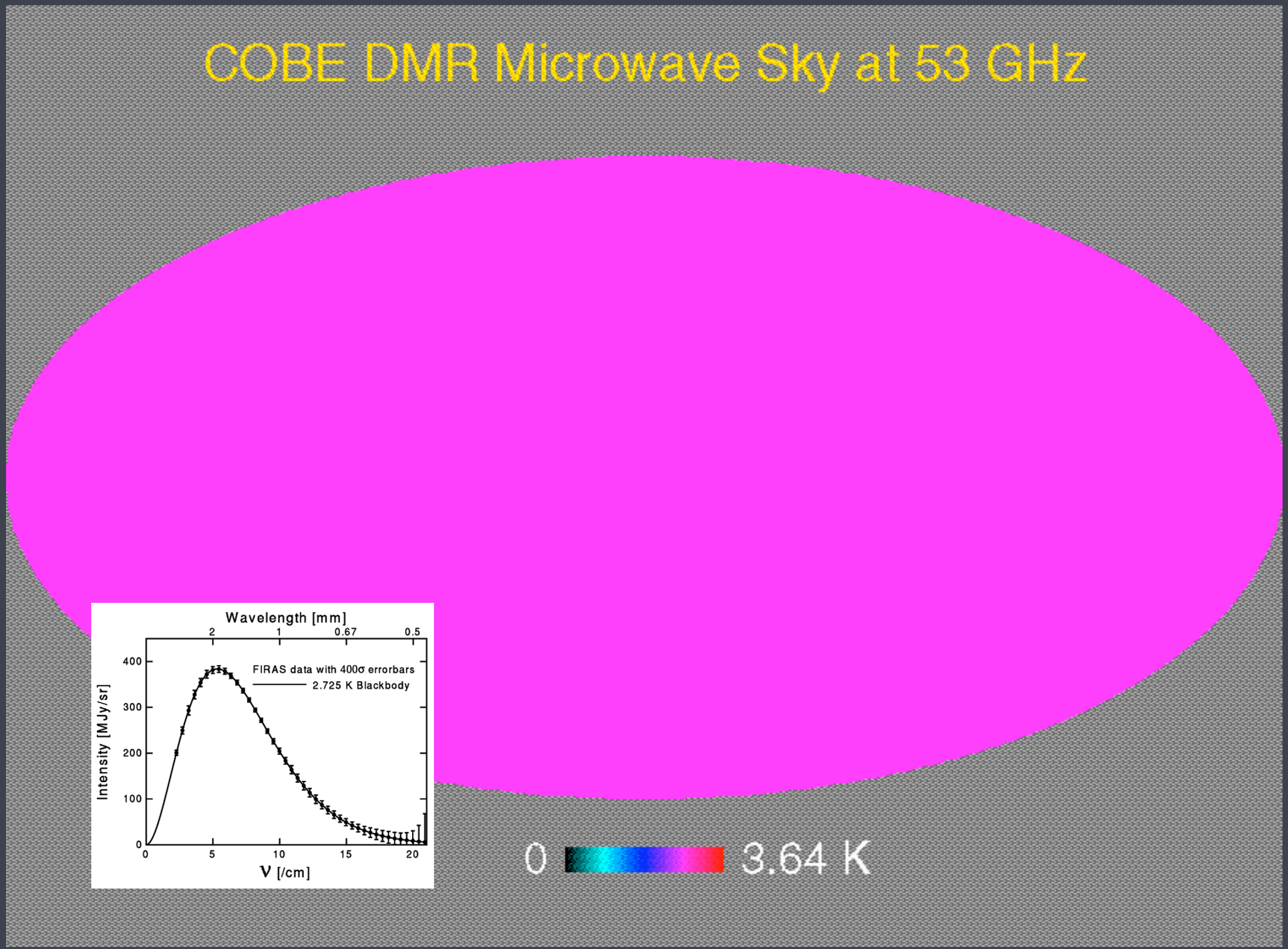



After all these non-cosmological signals are removed, we have a measurement of the cosmic microwave background of the whole sky — a map…

# the temperature of the CMB across the sky is *uniform*

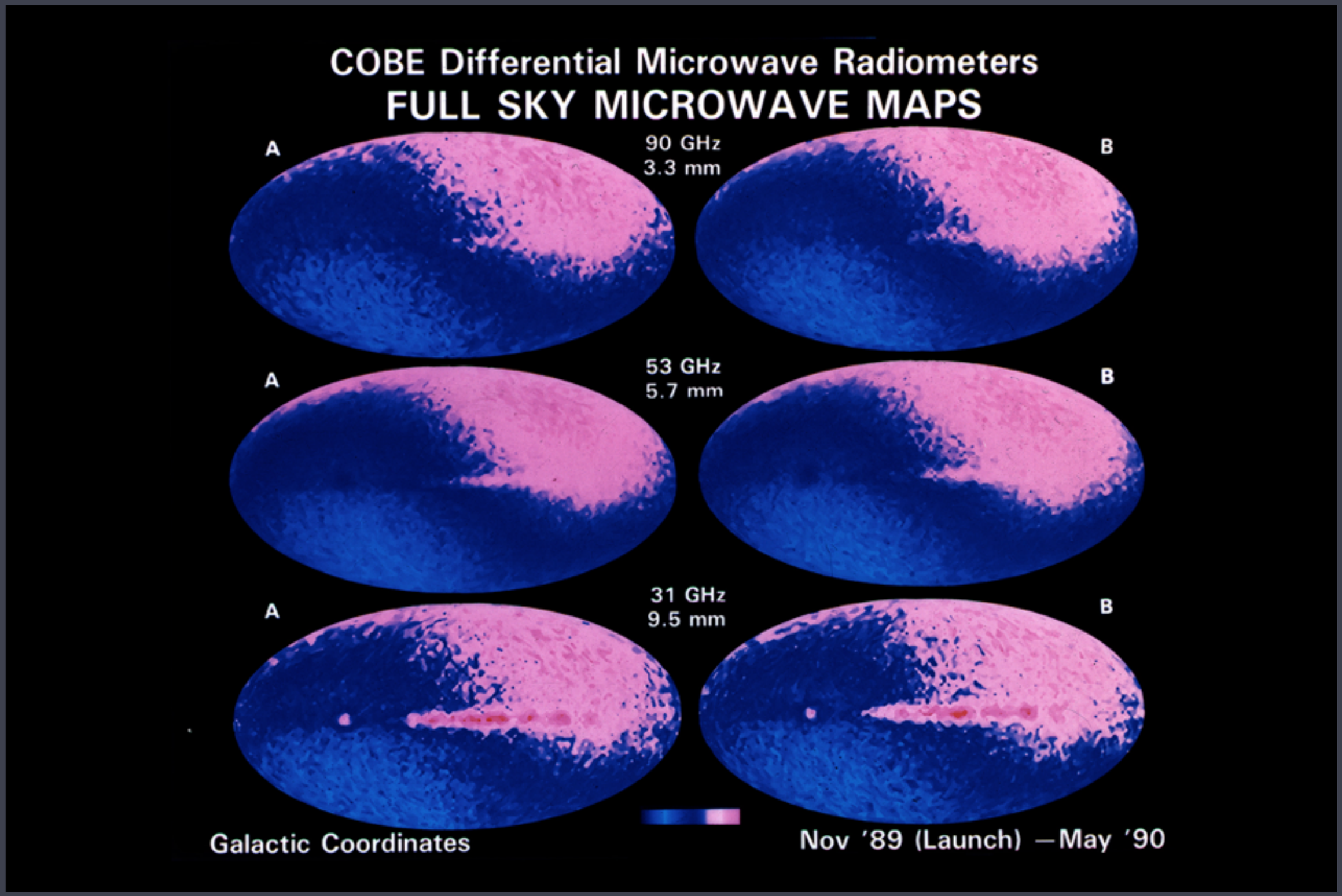


# it is T =2.725 K


COBE DMR Microwave Sky at 53 GHz
Wavelength [mm]
2
1
0.67
0.5
400
300
200
100
0
FIRAS data with 400σ errorbars
2.725 K Blackbody
Intensity [MJy/sr]
0
5
10
15
20
ν [/cm]
0
3.64 K

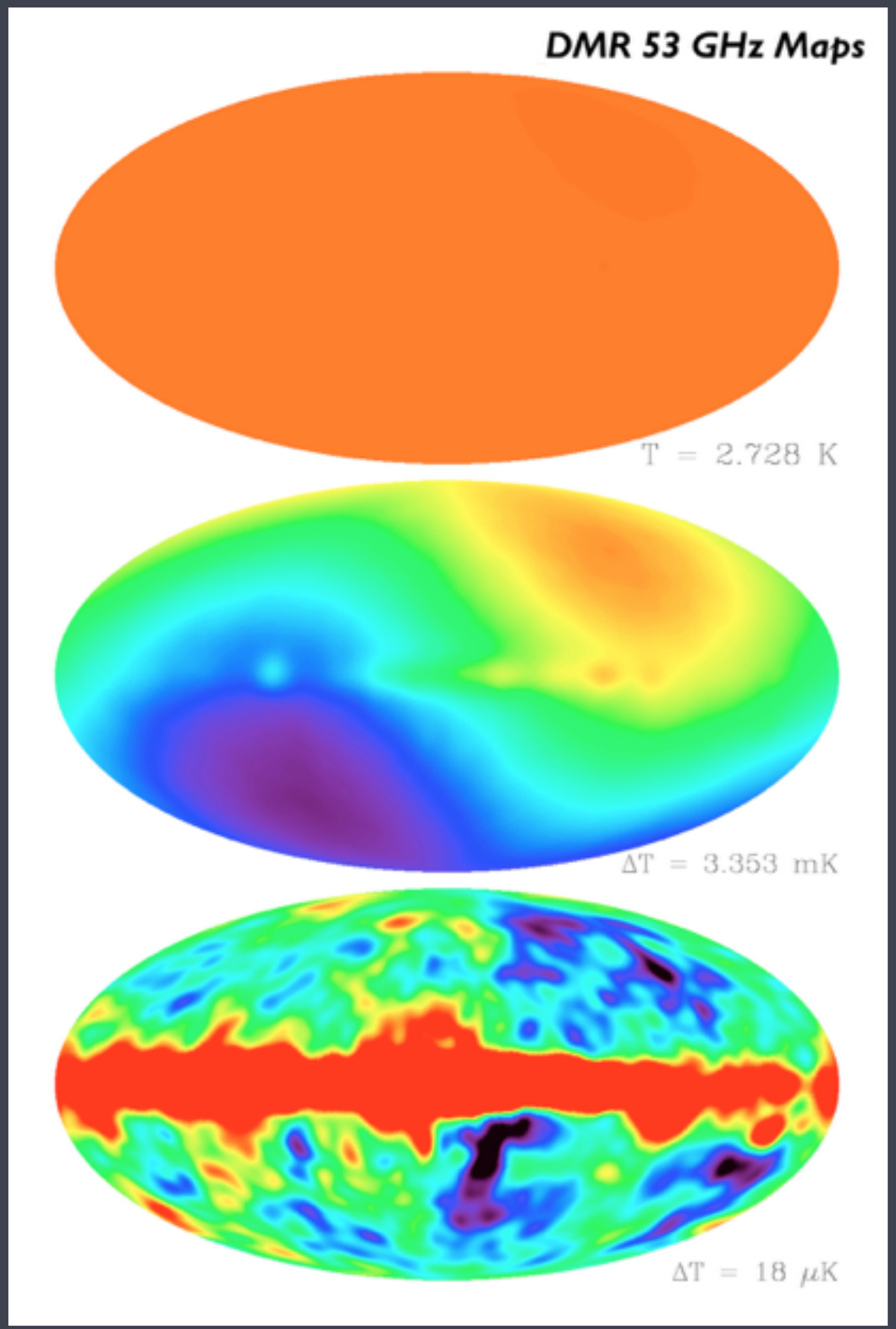
# COBE (early 1990s) - first detailed map of the CMB

this is the dipole Doppler shift signal



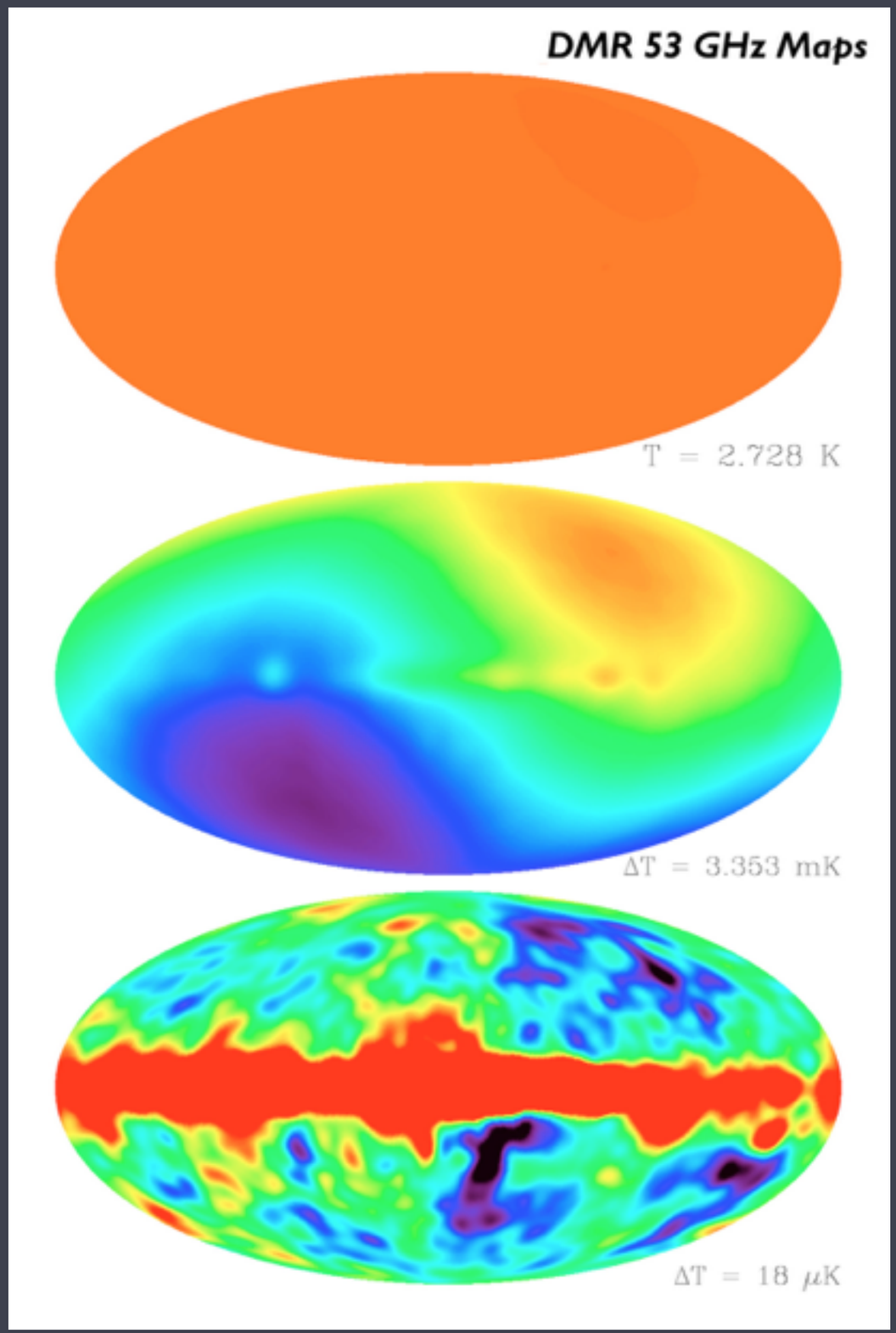
# COBE (early 1990s) - first detailed map of the CMB

Subtract the average signal and what's left is shown in the middle map



# COBE (early 1990s) - first detailed map of the CMB

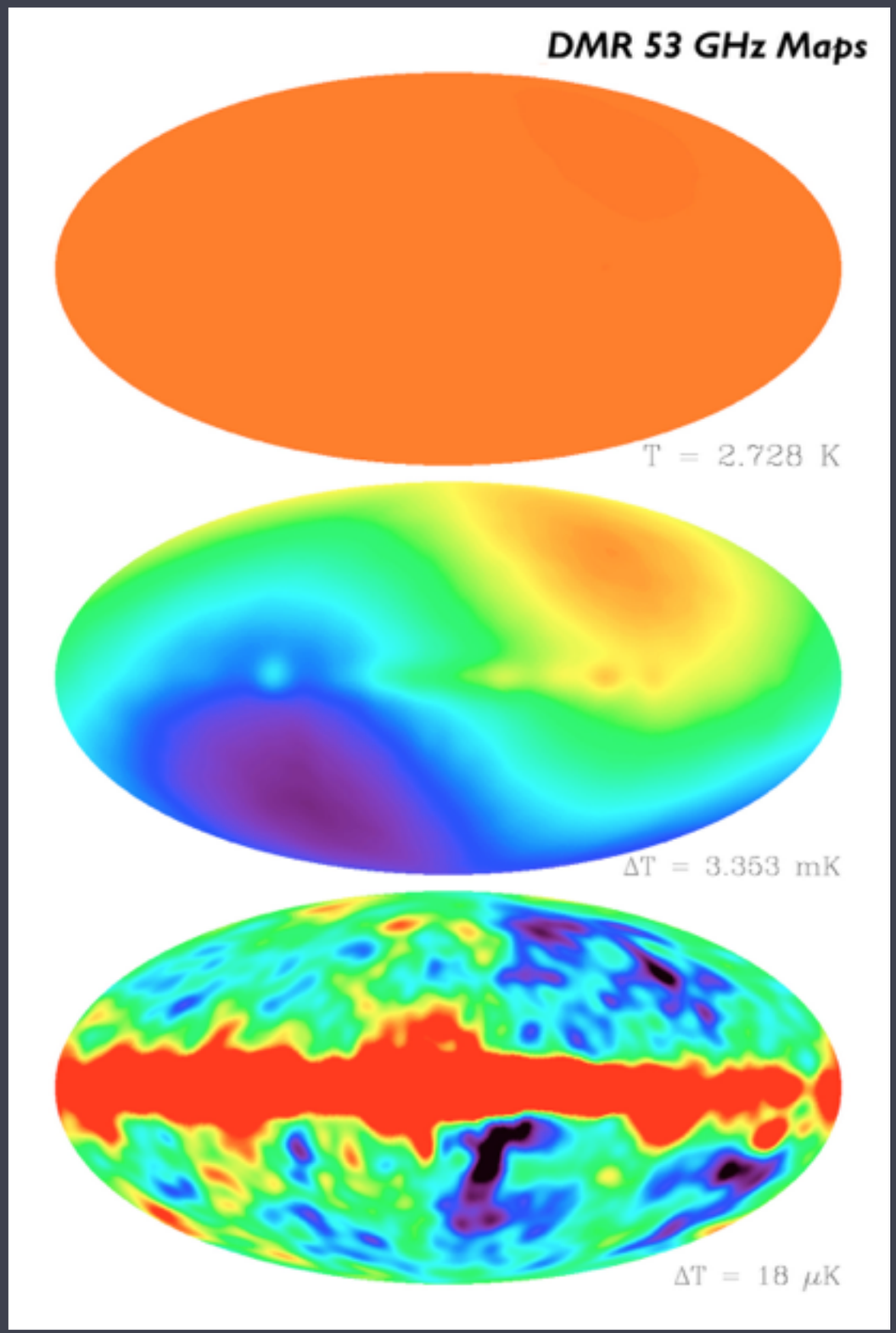
Subtract the average signal and what's left is shown in the middle map




The Earth is moving with respect to the CMB: the dipole signal

# COBE (early 1990s) - first detailed map of the CMB

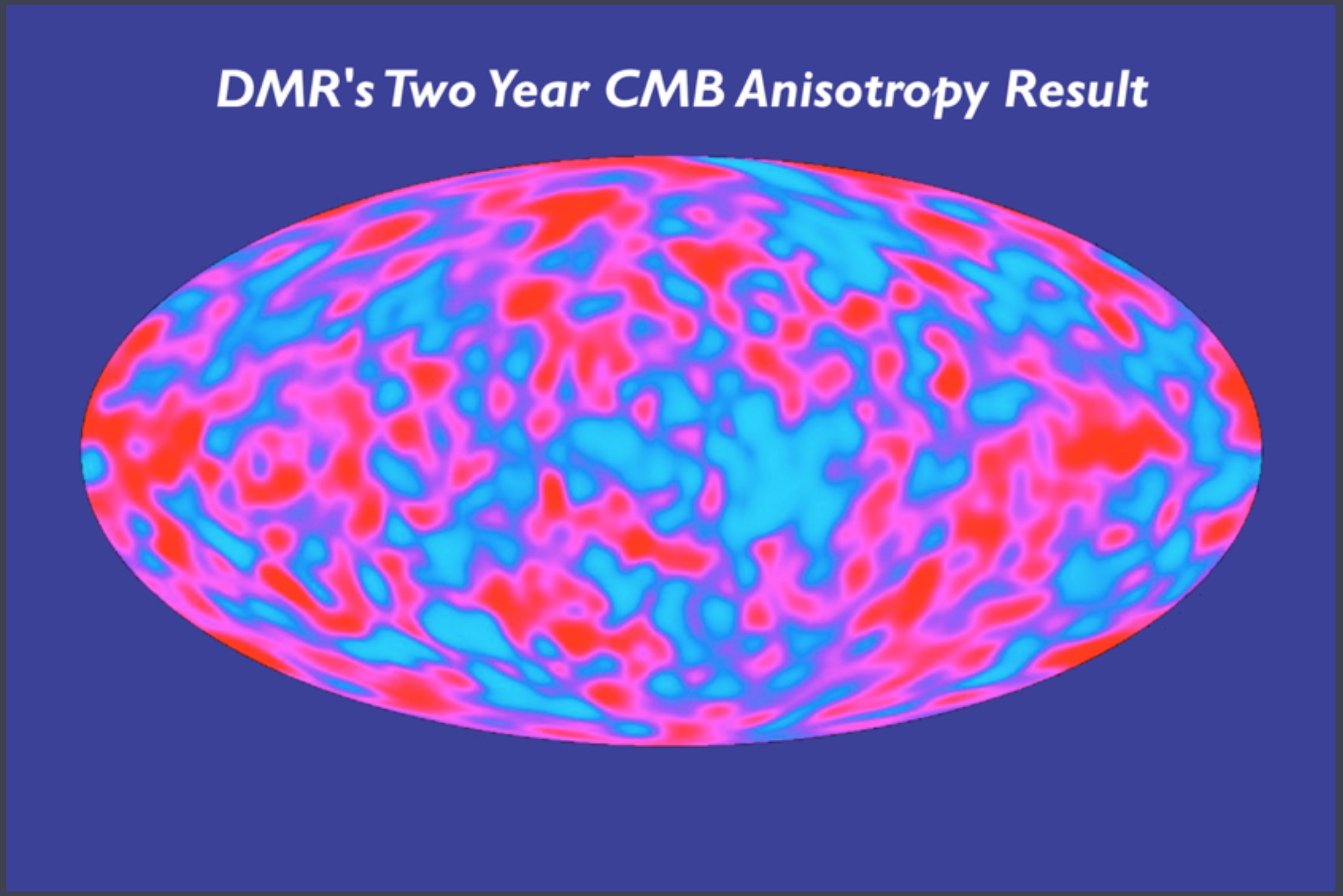
Subtract the dipole signal and what's left is shown in the bottom map




18 microkelvin out of 2.7 K — there's a signal — lump, and some residual Milky Way

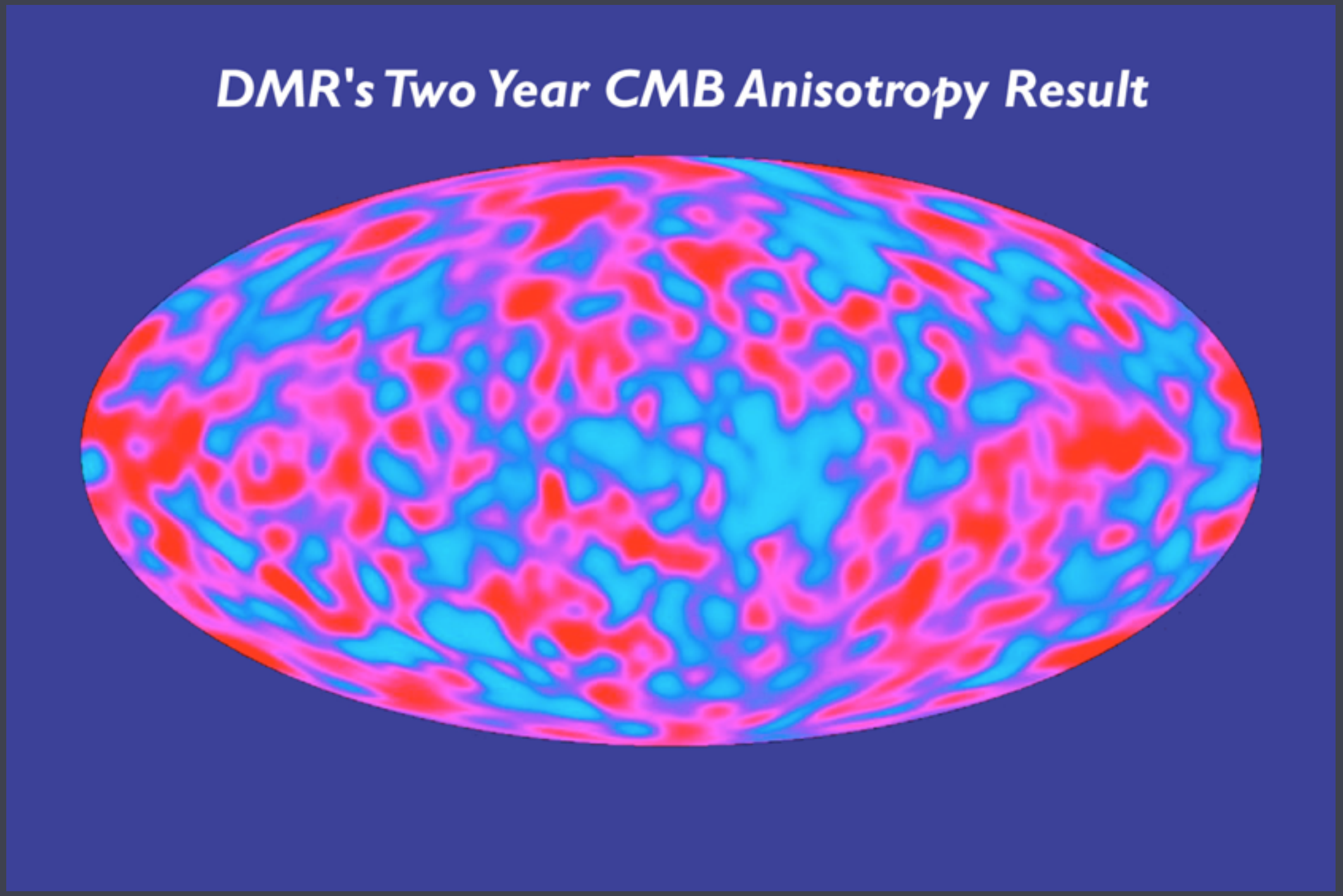
# COBE (early 1990s) - first detailed map of the CMB

this is the residual CMB signal (after all the foreground subtractions)



# COBE (early 1990s) - first detailed map of the CMB

these fluctuations in brightness are at the 1 part in 100,000 level



a later mission, WMAP, measured variation, on a smaller spatial scale