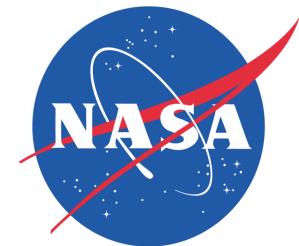
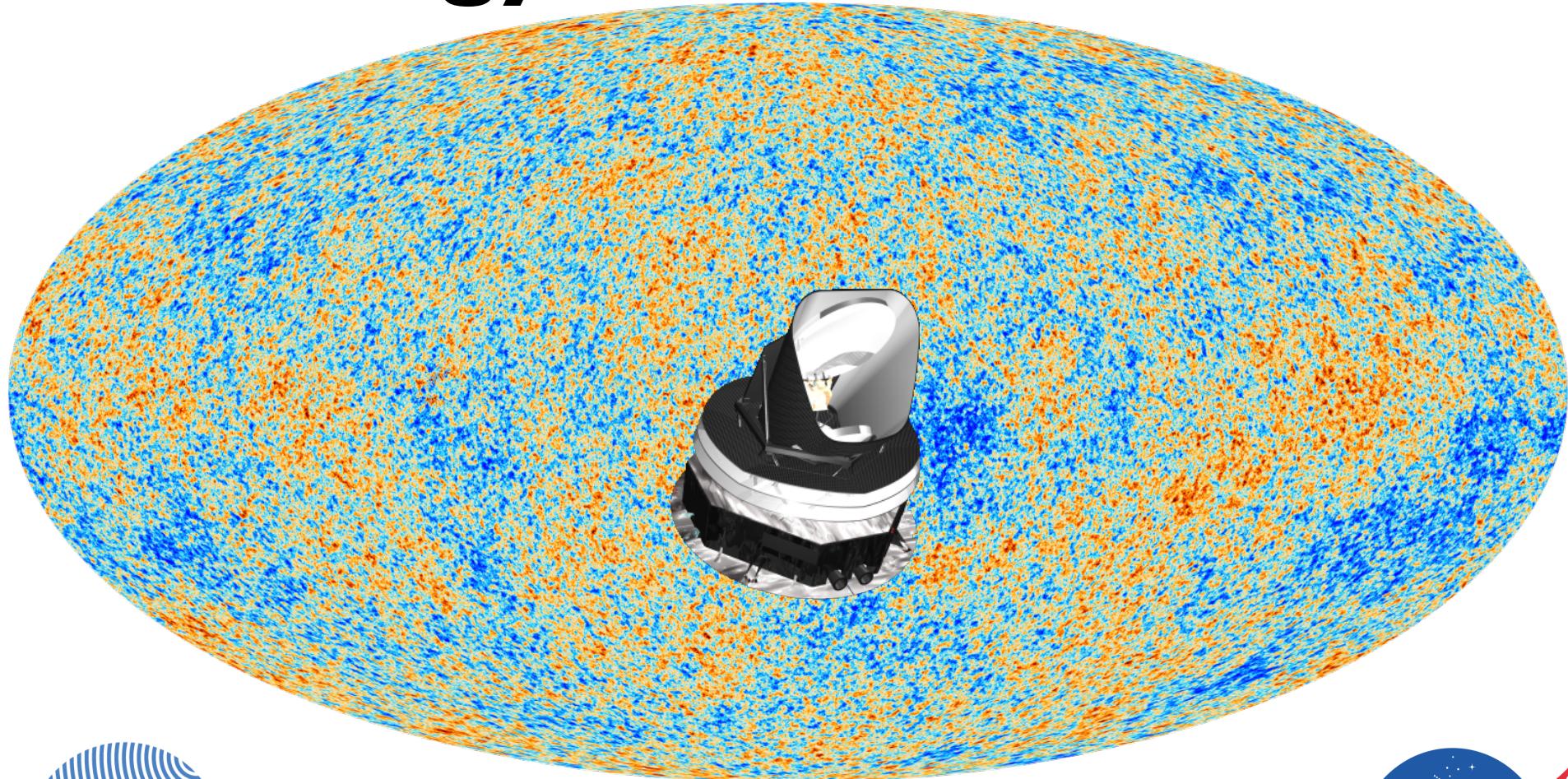
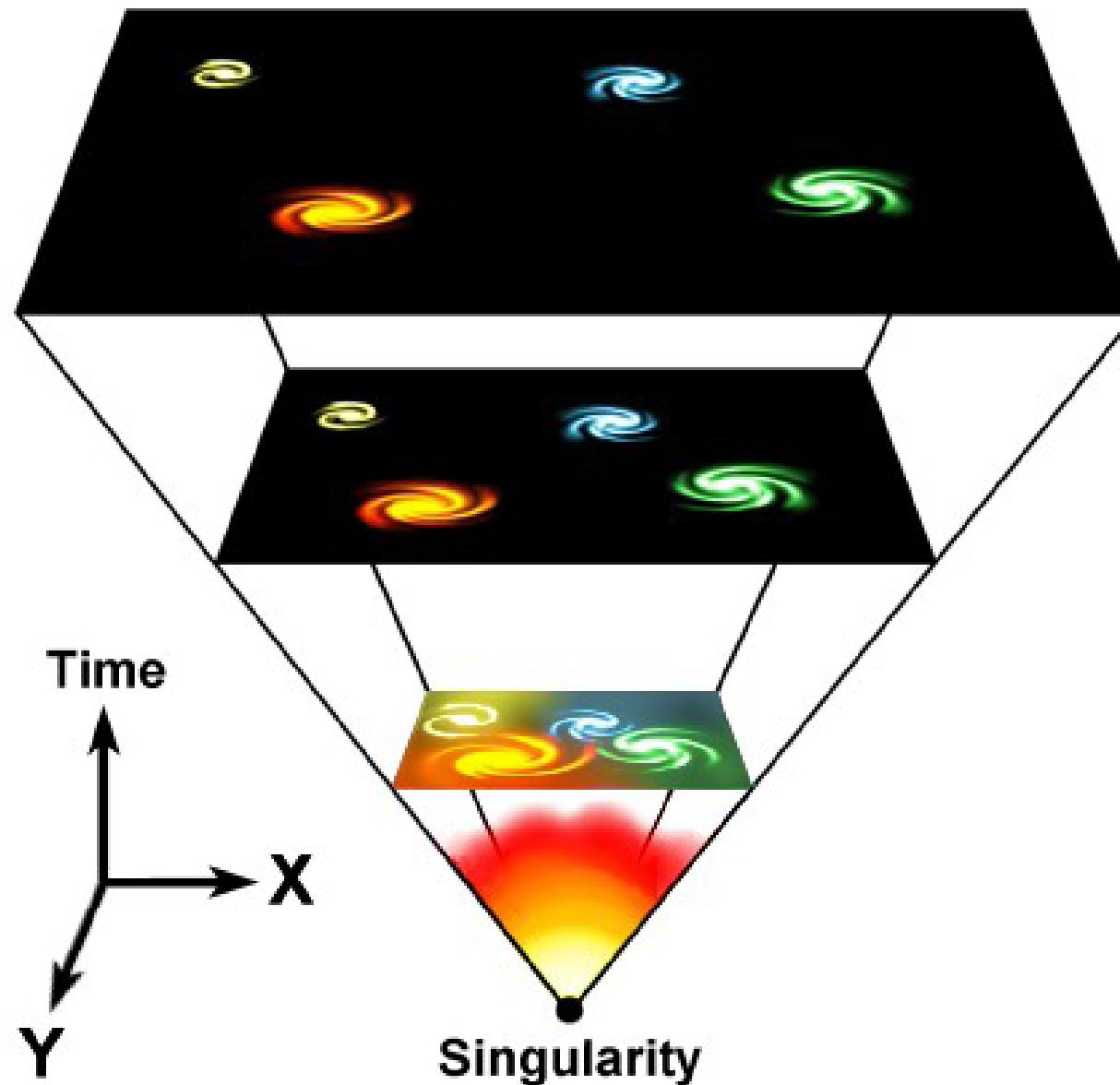


# The Universe's Baby Picture: Cosmology Results from Planck



Kevin Huffenberger, *University of Miami*

# Expanding universe & the Big Bang



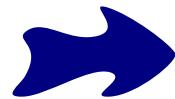
# **Hot, dense objects glow**



**Blackbody radiation - Planck Spectrum**

# Cosmic Microwave Background

Hot, dense initial state

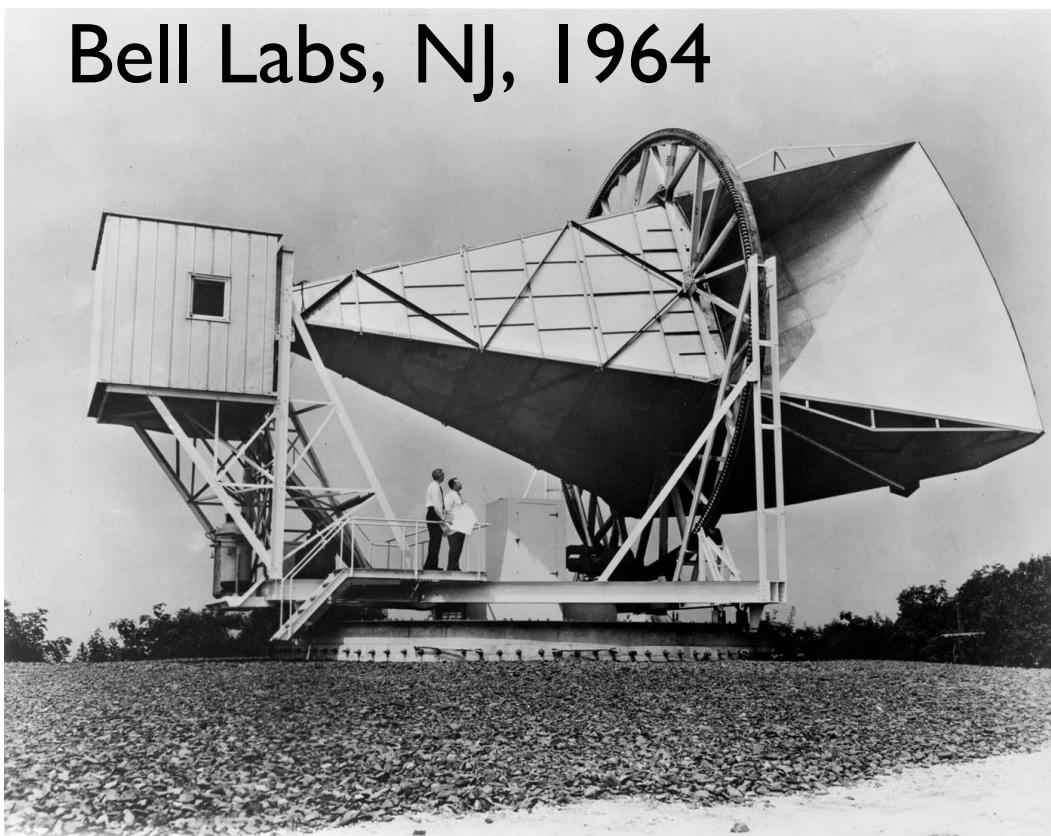


Relic Background Radiation

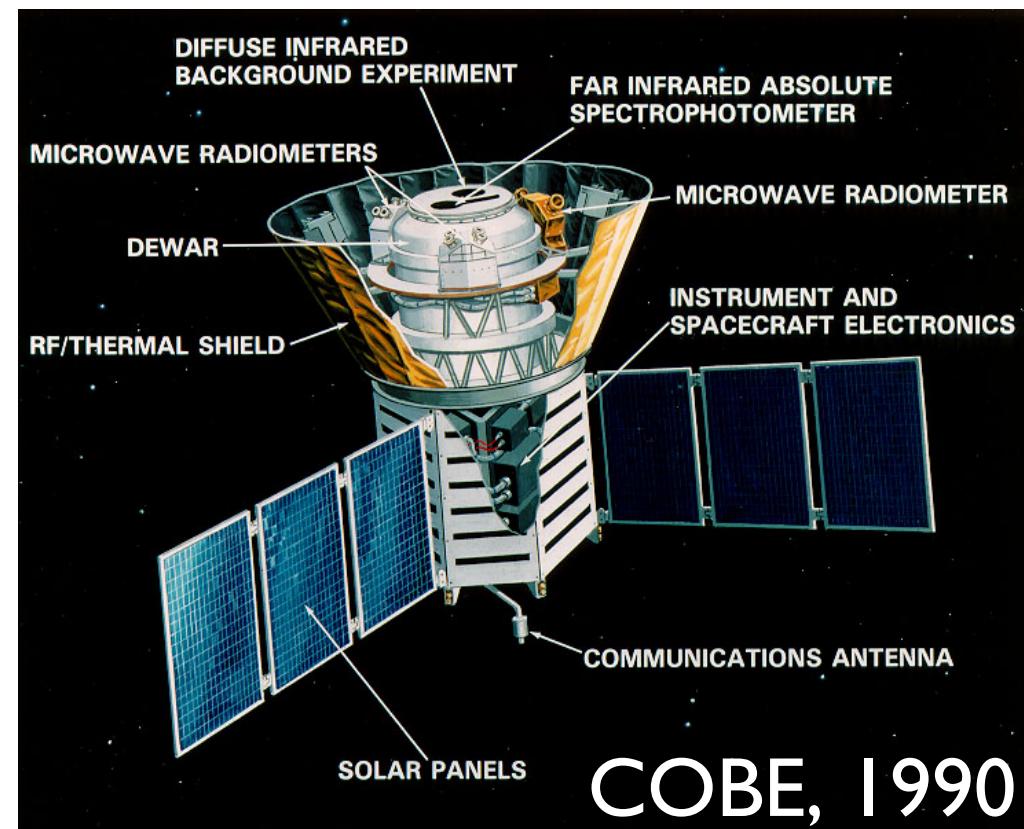
Redshifted to microwaves

Cold:  $\sim 3$  K above abs. zero

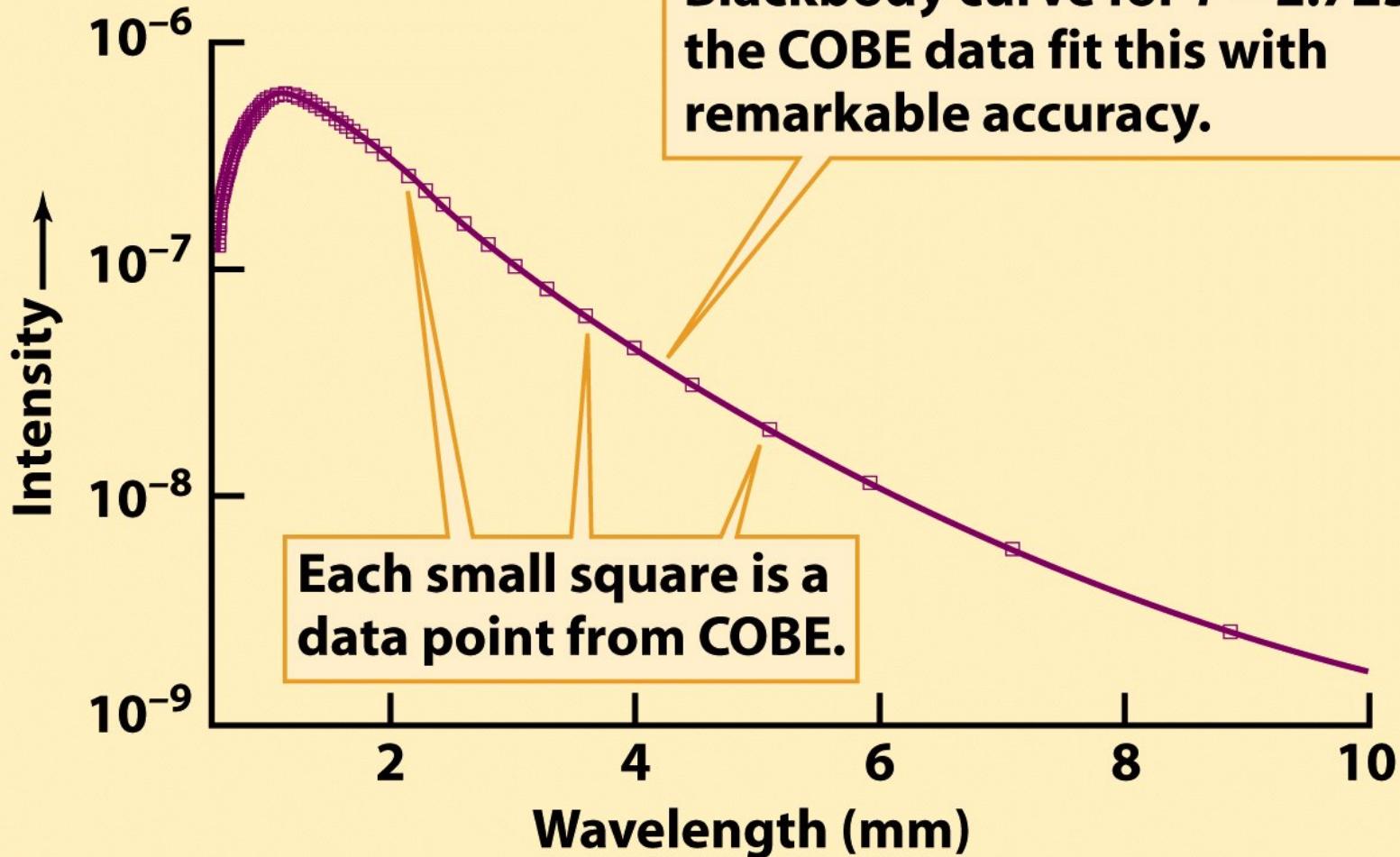
Bell Labs, NJ, 1964



Each resulted in a  
Nobel prize!




COBE, 1990

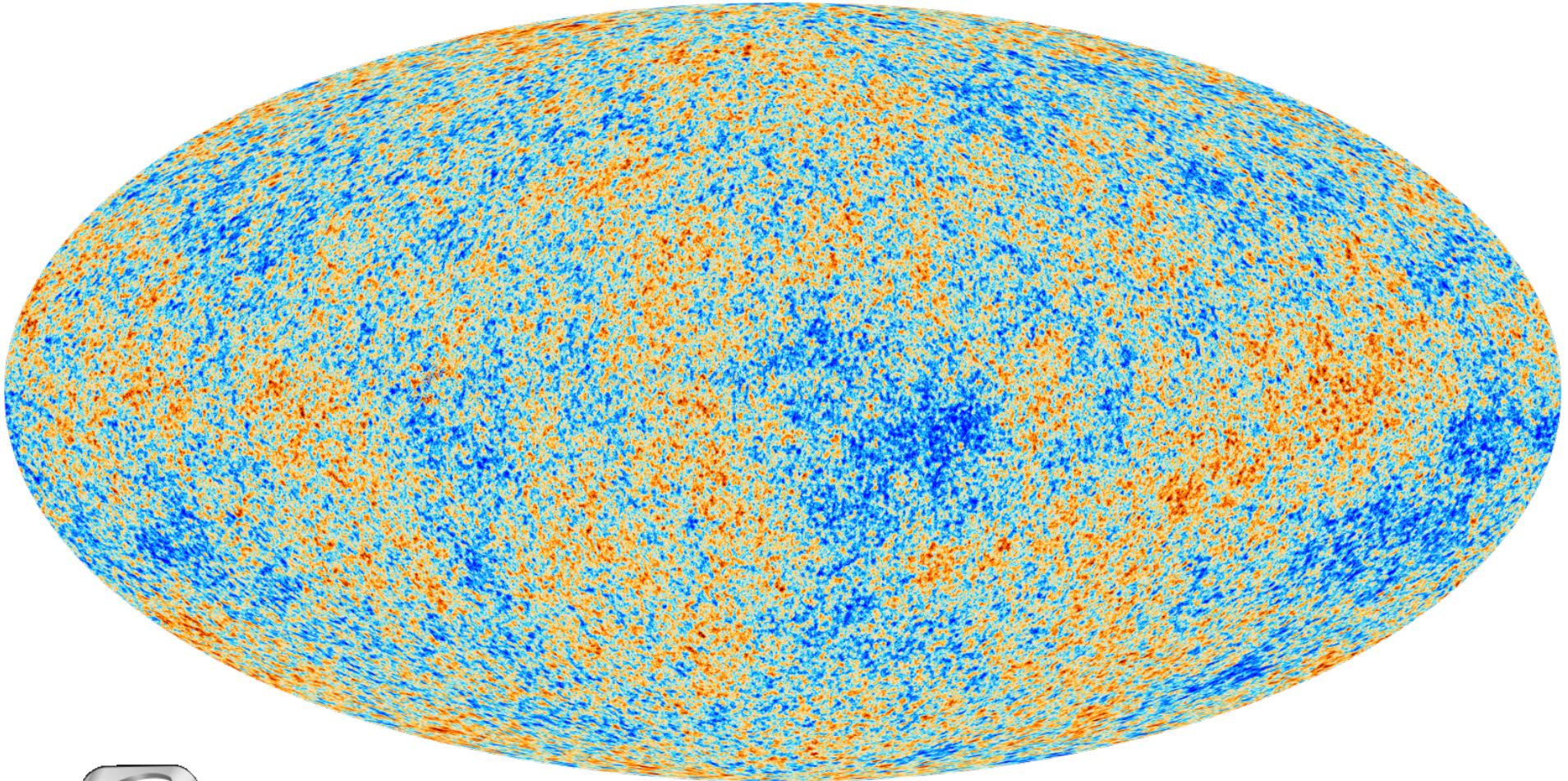


## The spectrum of the cosmic microwave background

Figure 26-7b  
*Universe, Eighth Edition*  
© 2008 W.H. Freeman and Company



# CMB fluctuations

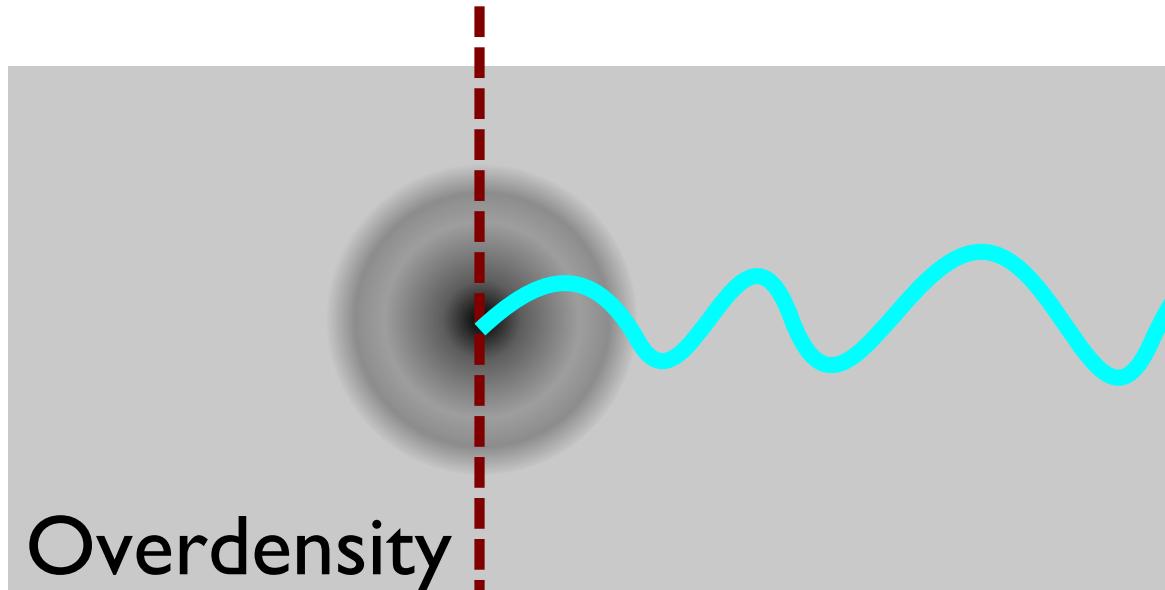


~ few hundred  $\mu\text{K}$  around mean  $T$



# Probing gravitational potential

Recombination



Overdensity

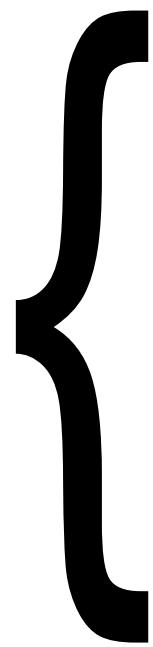
Potential

cold photon!



# Inflation and initial fluctuations

Unknown physics at high energies causes  $\exp(60)$ -fold expansion could explain:



spatial flatness

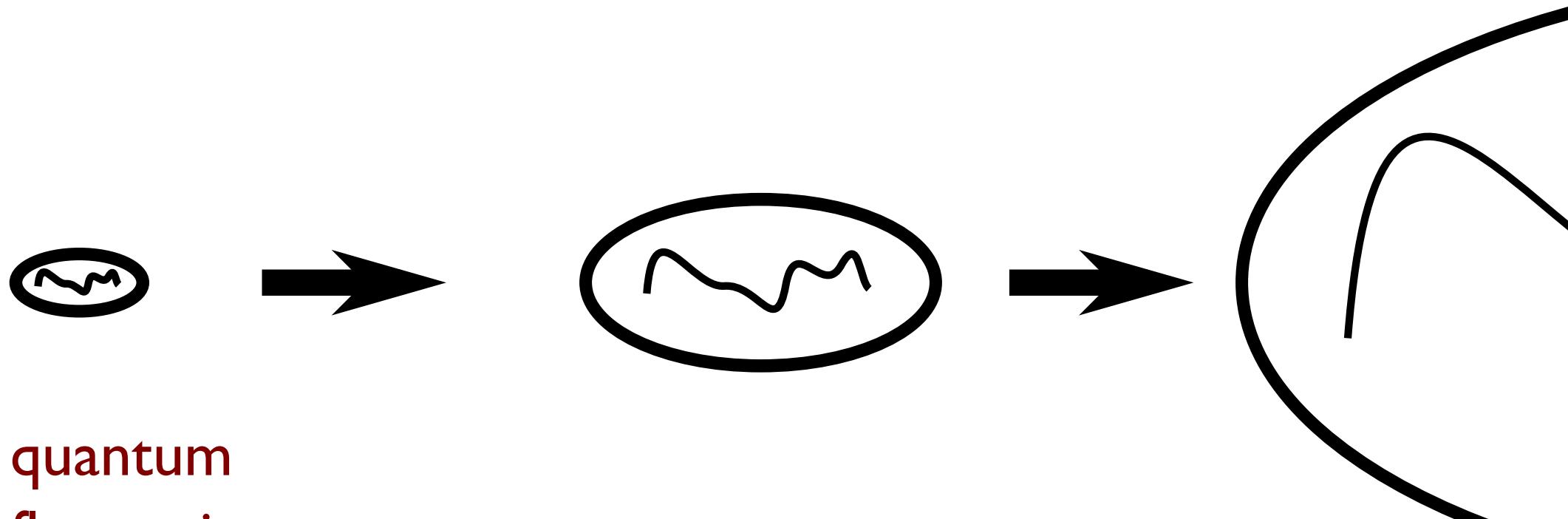
rarity of magnetic monopoles

uniformity of CMB sky

Expand by  $10^{26}$  in  $10^{-32}$  s (!) driven by a scalar field (?)

*Inflaton*

# Inflation and initial fluctuations



quantum  
fluctuations  
in field value

macroscopic

cosmological

*Nearly scale-free spectrum of initial fluctuations*

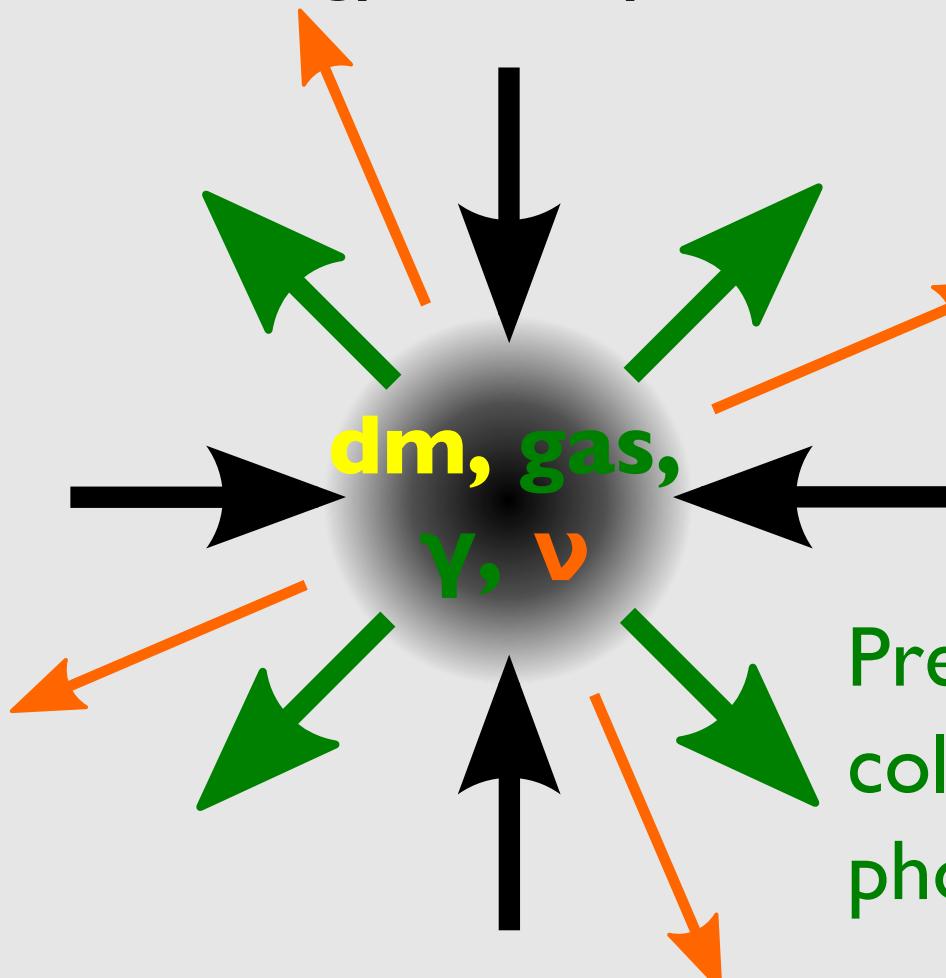
# Evolution of overdensity

Expansion of  
the universe

Gravity - from matter-  
energy density

Streaming of  
neutrinos

Pressure - from  
collisions with  
photons



# Evolution of overdensity

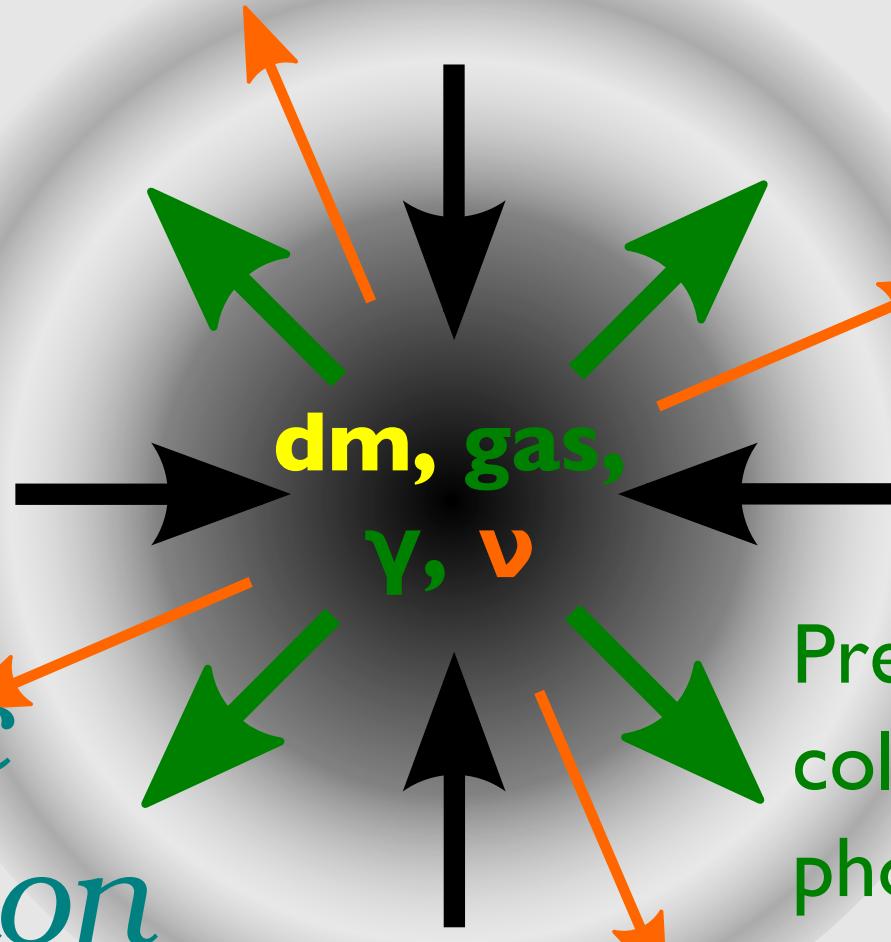
Expansion of  
the universe

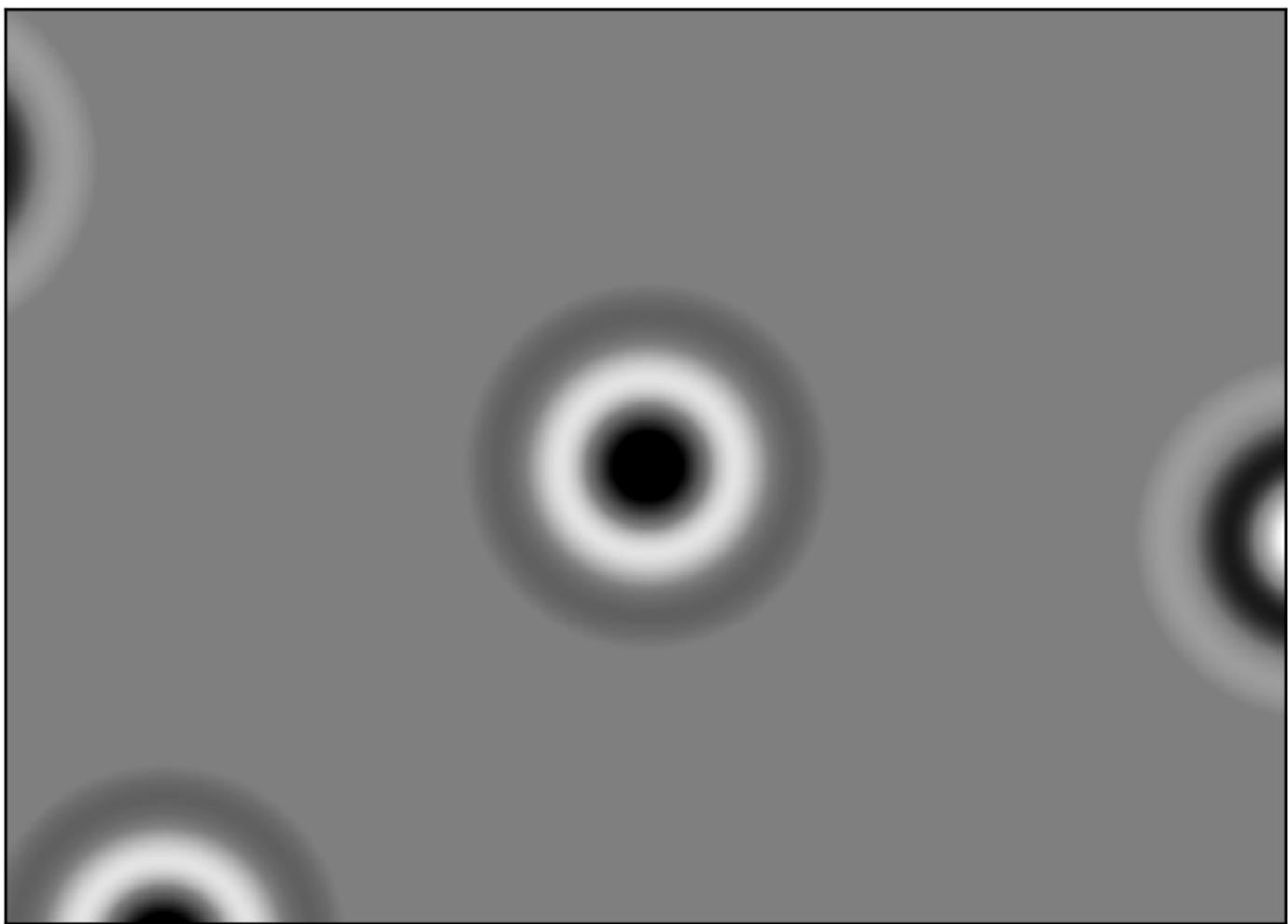
Gravity - from matter-  
energy density

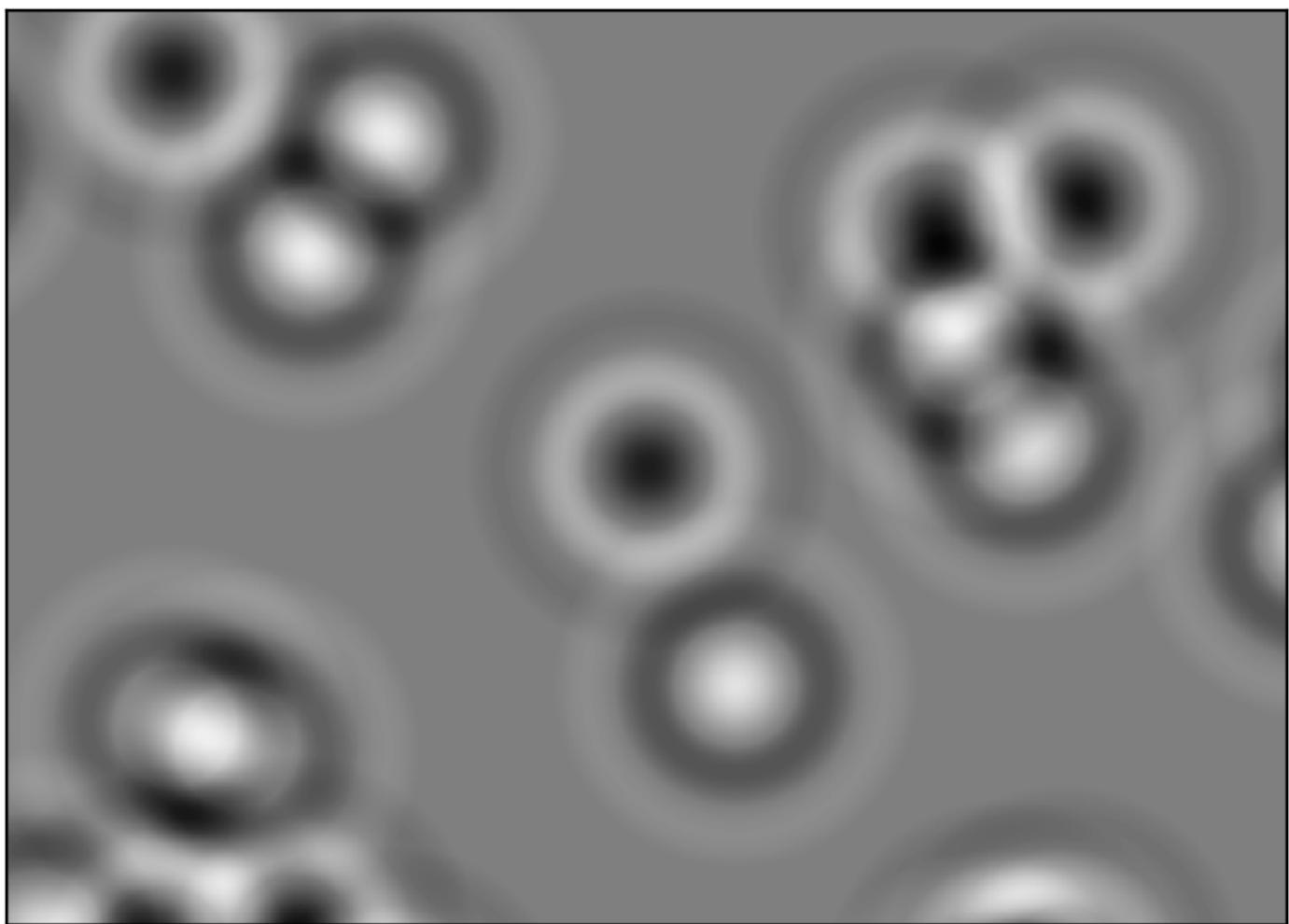
Streaming of  
neutrinos

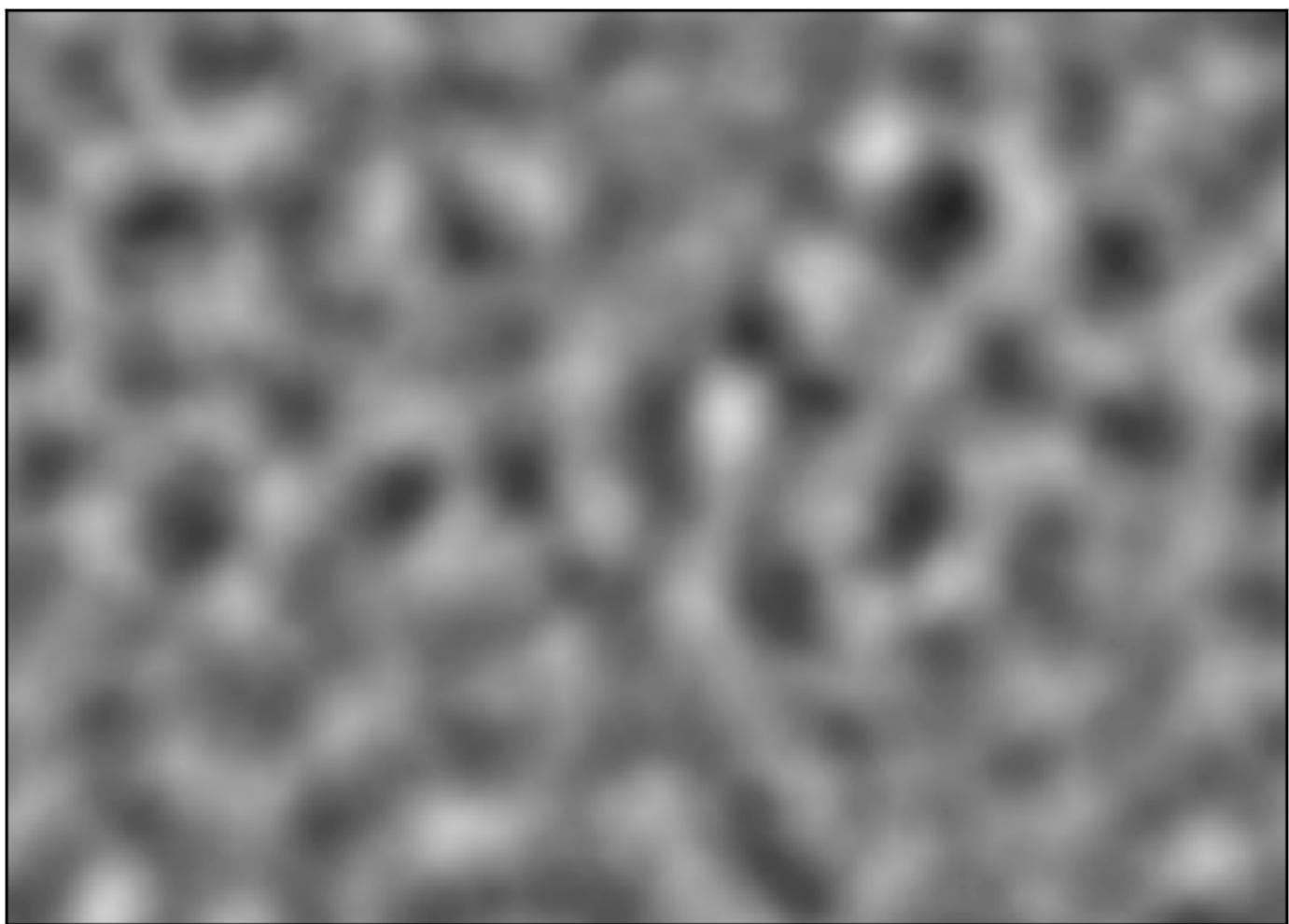
Acoustic  
Oscillation

Pressure - from  
collisions with  
photons

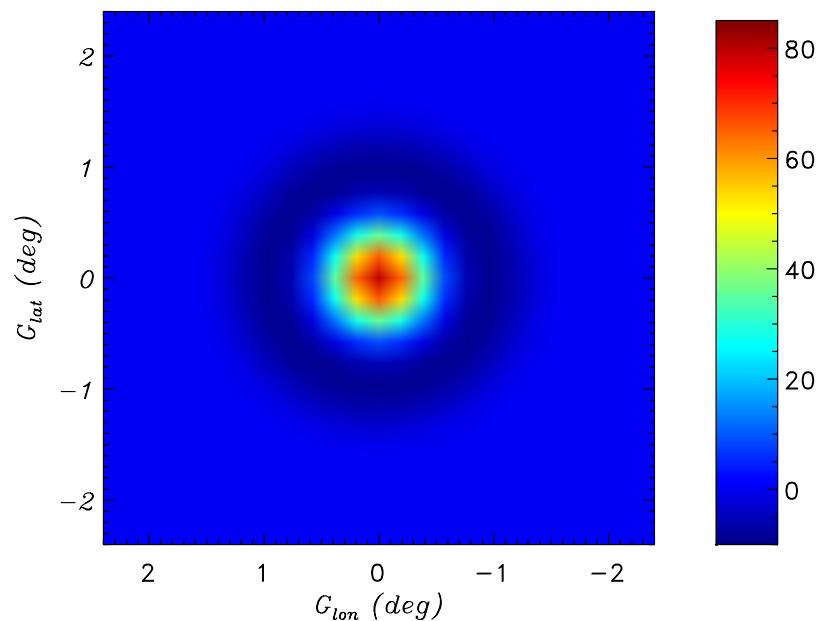
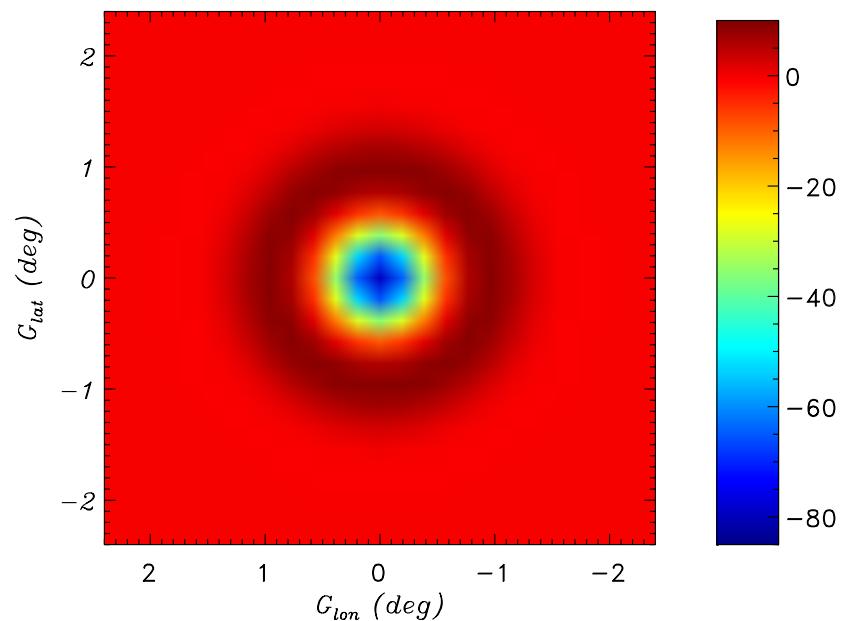
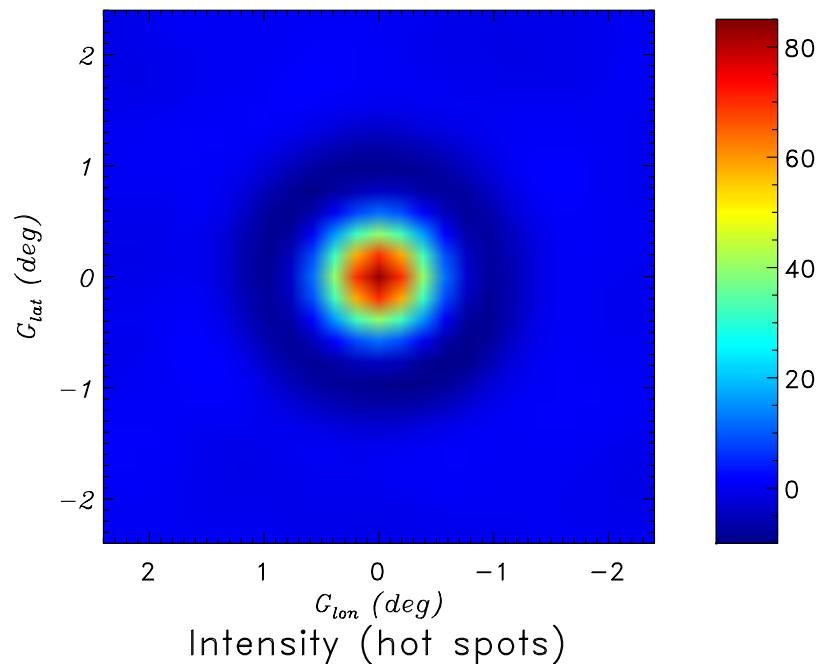
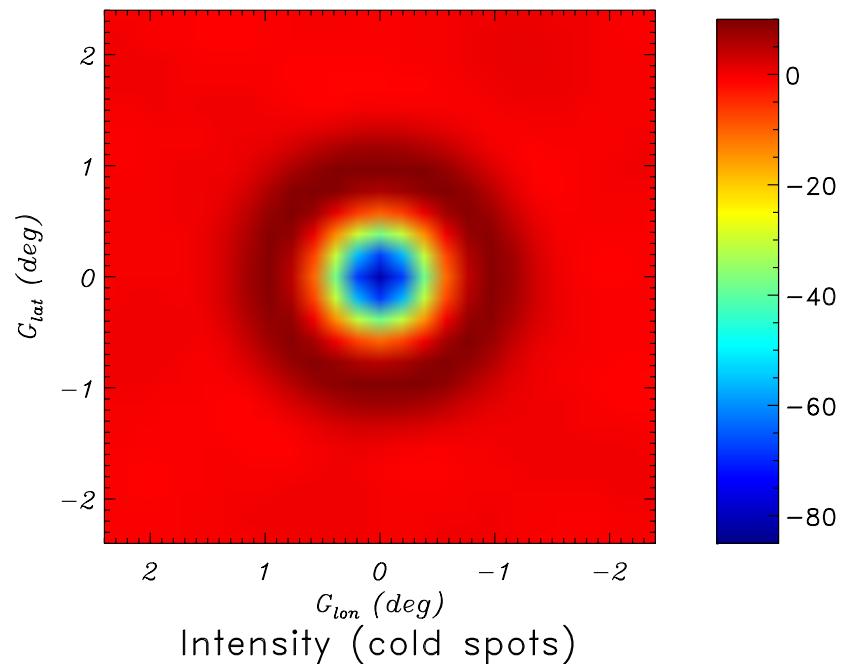




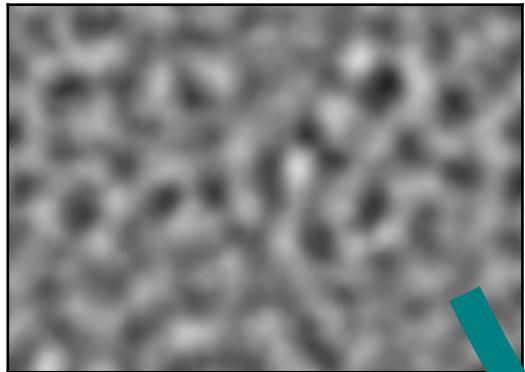




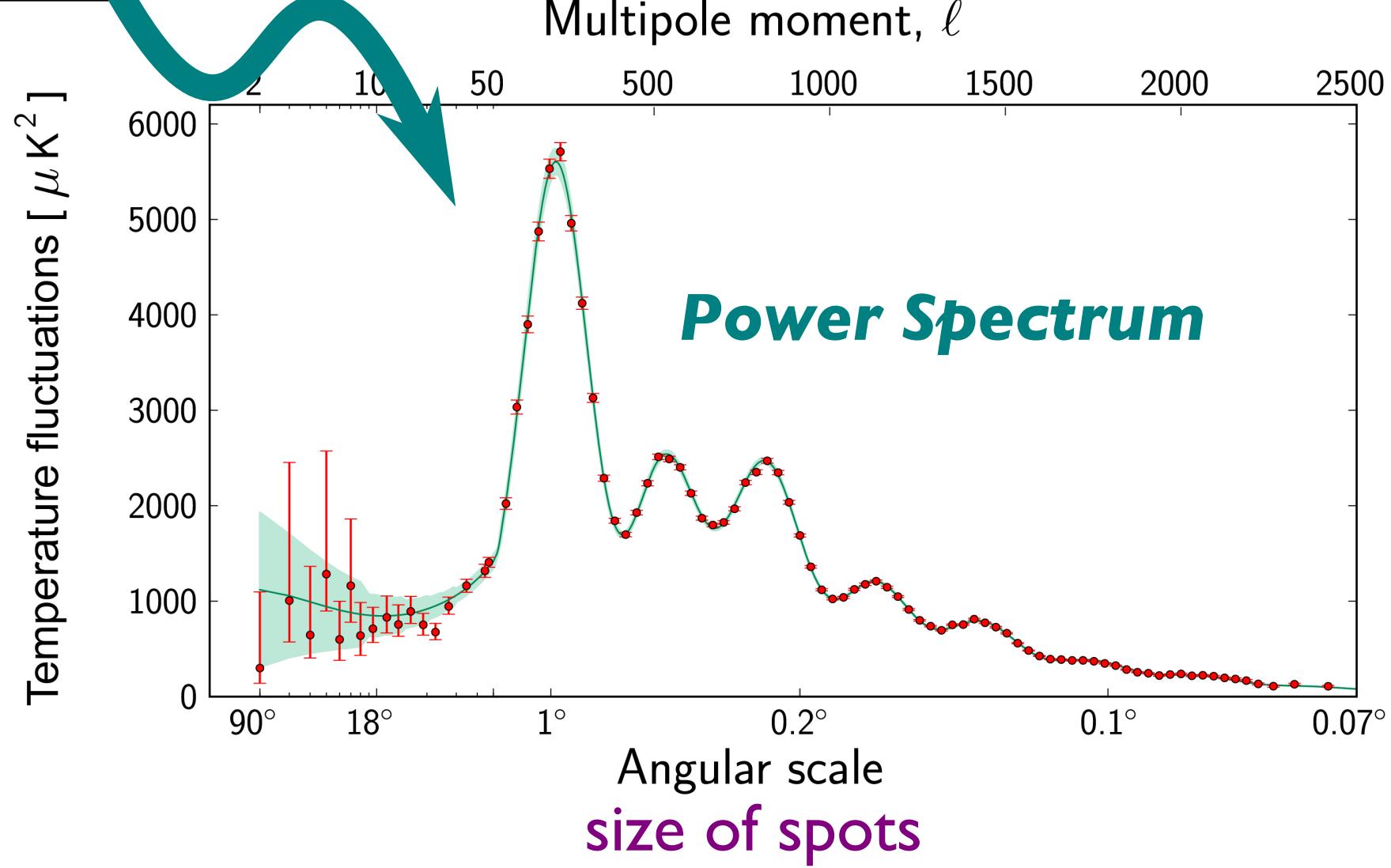
# Average Planck map around extrema



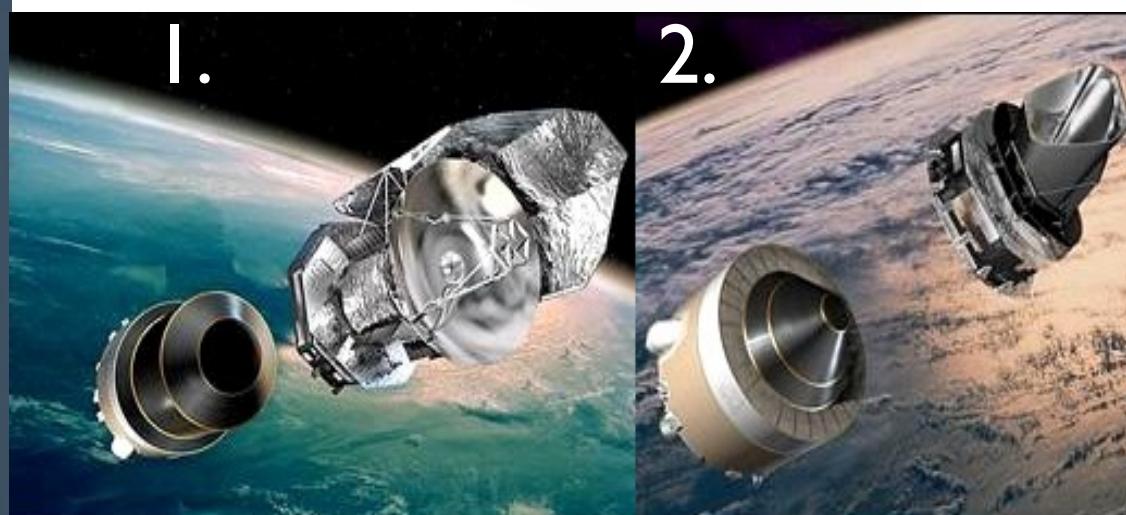
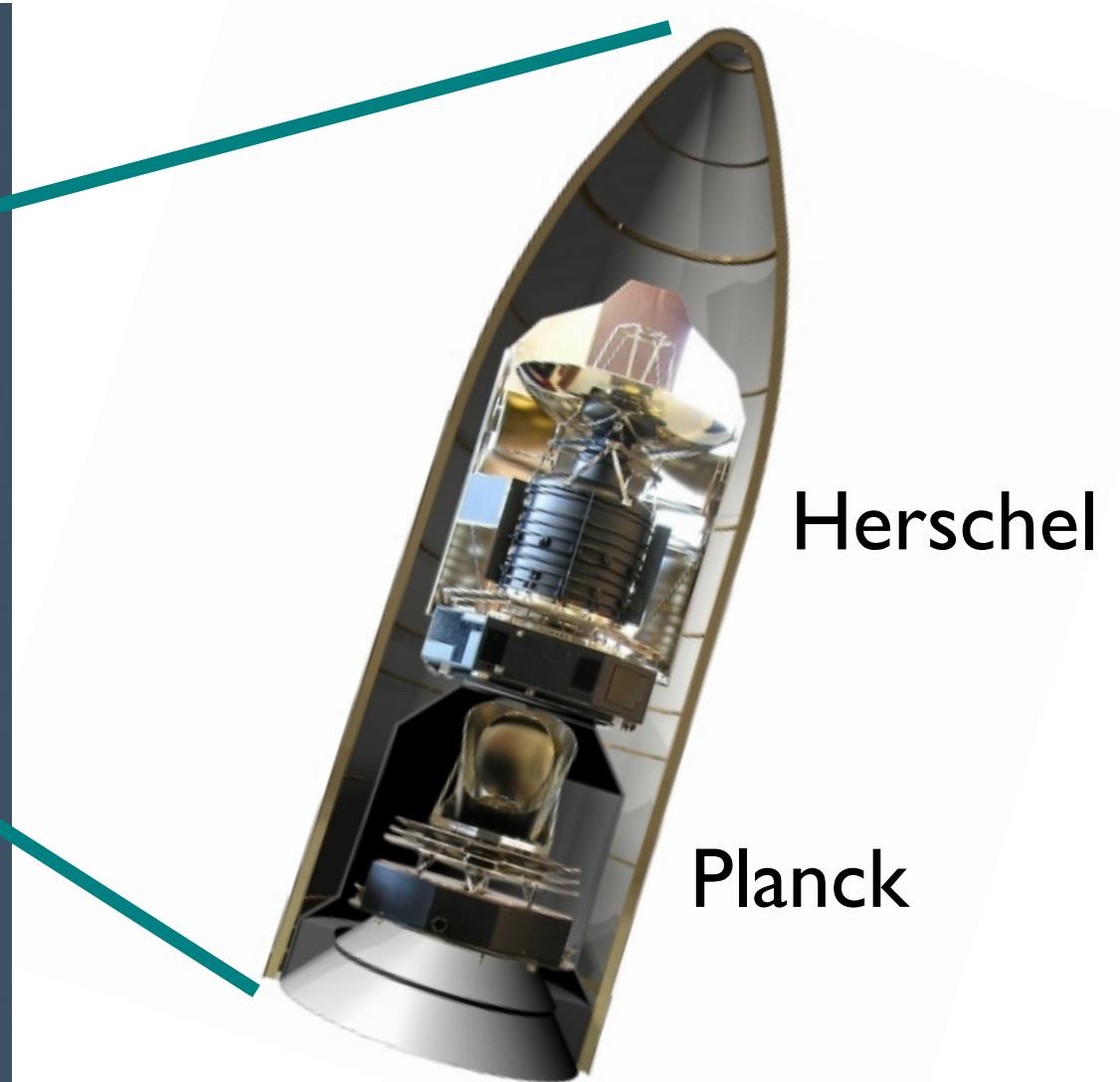
# Correlations in a single graph



intensity  
of  
hot & cold  
spots



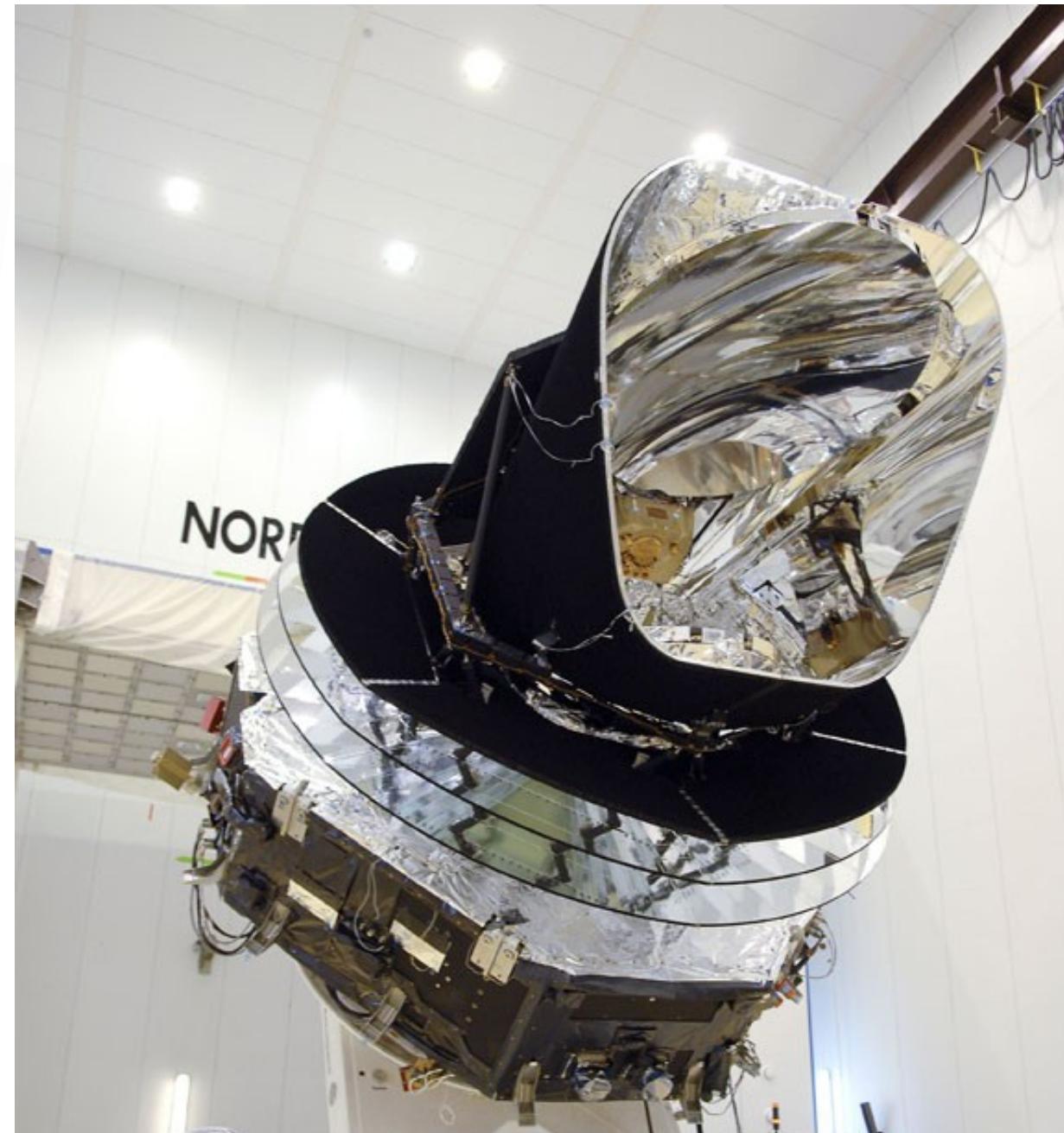
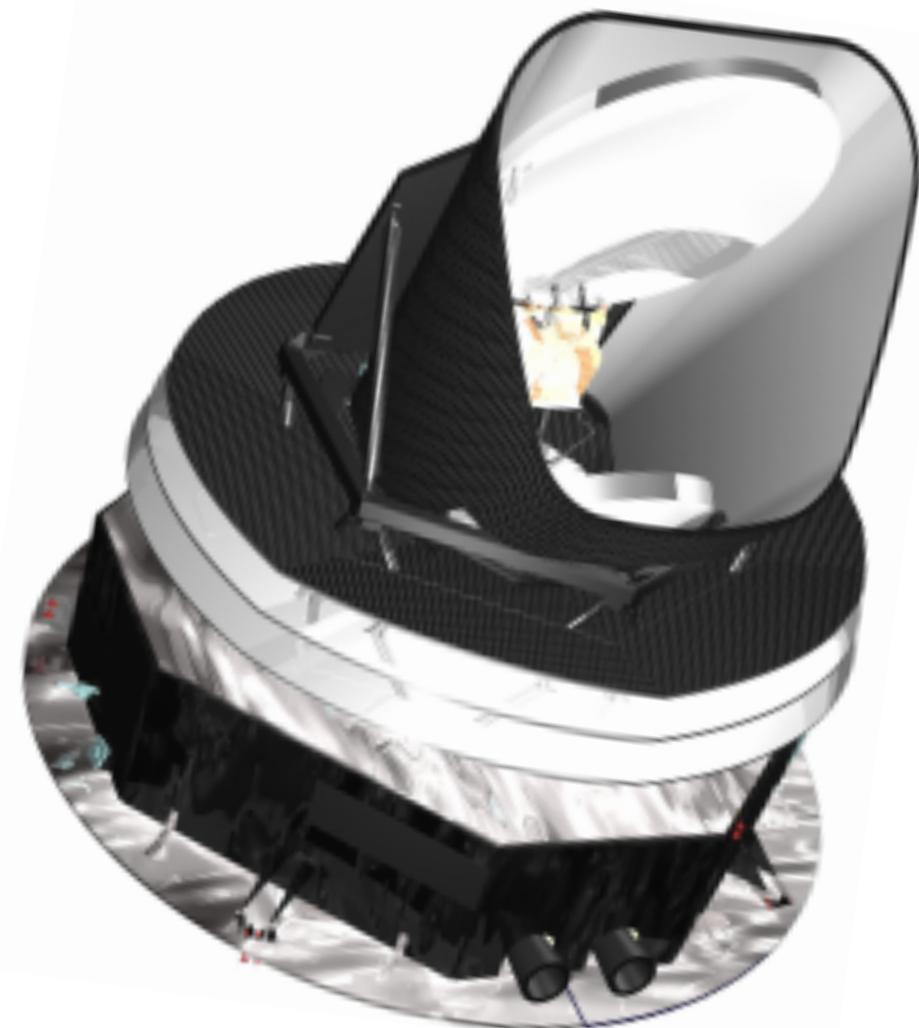
14 May 2009

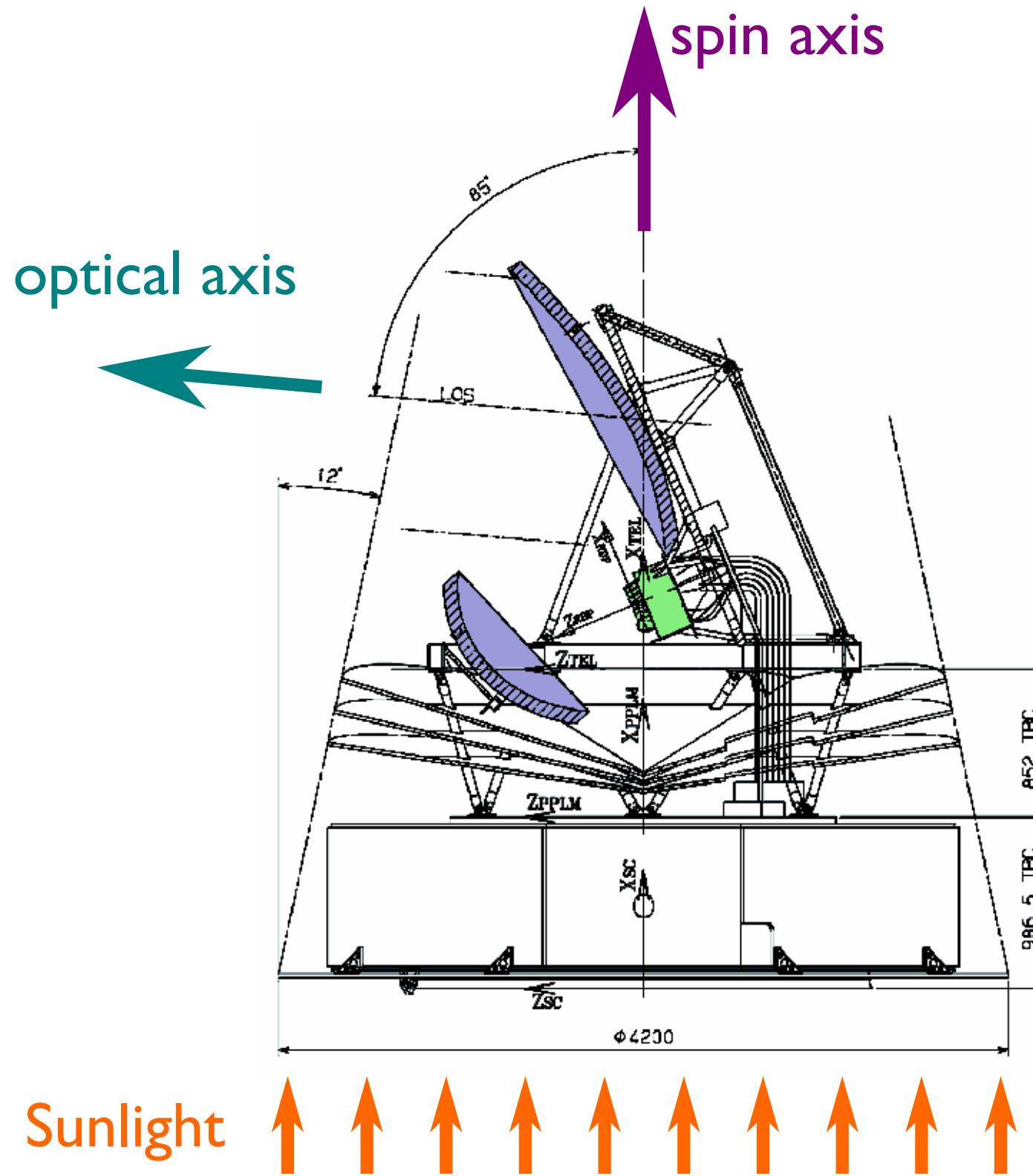


# 1.5 million km away at L2

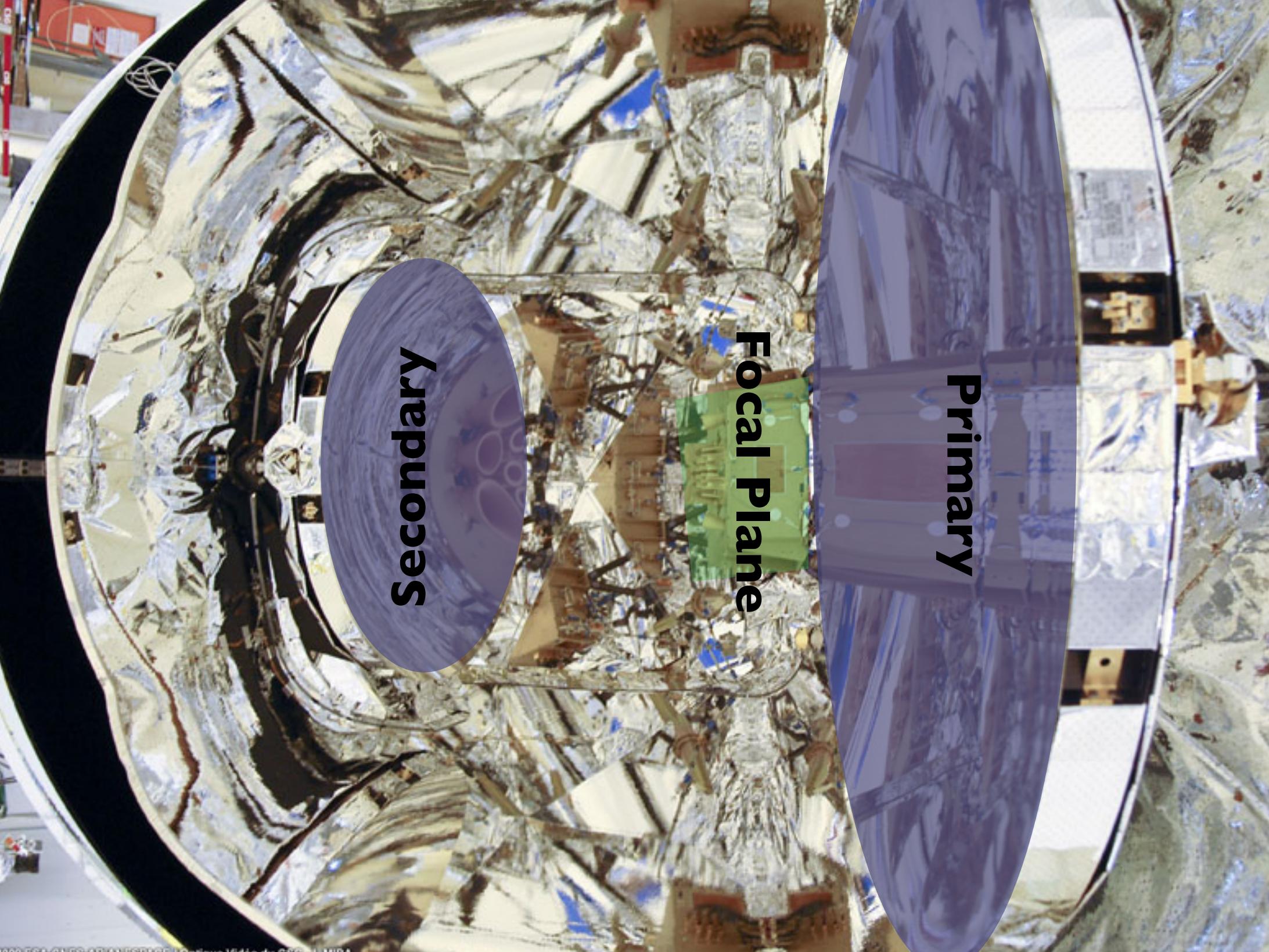


(movies)





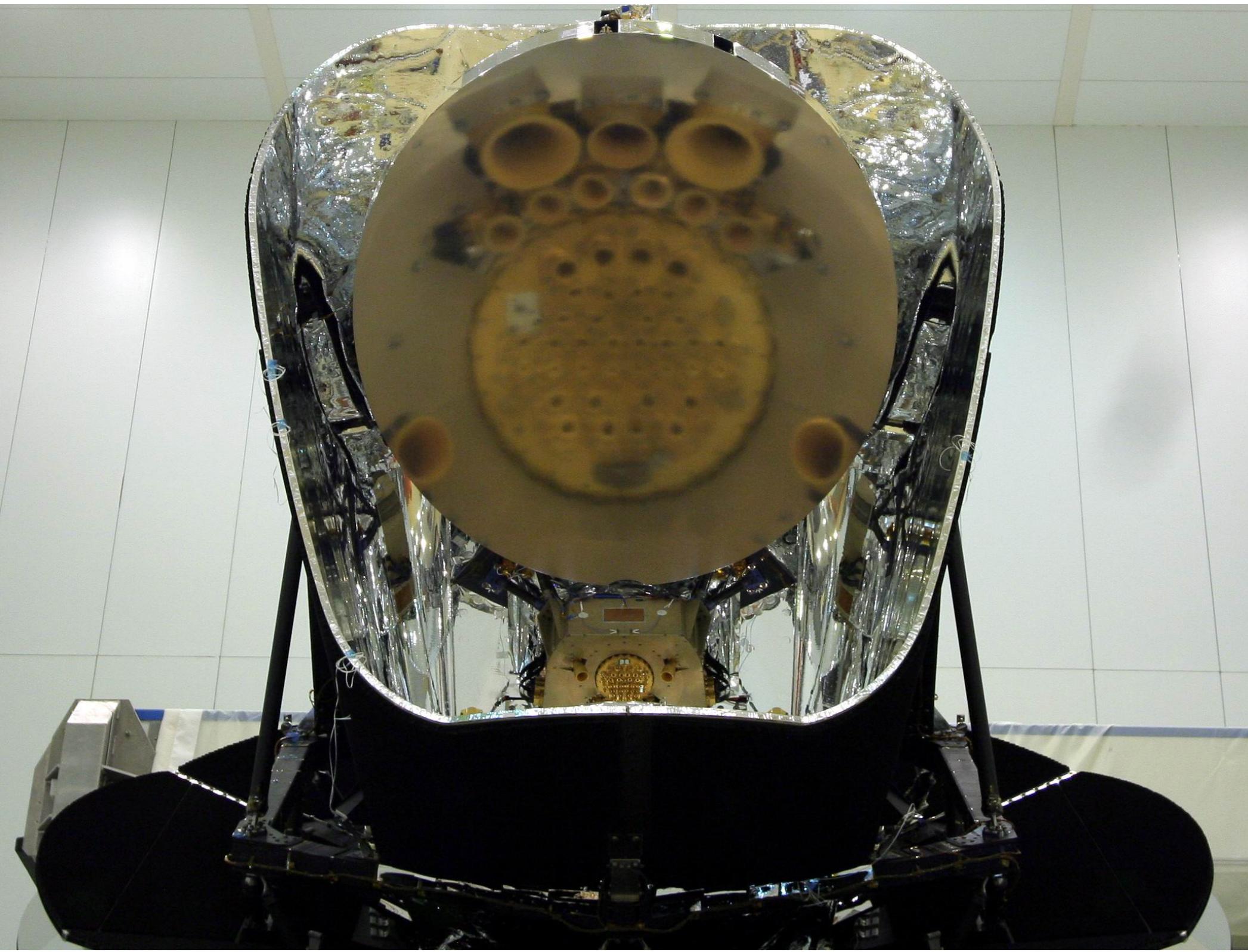




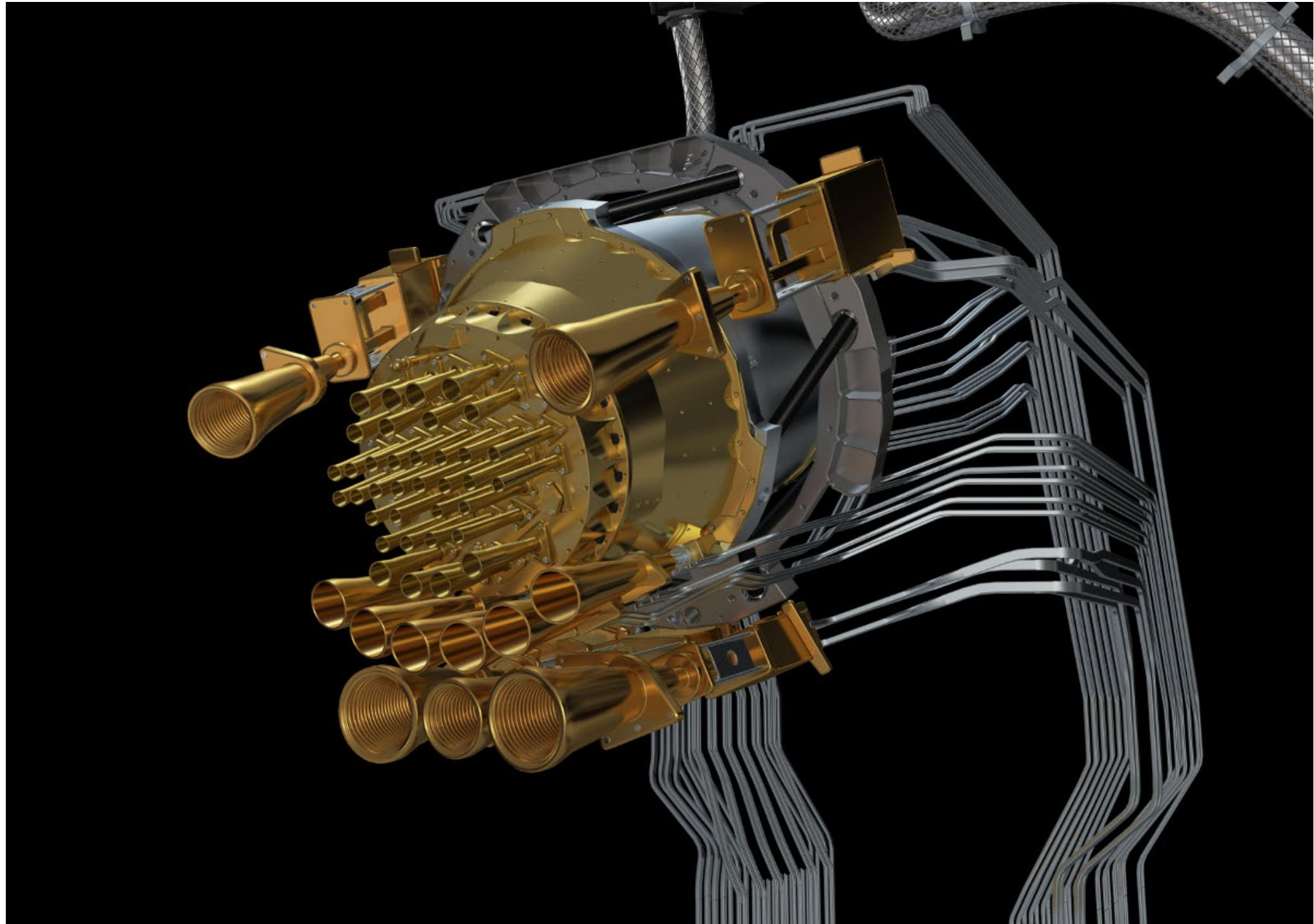
Secondary

Focal Plane

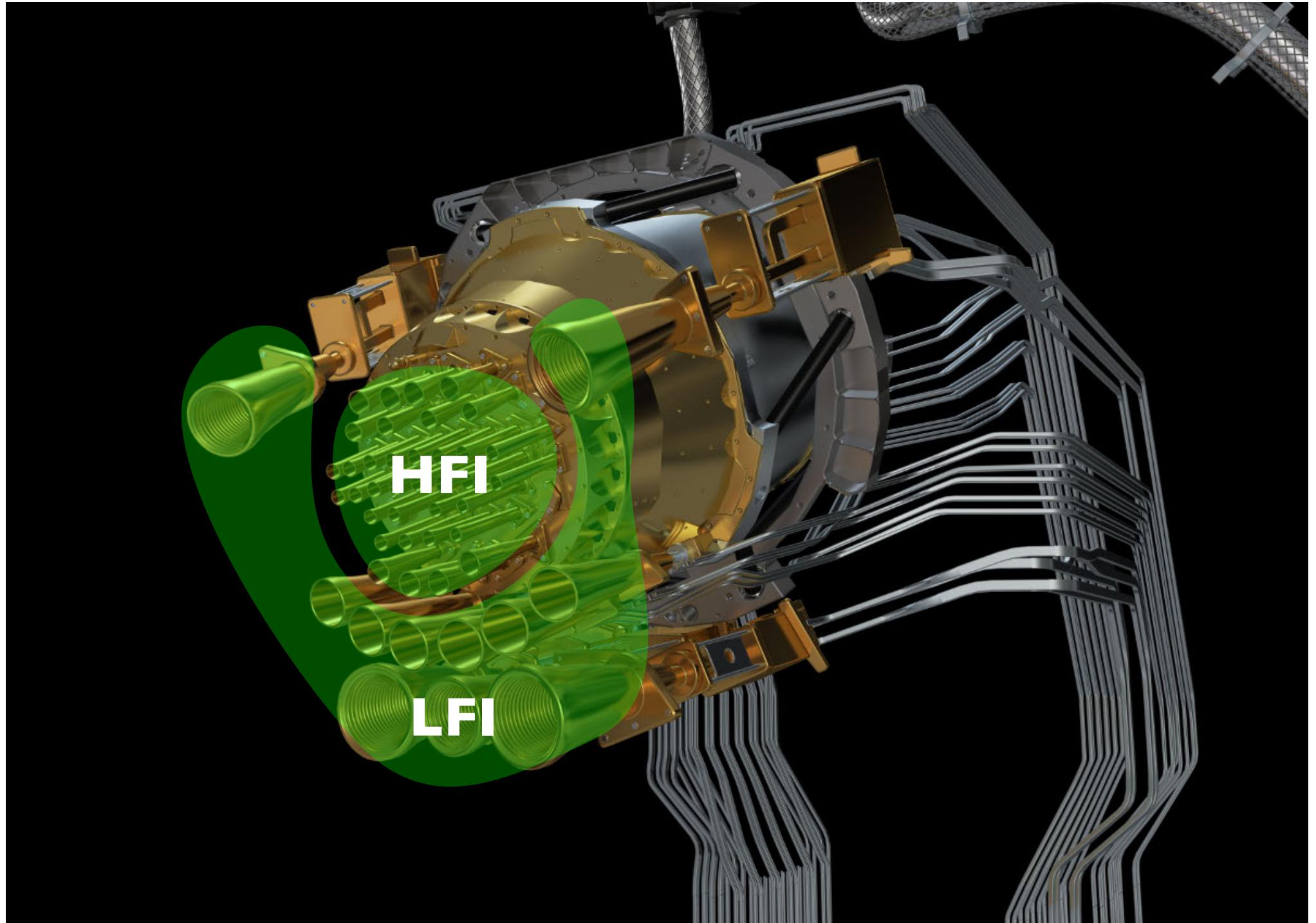
Primary



# Focal plane



# Focal plane



# Capabilities

Planck: 9 channels

30 44 70

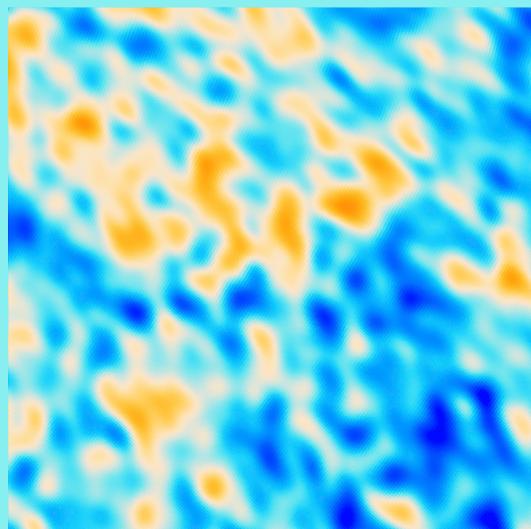
**LFI**

100 143 217 353 545 857 GHz

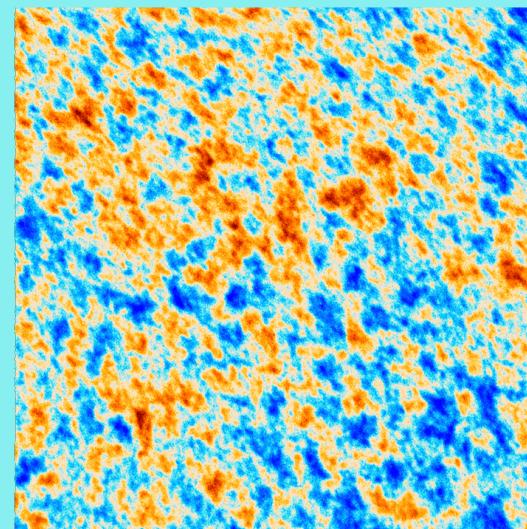
**HFI**

(20-30% bandwidth)

WMAP



Planck



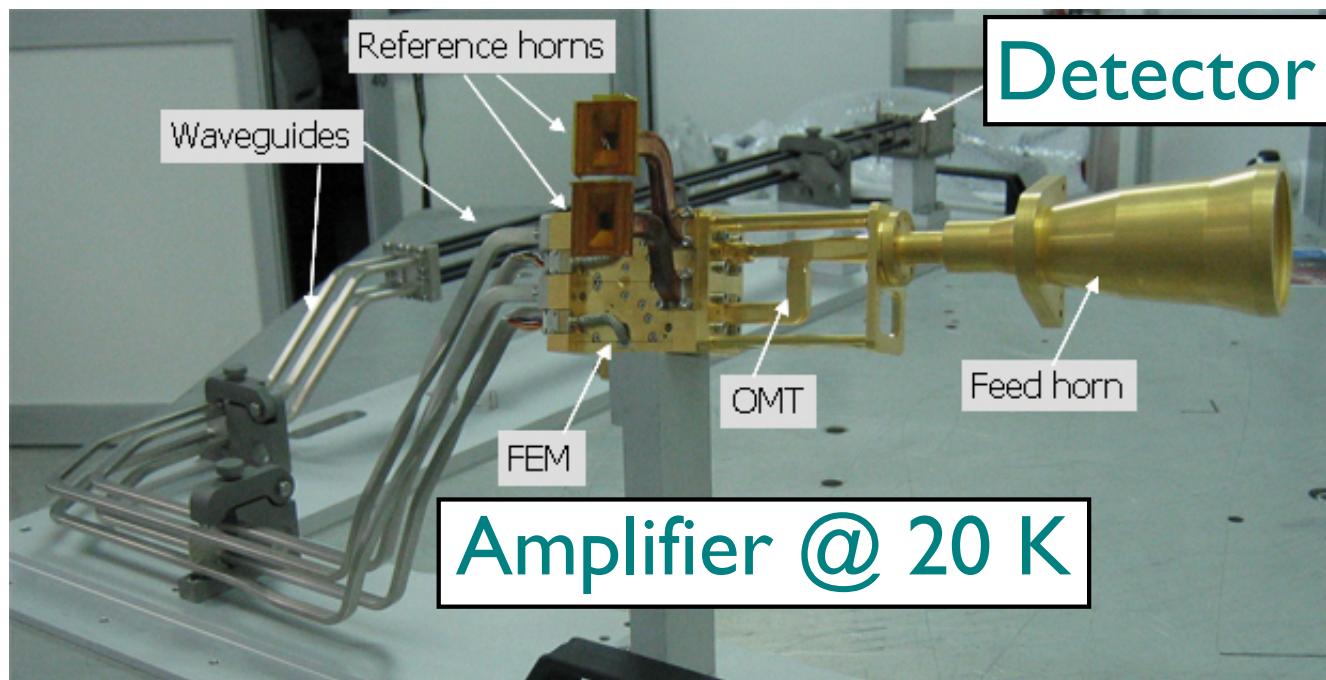
"3 times better resolution

&

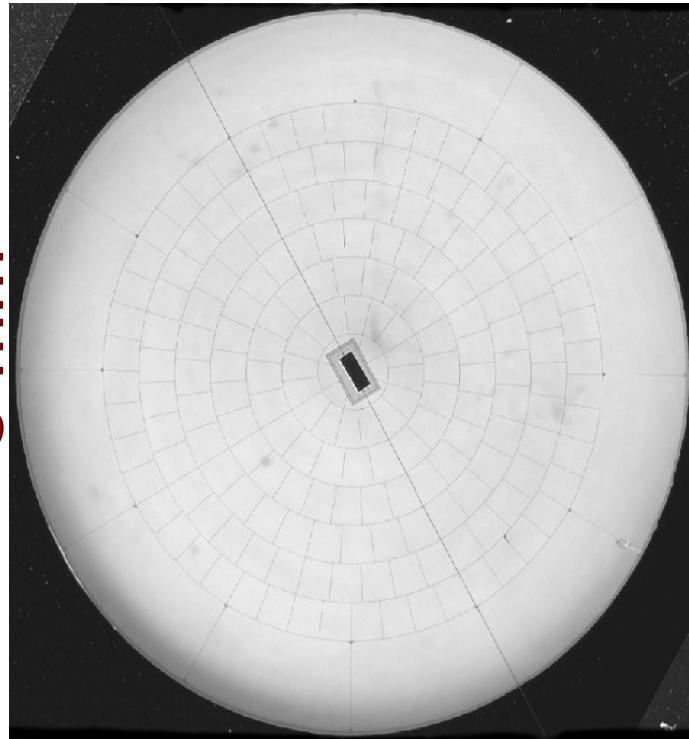
10 times lower noise than WMAP"

# Technology - Low Frequency Instrument

## Polarization sensitive radiometer

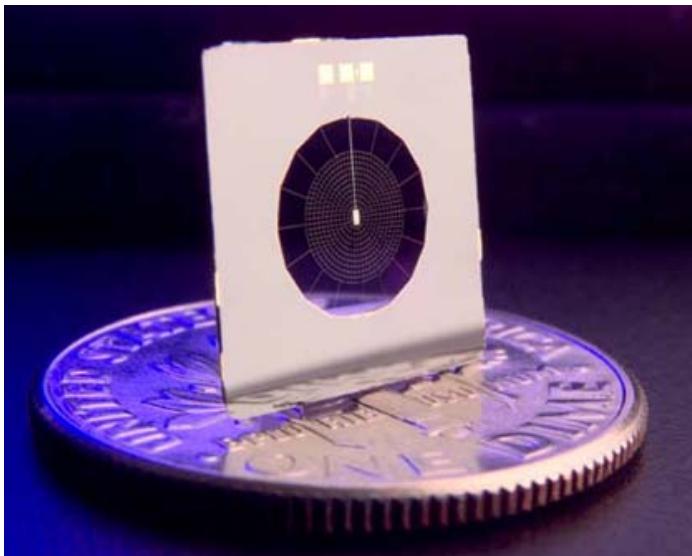


# Technology - High Frequency Instrument



~ 5 mm

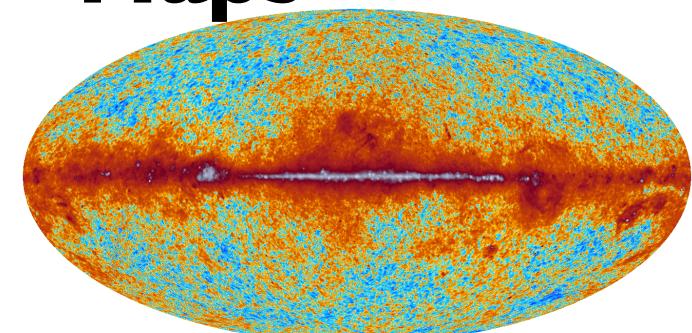
@ 0.1 K



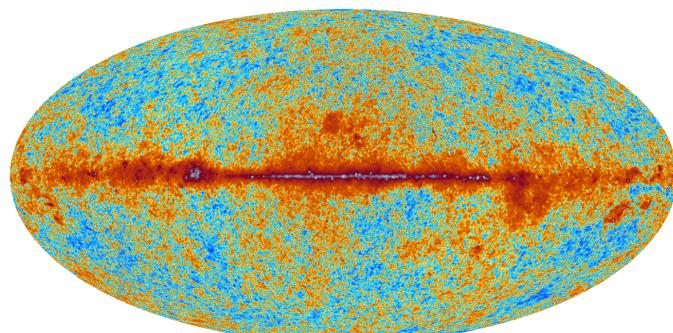
*O Langley invented the **bolometer**,  
Which is really a kind of thermometer.  
You can measure the heat  
Of a polar bear's seat  
At a distance of half a kilometer.*



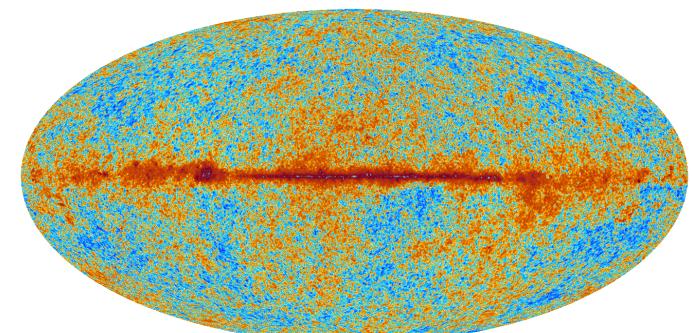
# Maps



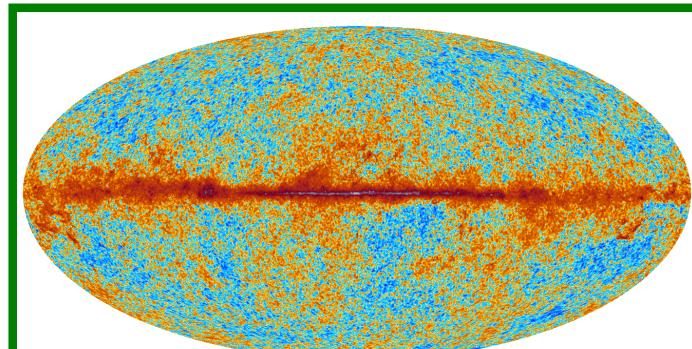
30



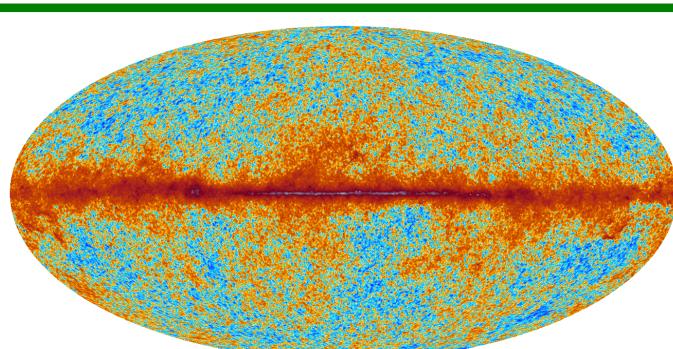
44



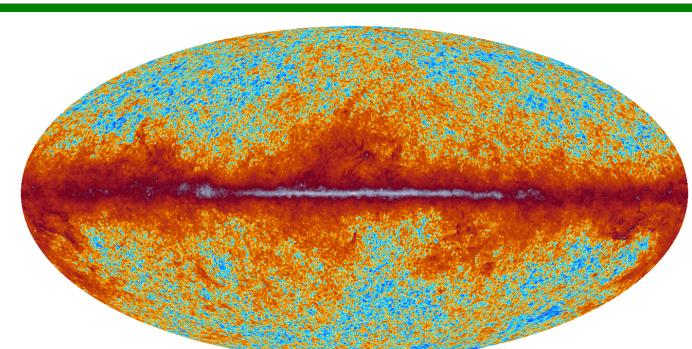
70



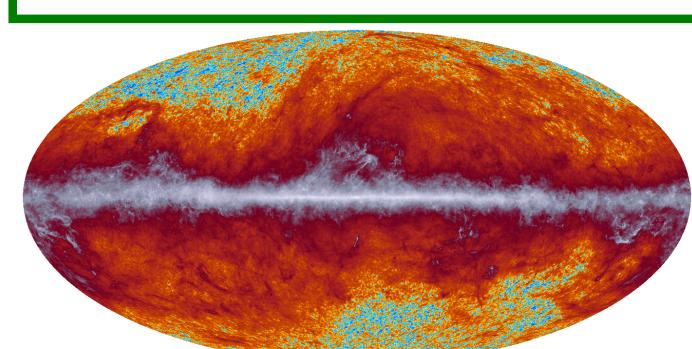
100



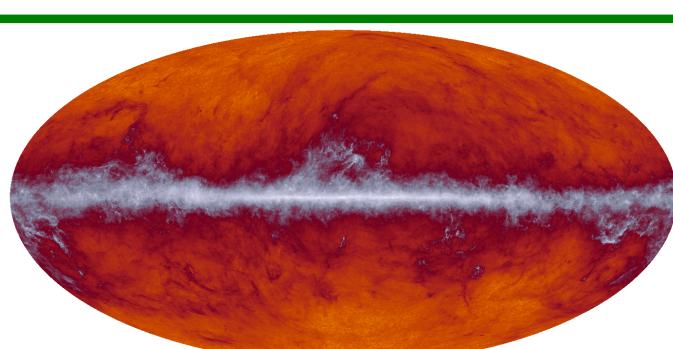
143



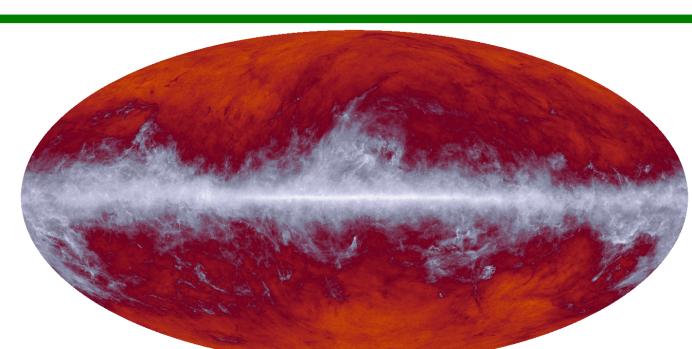
217



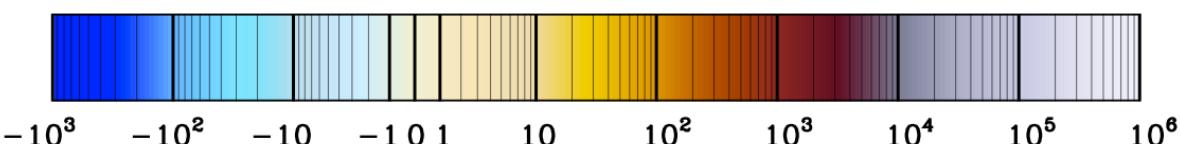
353



545



857



30–353 GHz:  $\delta T$  [ $\mu\text{K}_{\text{CMB}}$ ]; 545 and 857 GHz: surface brightness [kJy/sr]

"All the News  
That's Fit to Print"

# The New York Times

National Edition

Florida. A mix of sun and clouds. Afternoon showers. Highs 70s to near 80. Showers central and north tonight. Partly cloudy south. Lows 50s to 70s. Weather map, Page B10.

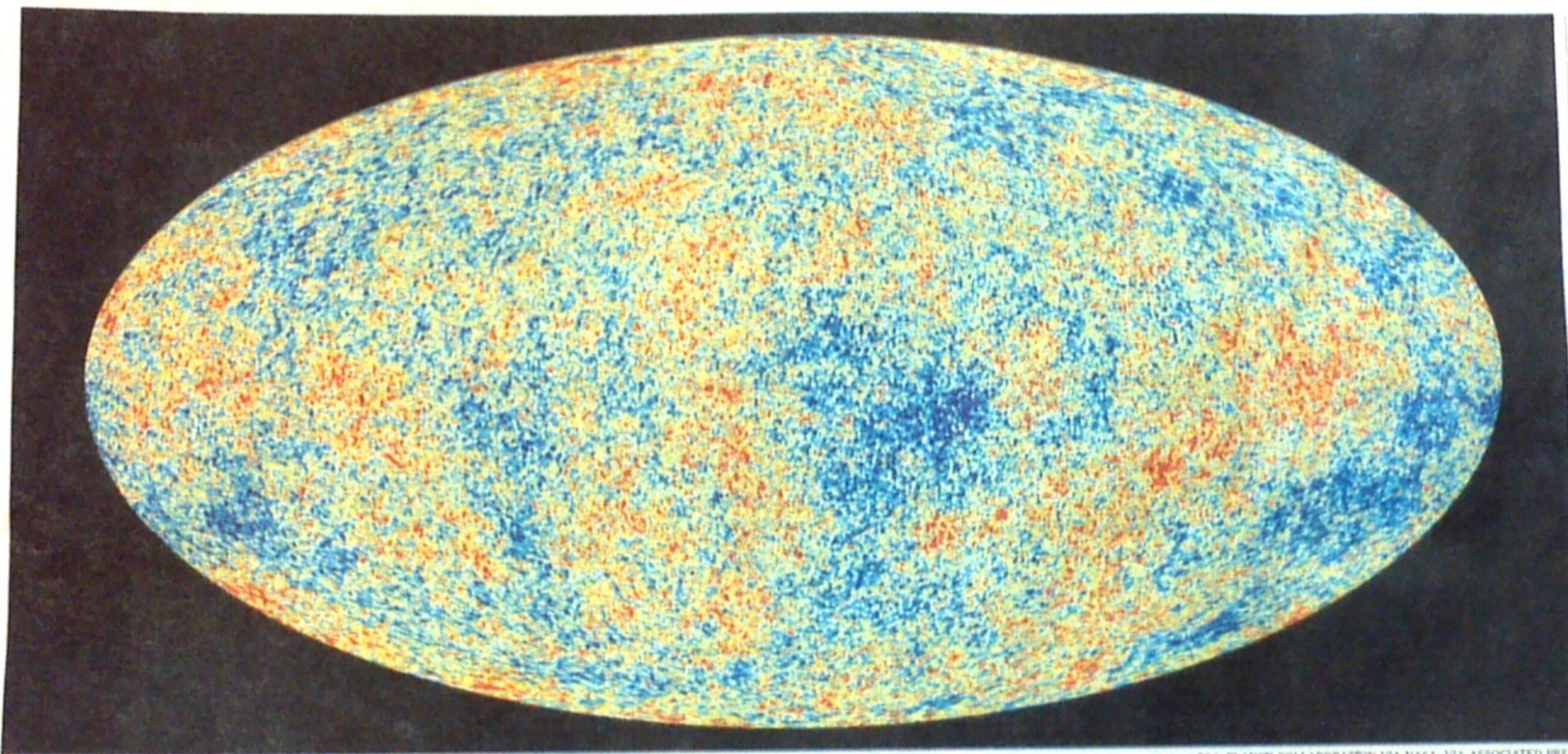
VOL. CLXII . . . No. 56,083

© 2013 The New York Times

FRIDAY, MARCH 22, 2013

Printed in Deerfield Beach

\$2.50



ESA, PLANCK COLLABORATION VIA NASA, VIA ASSOCIATED PRESS

## The Cosmos, Back in the Day

An image from data recorded by a European Space Agency satellite shows a heat map of the universe as it appeared 370,000 years after the Big Bang. Page A10.

*As Pollution Worsens in China,*

*Once Few, Women Hold More Power in Senate*

## PRESIDENT URGES ISRAELIS TO PUSH EFFORT FOR PEACE

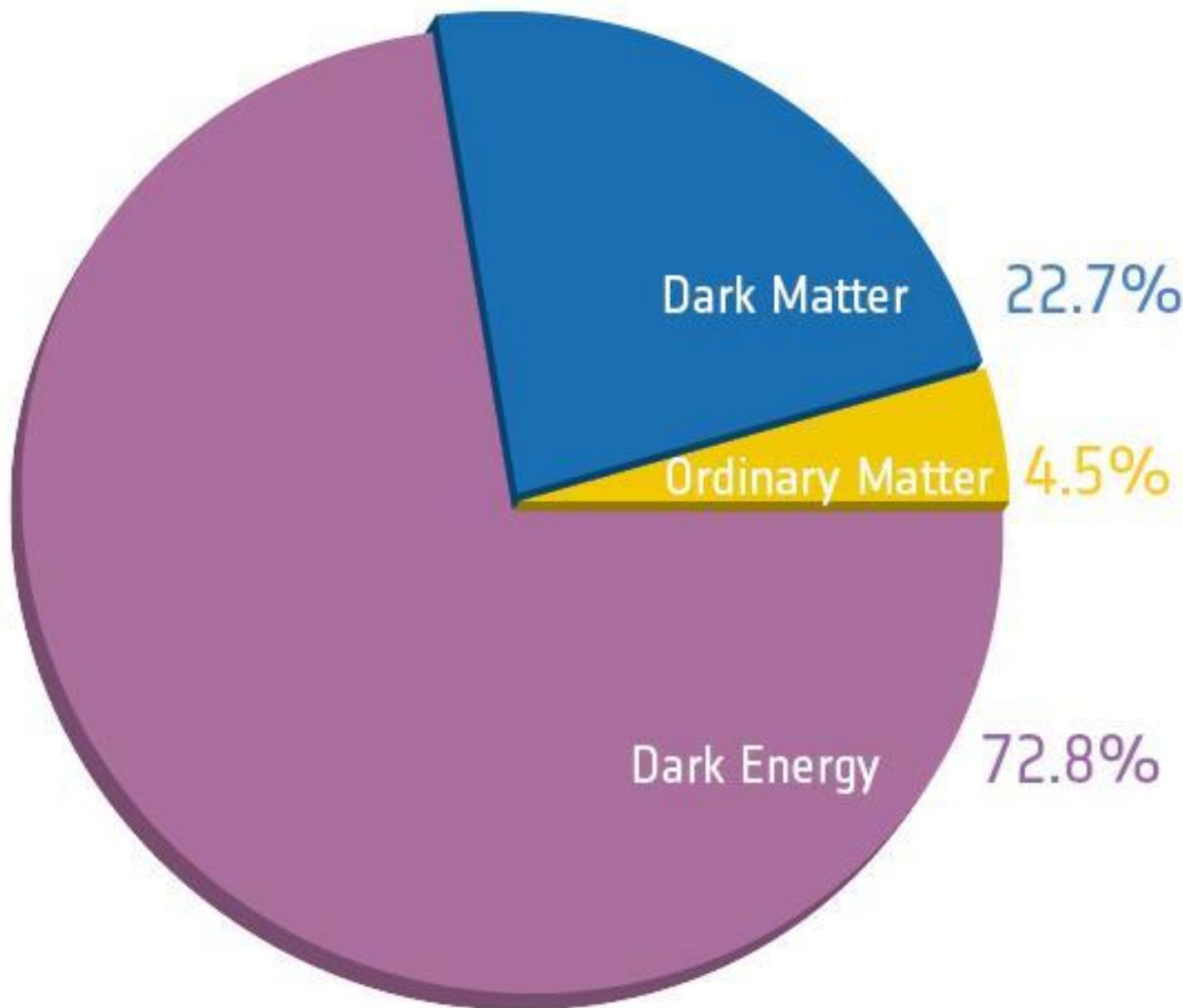
### APPEAL AIMED AT YOUNG

In Jerusalem, He Eases Stance on Settlement Halt Before Talks

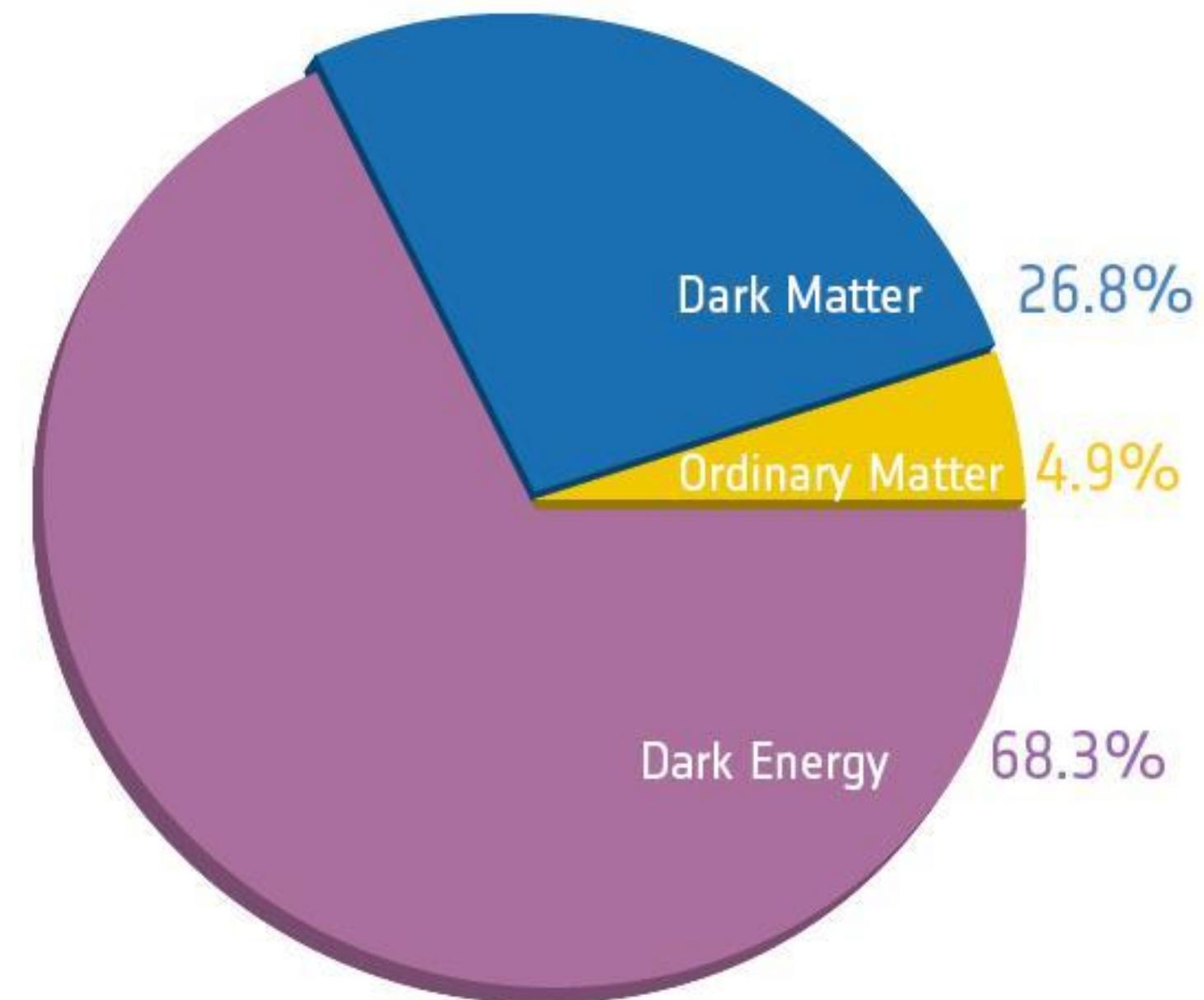
By MARK LANDLER

JERUSALEM — President Obama, appealing to very disparate audiences to solve one of the world's thorniest problems, moved closer on Thursday to the Israeli government's position on resuming long-stalled peace talks with the Palestinians, even as he passionately implored young Israelis to get ahead of their own leaders in the push for peace.

Addressing an enthusiastic crowd of more than 2,000, Mr. Obama offered a fervent, unsparing case for why a peace agreement was both morally just and in Israel's self-interest. Younger Israelis, Mr. Obama said, should empathize with their Palestinian neighbors living under occupation — or, as he put it, "look at the world through their eyes."



Before Planck



After Planck

 RECENT NEWS

# Universe Older, Wider Than Previously Thought

AMERICAN VOICES • Opinion • ISSUE 49•12 • Mar 22, 2013

[!\[\]\(d2555635330fa7c471cdeb88436b9450\_img.jpg\) 167](#) [!\[\]\(1f48883131671cf287d23231f73da558\_img.jpg\) 86](#) [!\[\]\(9c086d5634753fb2e3959ed12c2daaf7\_img.jpg\) 4](#)

Astronomers determined that the universe is actually 13.8 billion years old, about 80 to 100 million years older than previously believed, and that it is also a bit wider than once thought. What do you think?



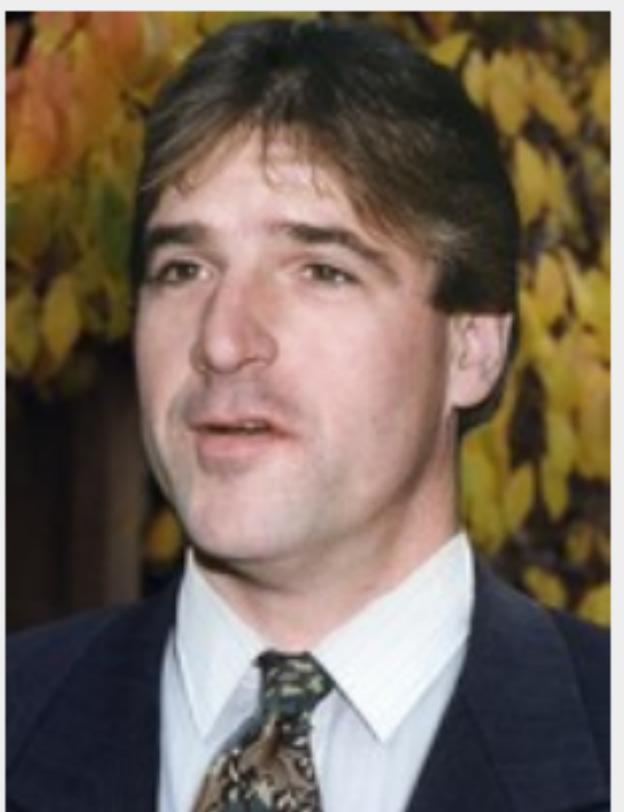
*"How embarrassing."*

Victoria Rosegard –  
Street Cleaner



*"Typical. You give birth to a few trillion galaxies and then people just talk about how old and fat you've gotten."*

Francois Jenevein –  
Hide Trimmer



*"Just like it says in Leviticus."*

Chris Vanderhorst –  
Systems Analyst

Future Christian Drinking And Doing Drugs And Thinking It's One Big Joke

Fast-Talking Computer Hacker Just Has To Break Through Encryption Shield Before Uploading Nano-Virus

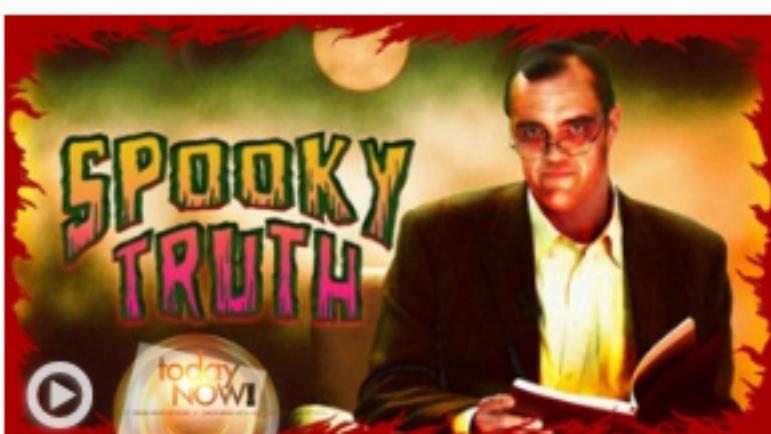
JCPenney CEO's Severance Package Includes 34,000 Pea Coats

Kim Jong-Un Wonders If Nuclear Threats Distracting Him From Real Goal Of Starving Citizenry

China Announces Plans To Build International Space Prison

Man Not Certain What Any Of His Coworkers' Names Are

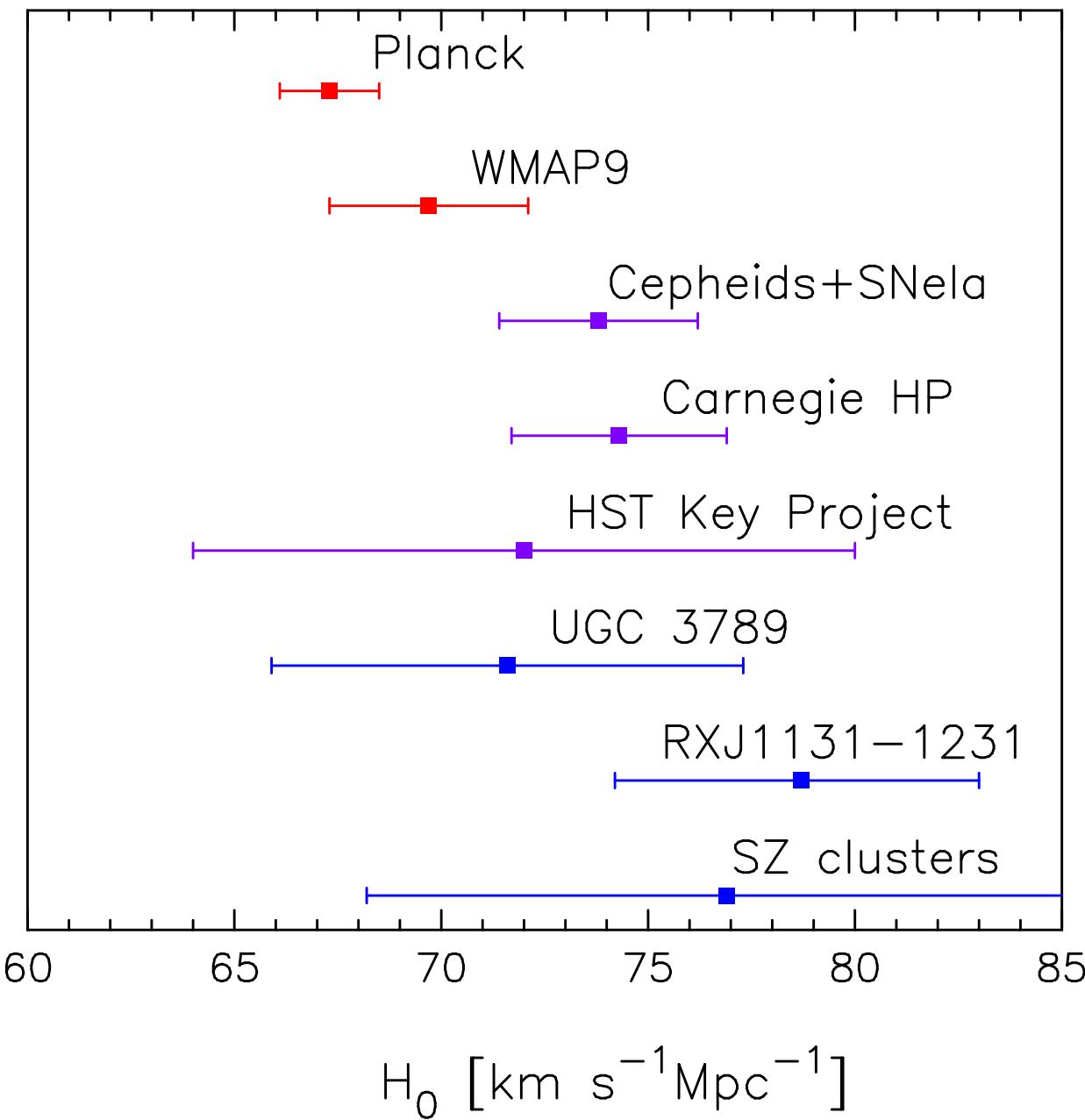
NATO Airstrike Destroys Key Taliban Day Care Center

 RECENT VIDEOS


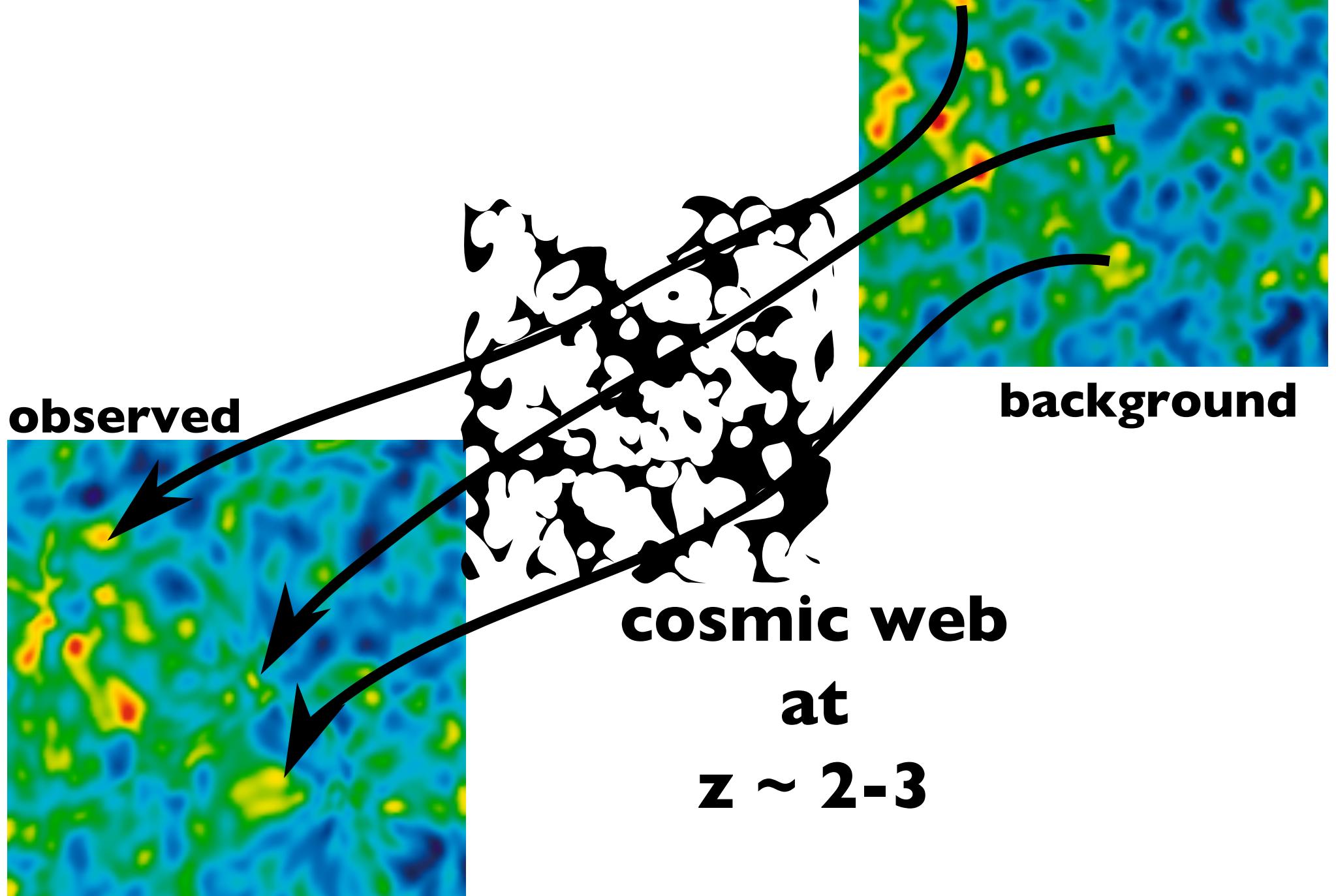
◀ Ian McKellen Officiating Patrick Stewart's Wedding

CDC: 1 In Every 50 U.S. Schoolchildren ... ➤

Popular Children's Book Author Reveals The 'Spooky Truth' About Creepy Conspiracy Theories ➤

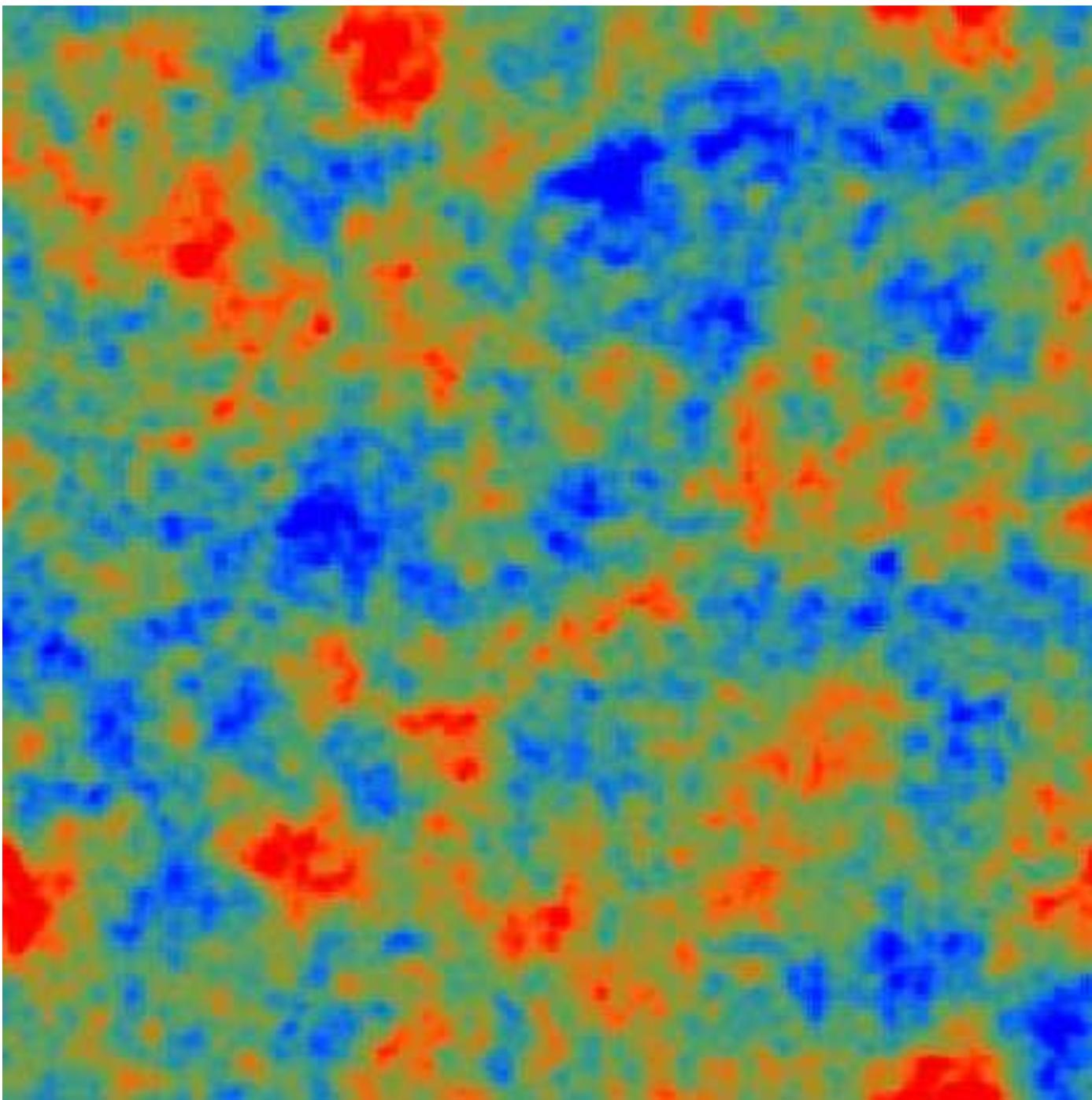


# CMB lensing



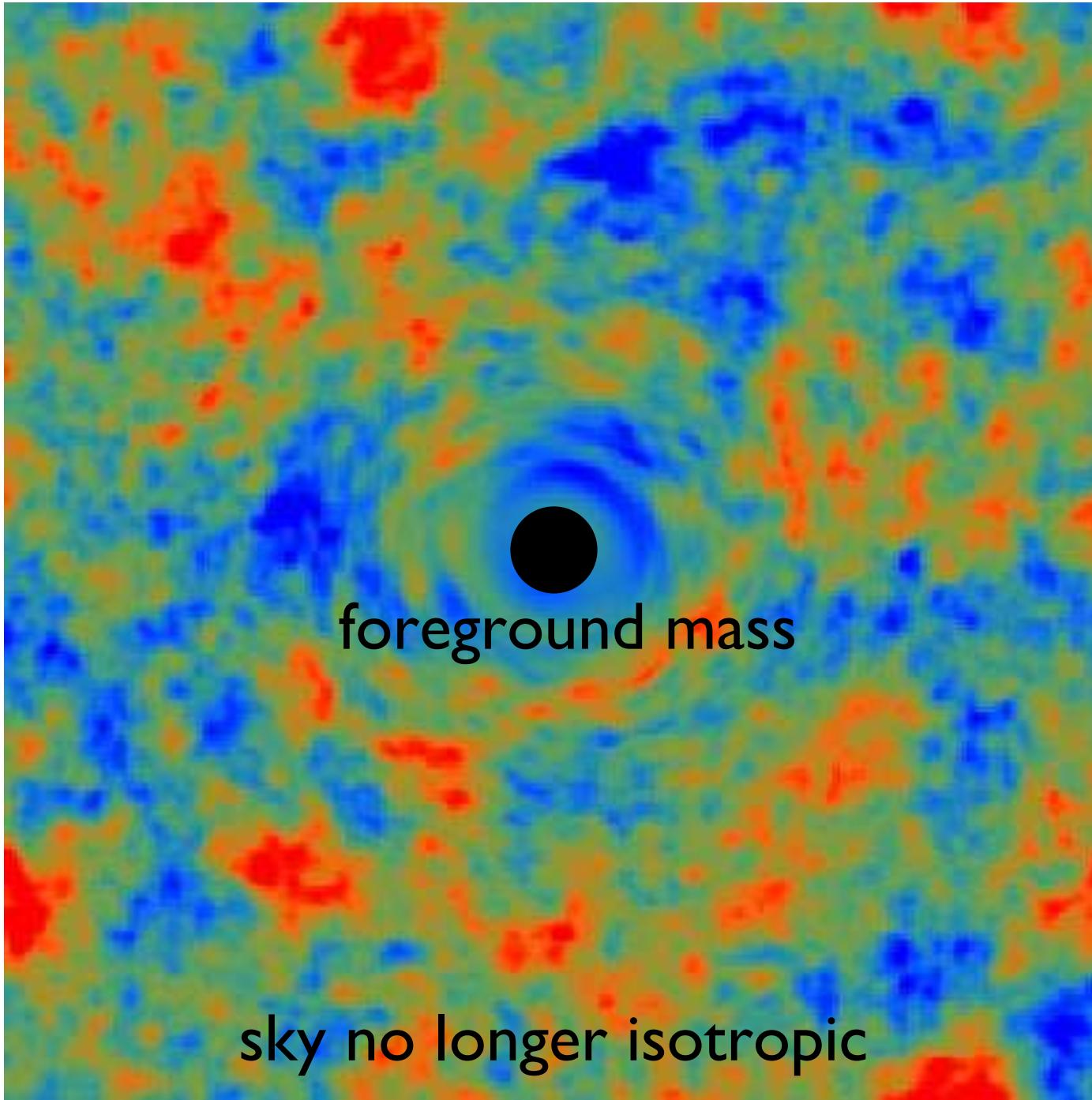
**CMB**

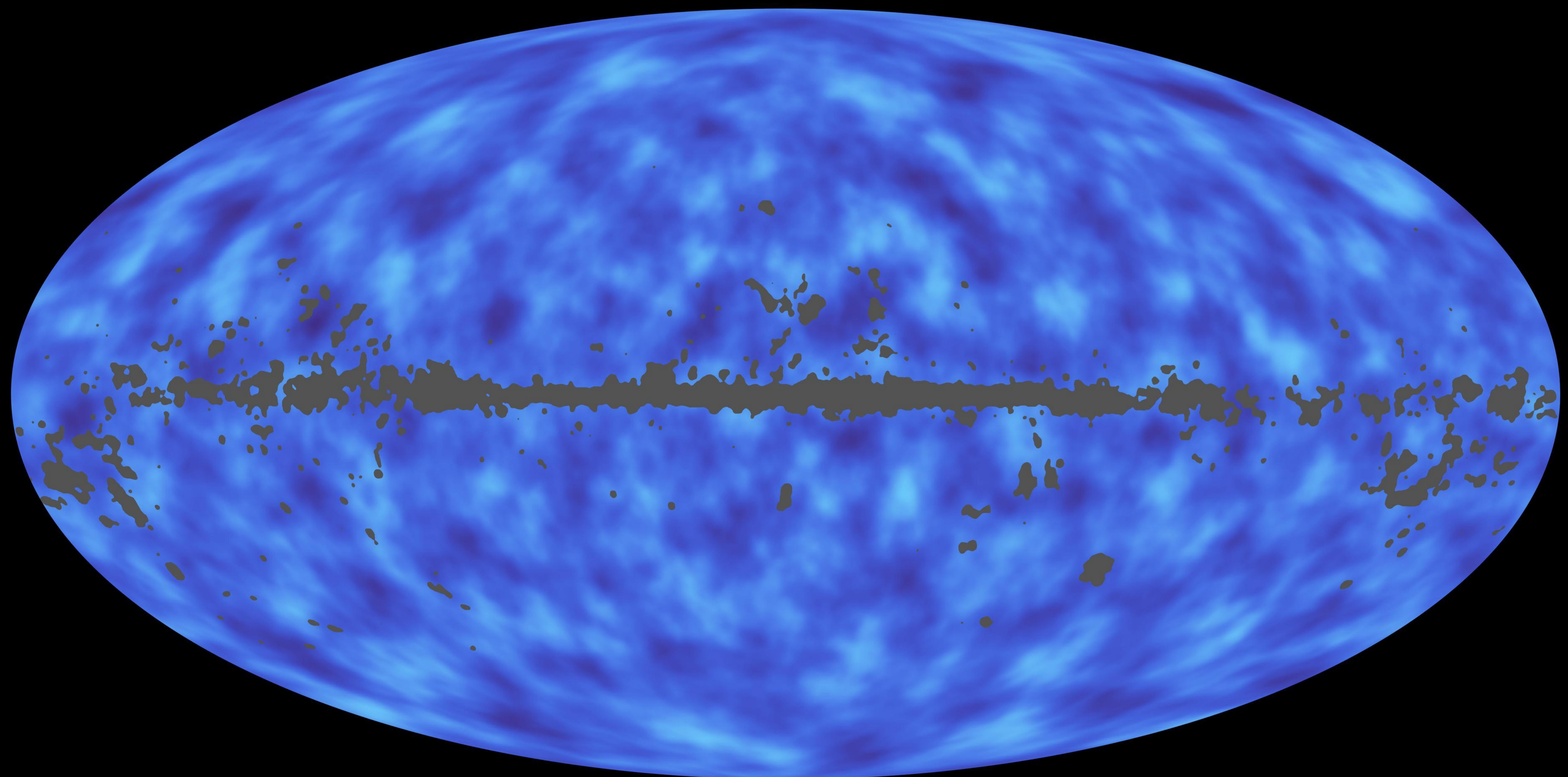
(Hu & Okamoto 2001)



# CMB lensed

(Hu & Okamoto 2001)





# Conclusions

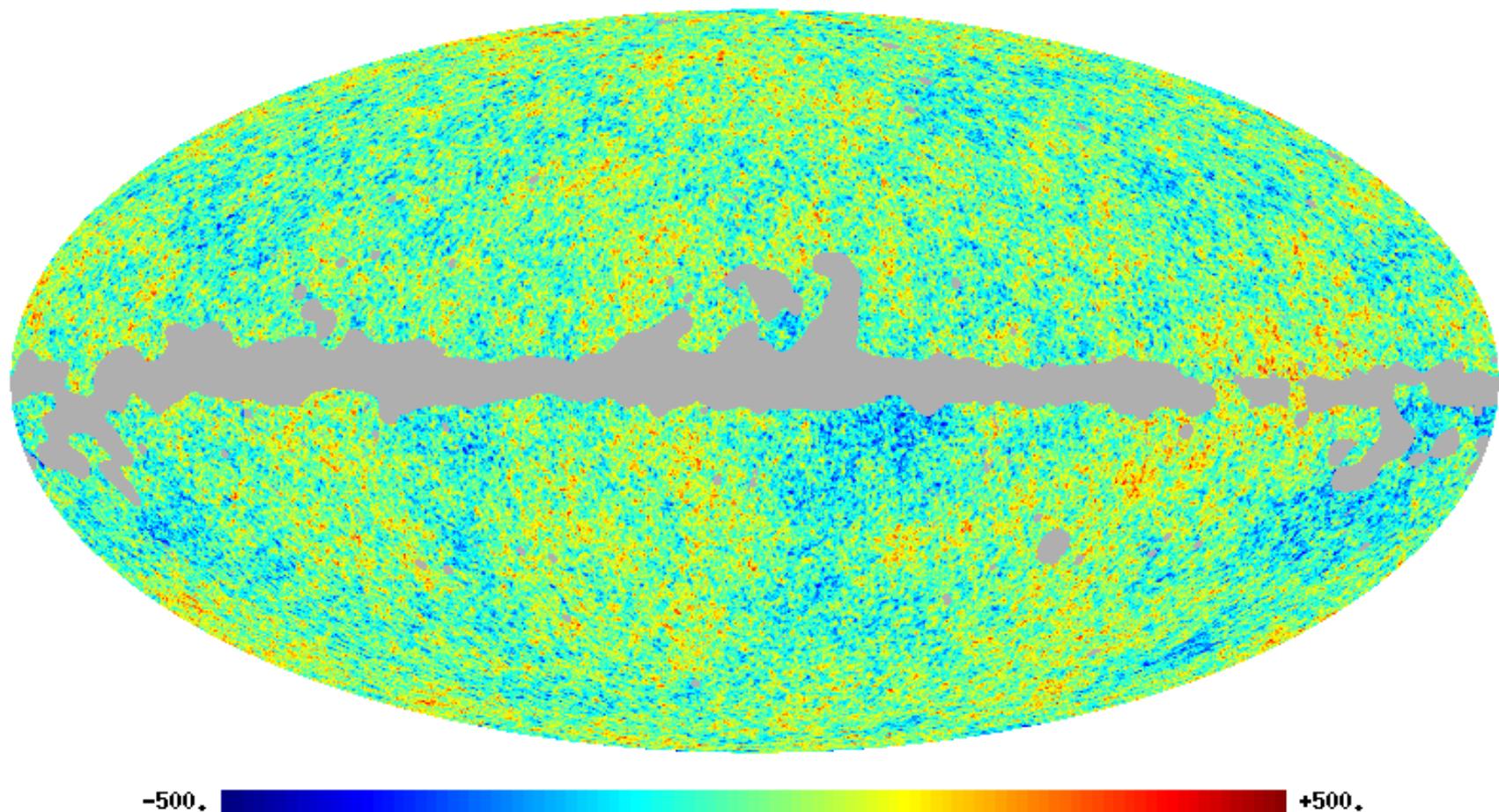
Planck has produced a rich store of data and cosmological results.

Next: Polarization

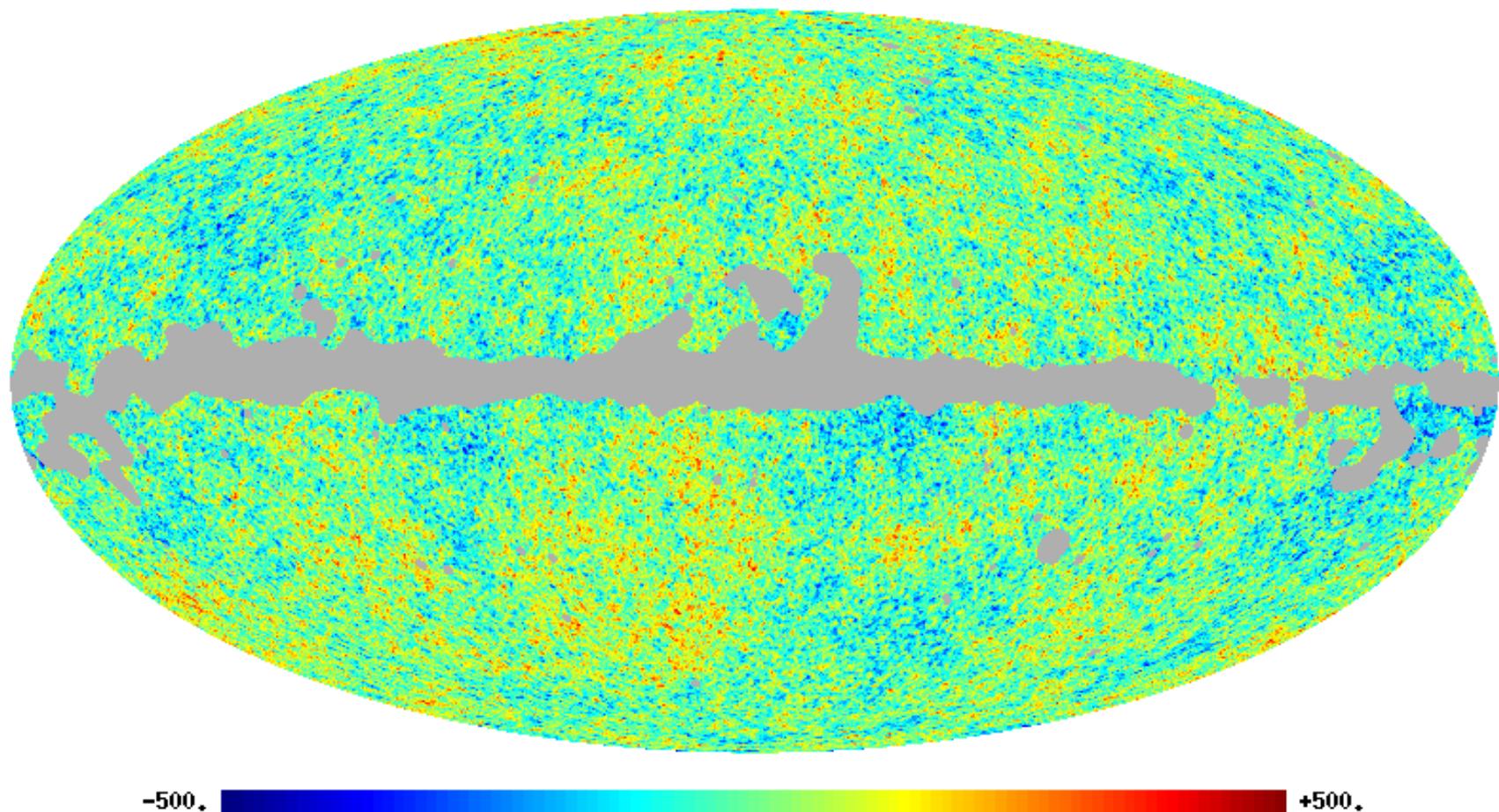
Large scale anomalies?



## The Observed CMB Sky

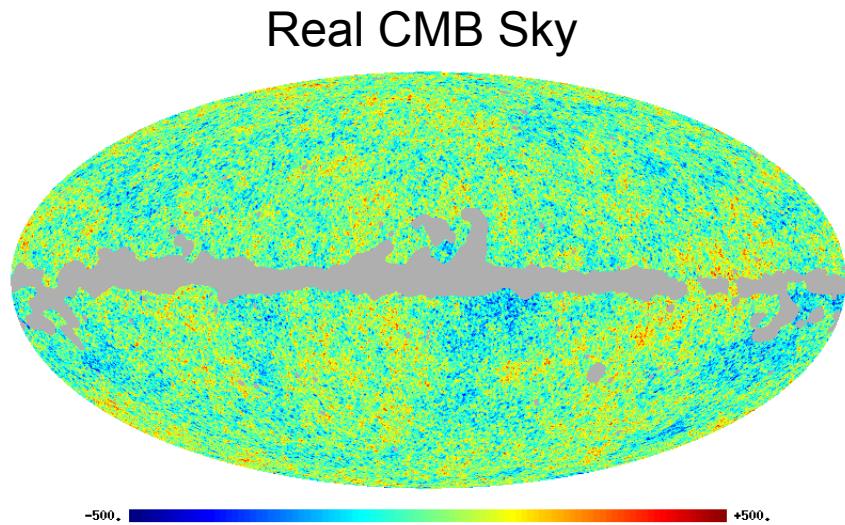


-500. +500.

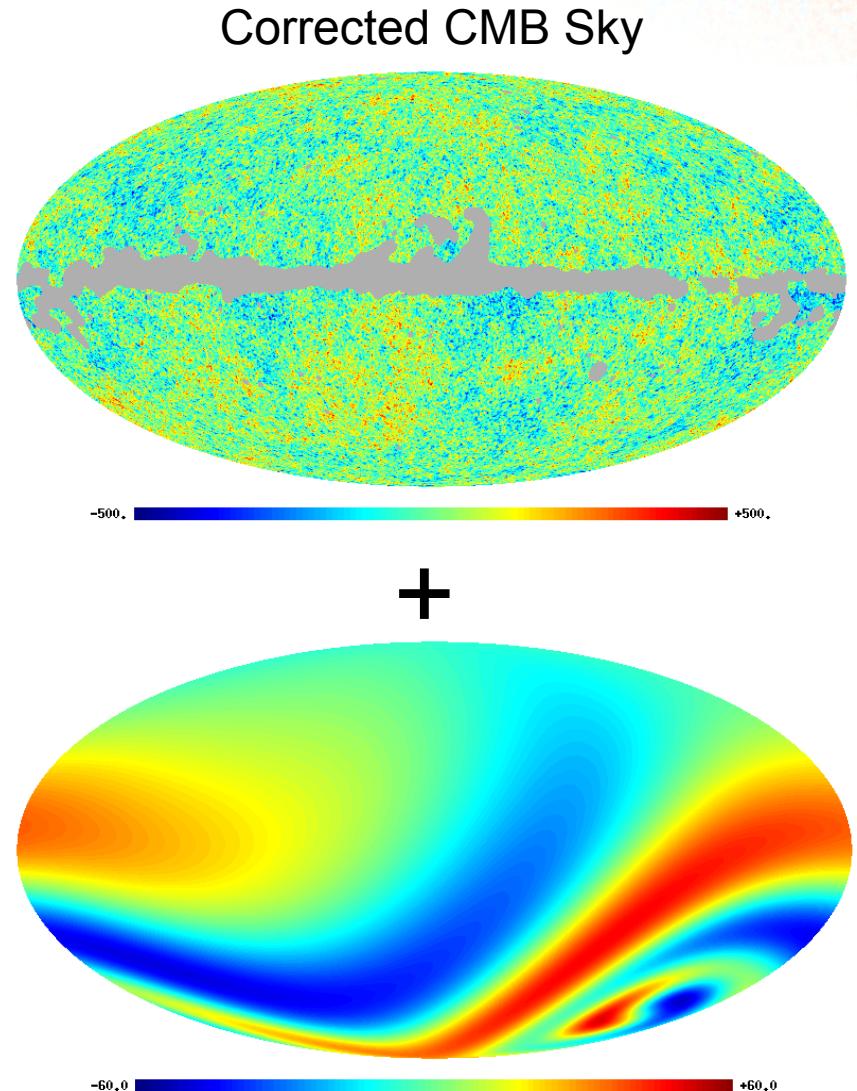




The Bianchi model **must be open** to fit the data, and cannot be merged with the overall flat cosmology that describes the observed universe



=



Correction that fits the sky:  
a homogeneous, anisotropic Bianchi VII<sub>h</sub> model