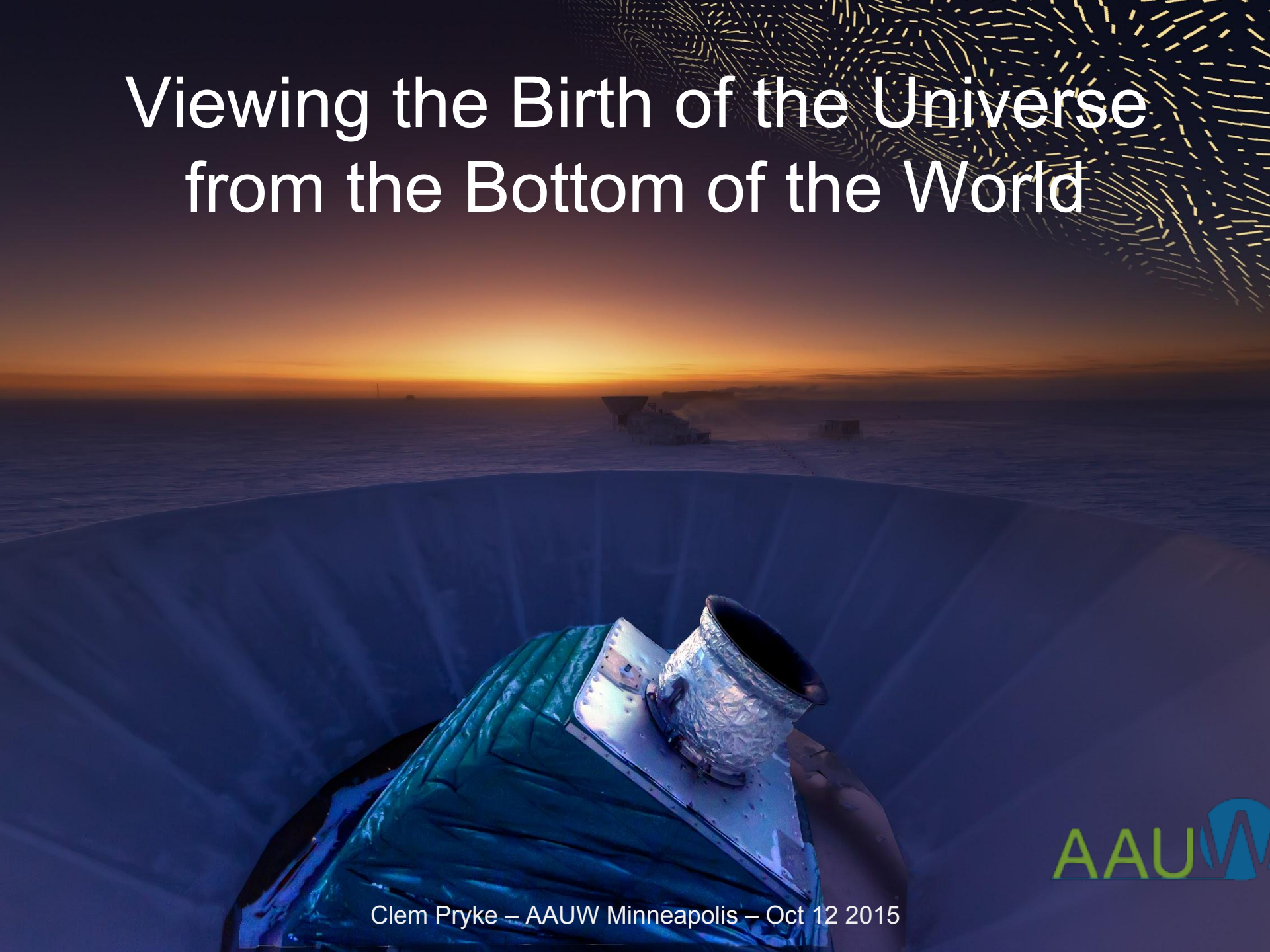
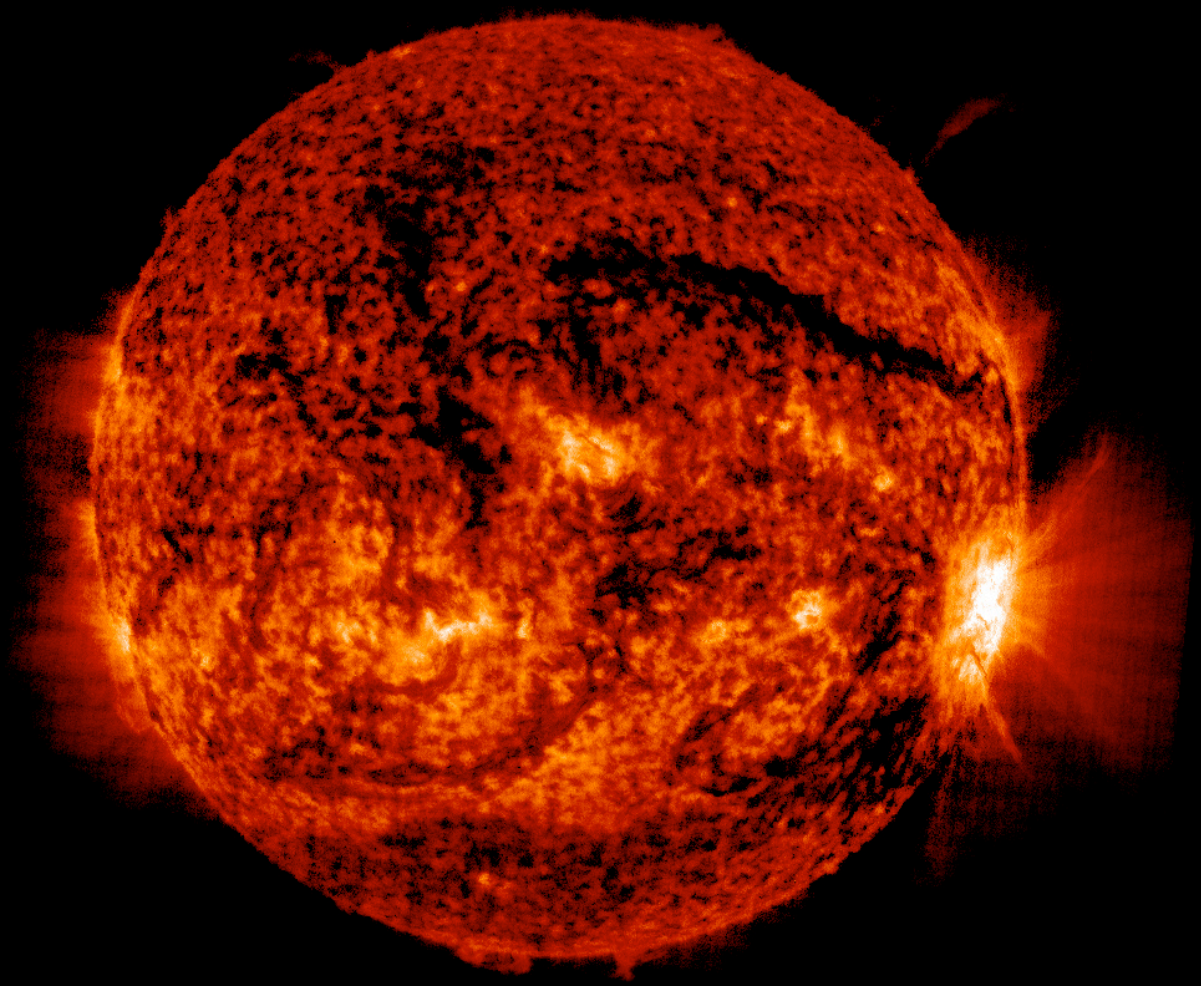
Viewing the Birth of the Universe from the Bottom of the World



Clem Pryke – AAUW Minneapolis – Oct 12 2015

Our Sun is a Star

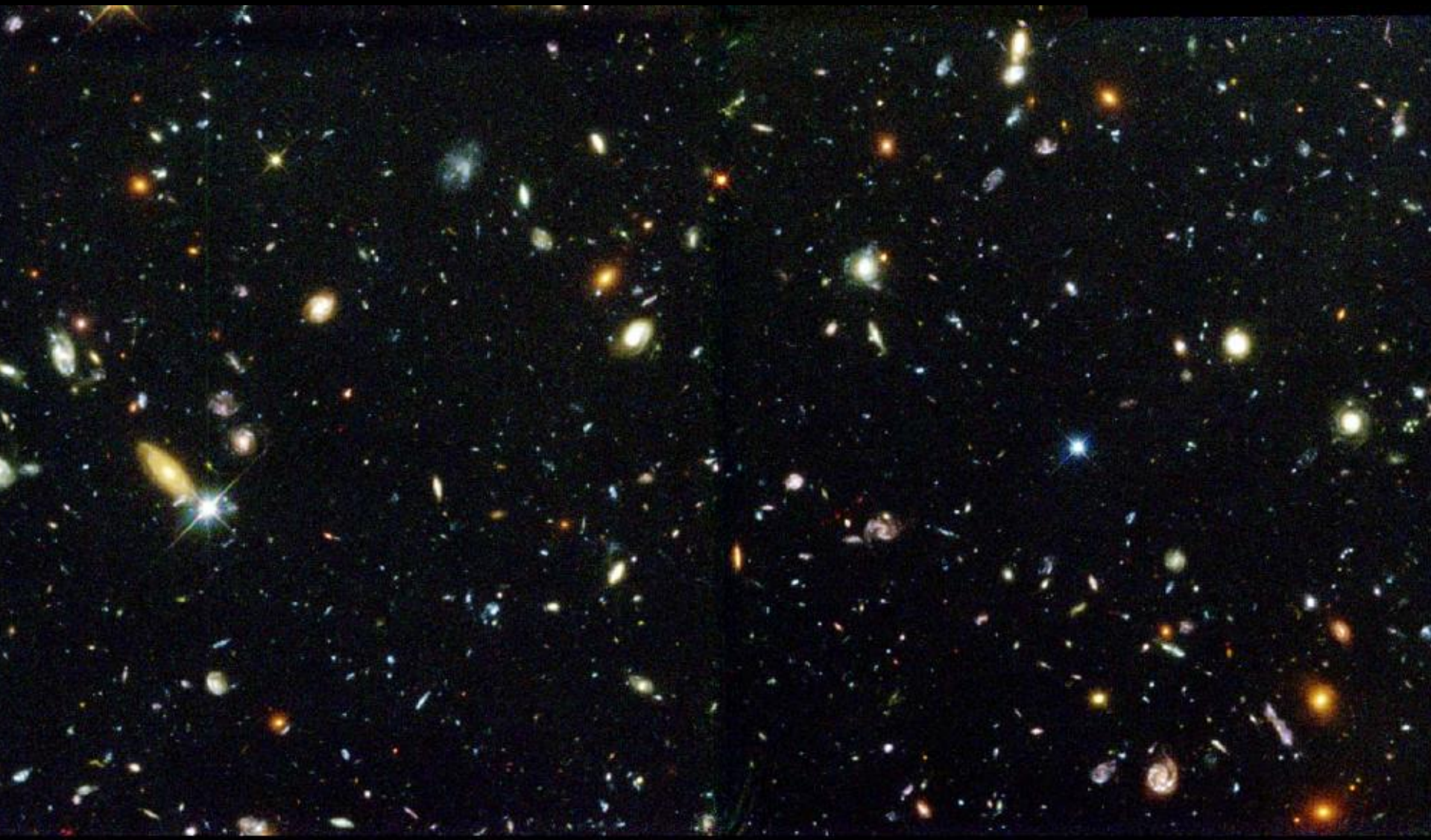


(Just an ordinary star)

…Many stars make a galaxy…

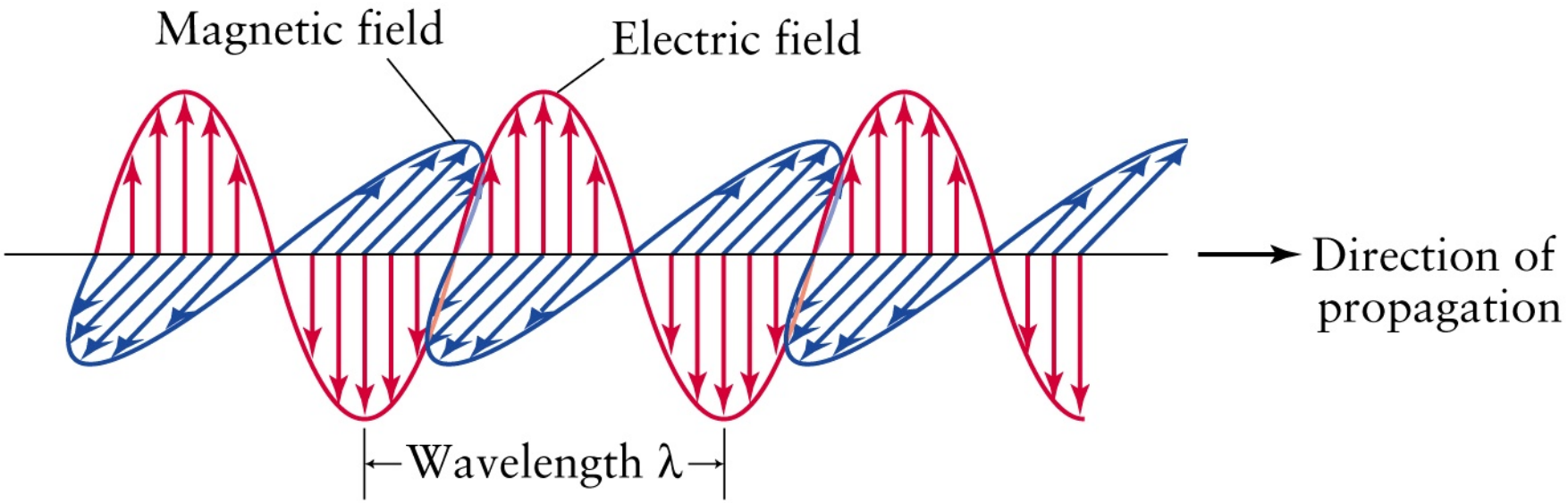
(A nearby galaxy similar to ours)

…There are many galaxies



The Universe is absolutely vast and we don’t appear to be in the least bit special

What is Light?



- Think of each ray of light as a microscopic "wavepacket"
- Moves forward fast – 186,000 miles per second – but not infinite speed (8 minutes from Sun to Earth)
- The peak-to-peak distance (wavelength) determines the color
- Radio waves are just long wavelength light

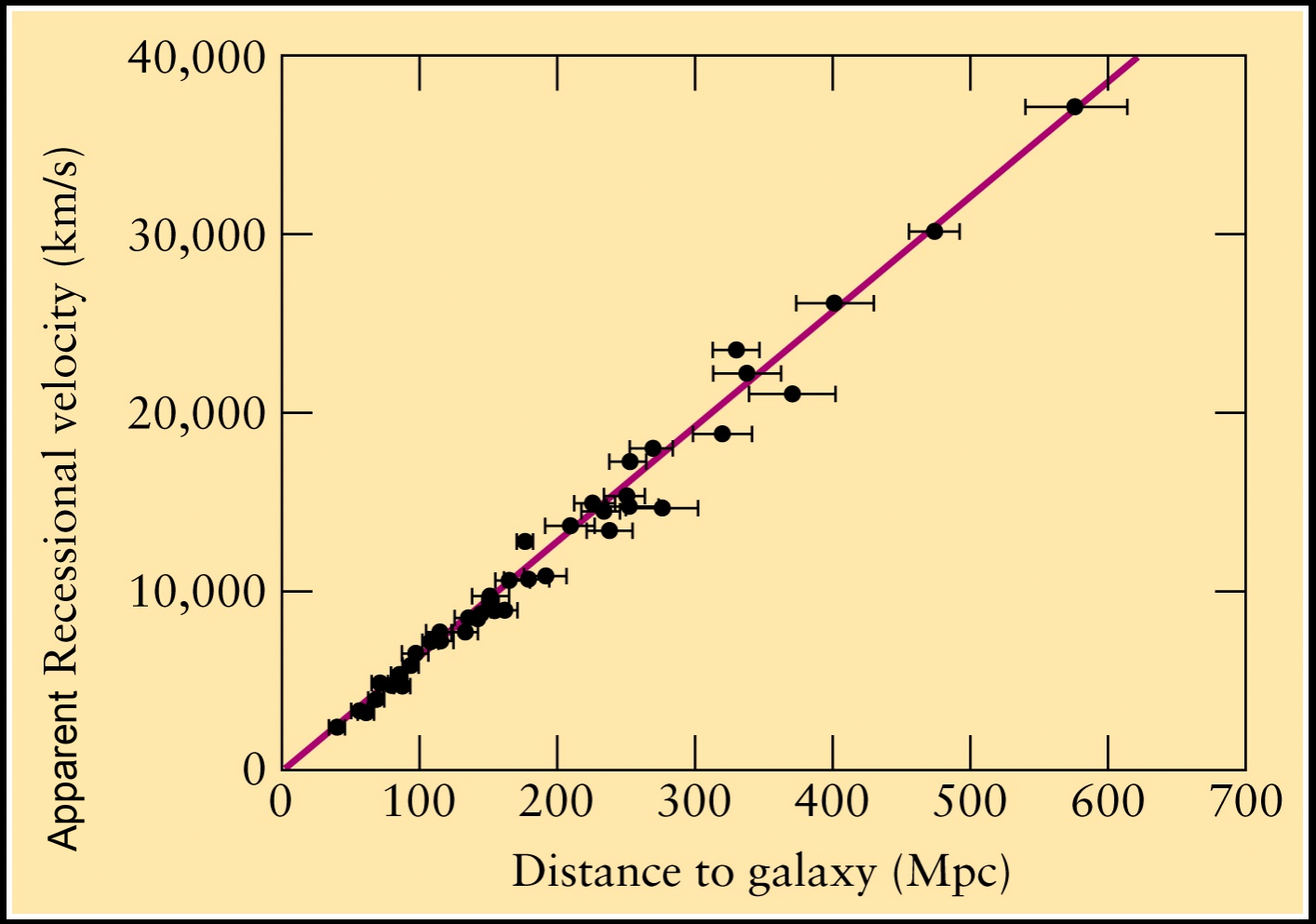
“Classic” Doppler Effect

- Imagine 3 stars emitting rays of light of the same “natural” wavelength (color)
- But light moves through space always at the same speed…
- Moving towards us = compressed = bluer
- Moving away from us = stretched = redder

Edwin Hubble “Observing” Distant Galaxies

Mount Wilson Observatory
(LA) 1920’s

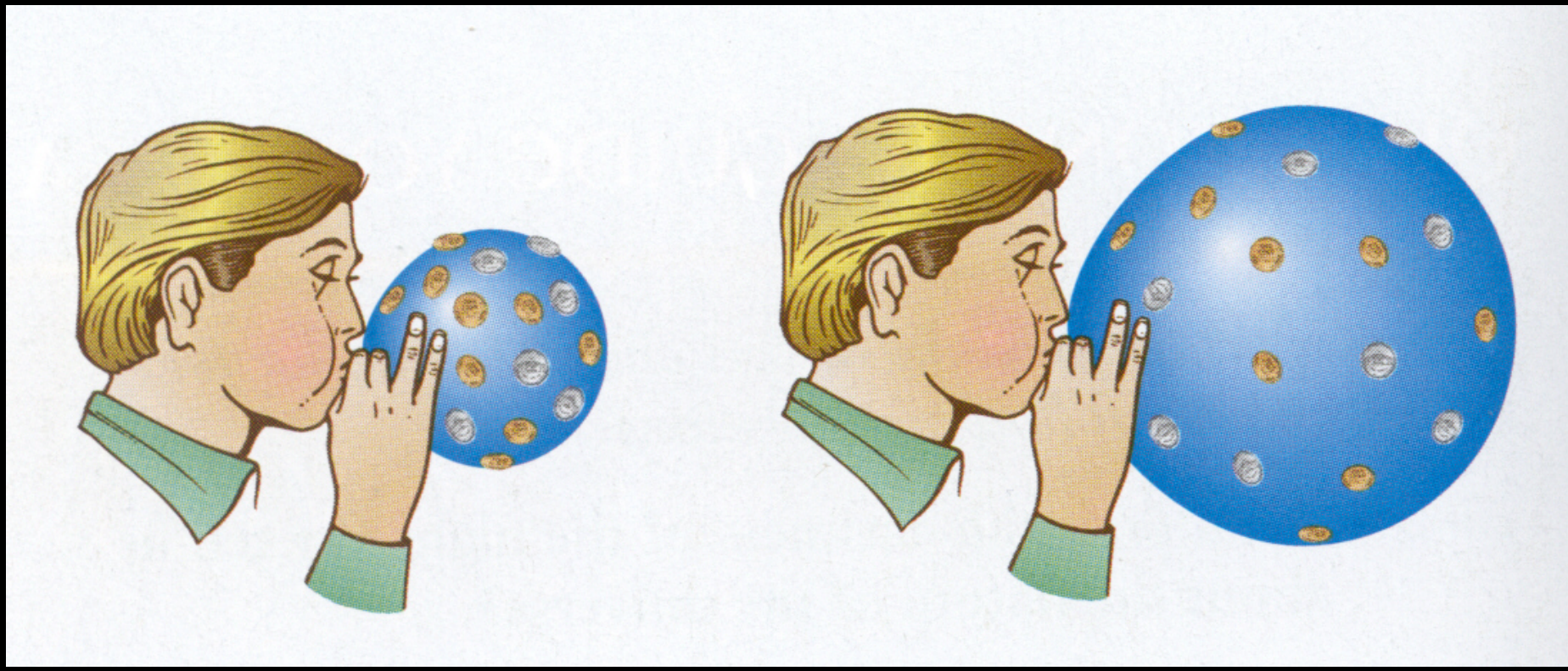
Hubble Diagram



The father away a galaxy is the faster it *appears* to be moving away from us…

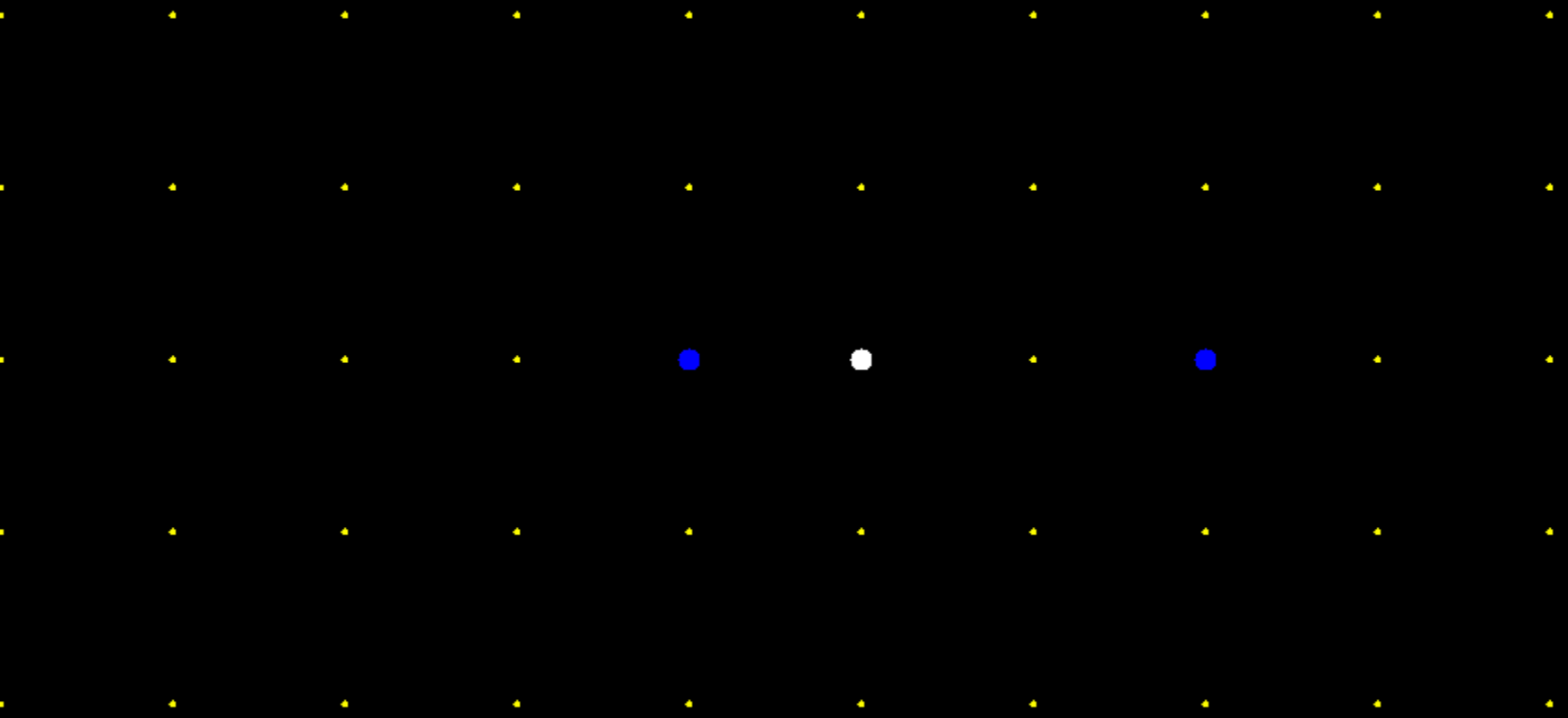
Are we the most unpopular place in the entire Universe?!

Expanding Universe?



- Simplest(!) explanation – the fabric of space itself is expanding
- From whereever you look more distant objects appear to be receding faster

Cosmological Doppler Effect

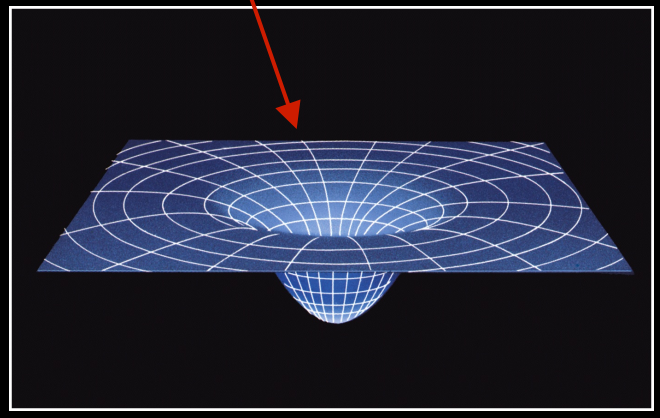


- Light rays stretch with the Universe – called “redshift”
- As we look *out* we look *back* in time

Einstein and General Relativity

In 1915 Albert Einstein devised the General Theory of Relativity

In GR space can be curved – and can expand/contract



$$R_{ij} - \frac{1}{2} g_{ij} R - \Lambda g_{ij} = 8\pi G T_{ij}$$

He fudged his equation to force a static Universe – later called this his “biggest blunder”

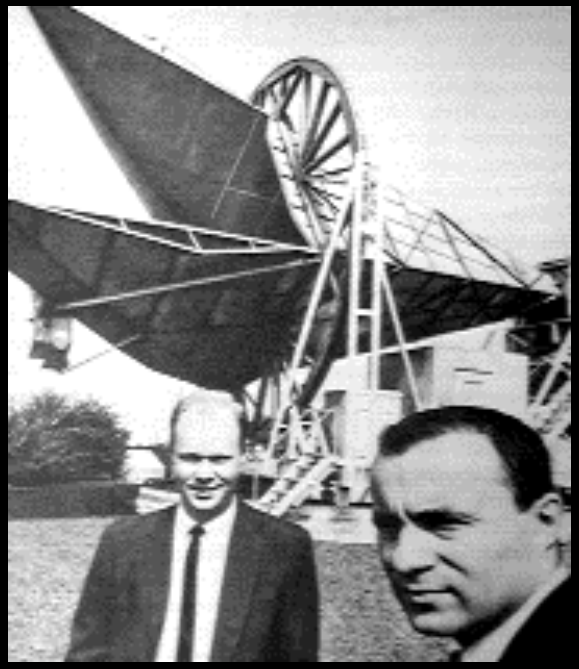
Modern cosmology in a nutshell:

Edwin Hubble

1) The universe is expanding.
(Hubble, 1920s)

2) It was once hot and dense, like the inside of the Sun.

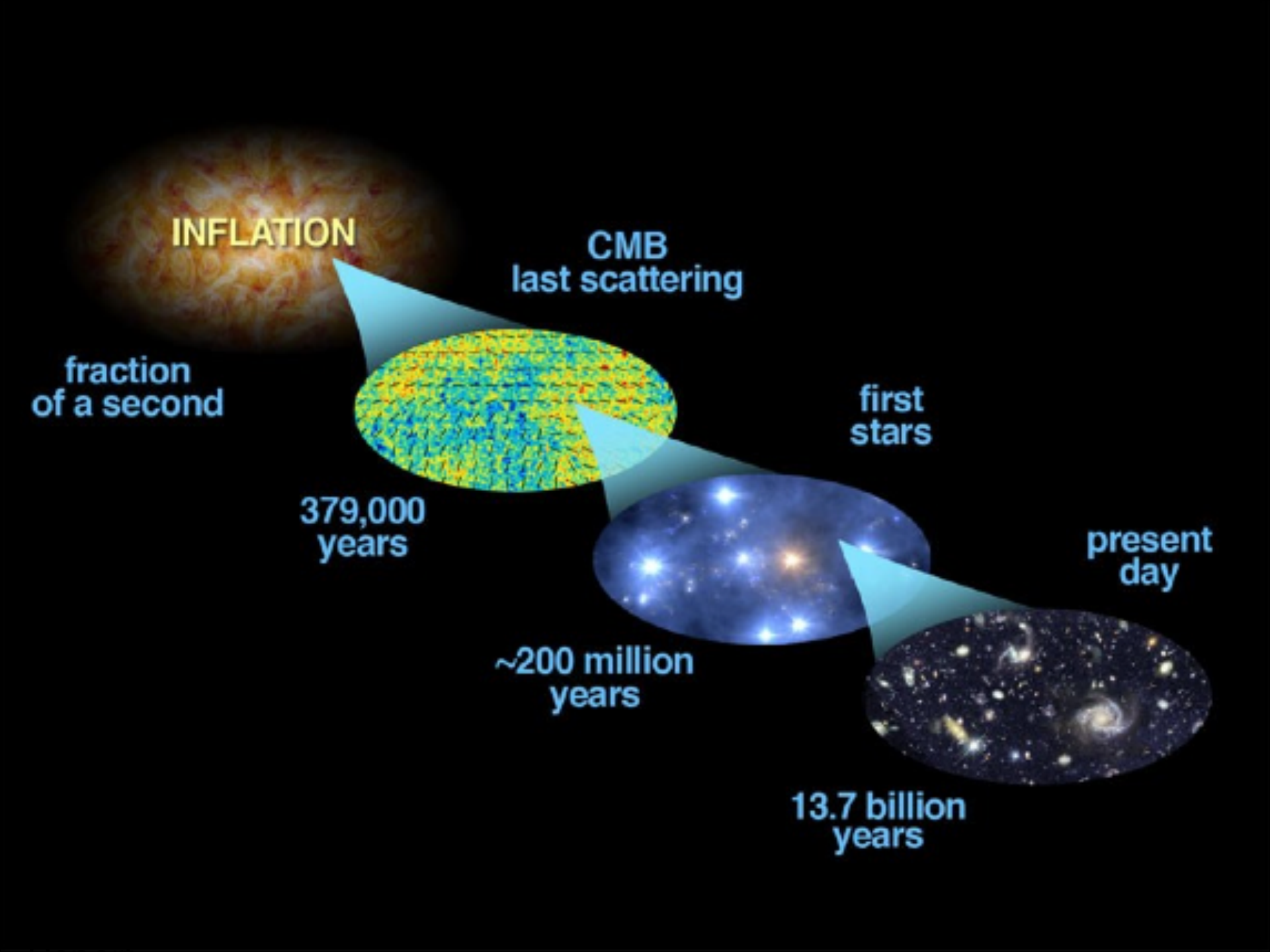
(Alpher, Gamow, Herman, 1940s)



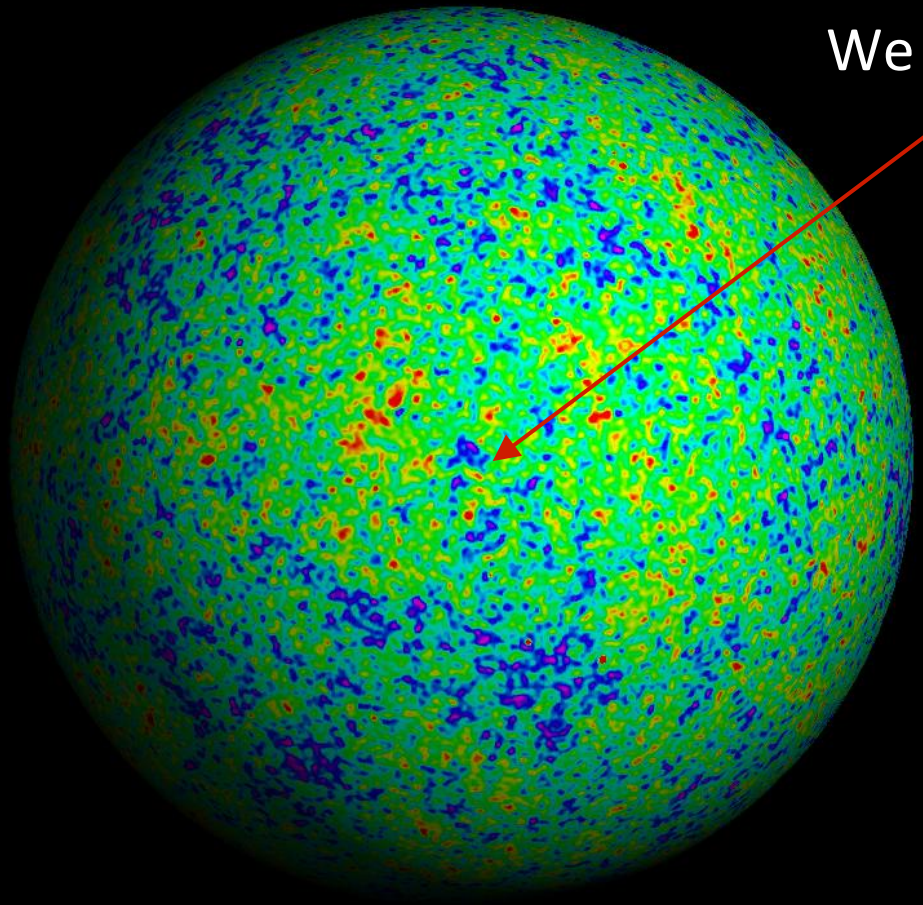
Bob Wilson & Arno Penzias
1978 Nobel Prize

3) You can still see the glow!
The *Cosmic Microwave Background*
(Penzias & Wilson, 1964)

⇒ acceptance of the "HOT BIG BANG"

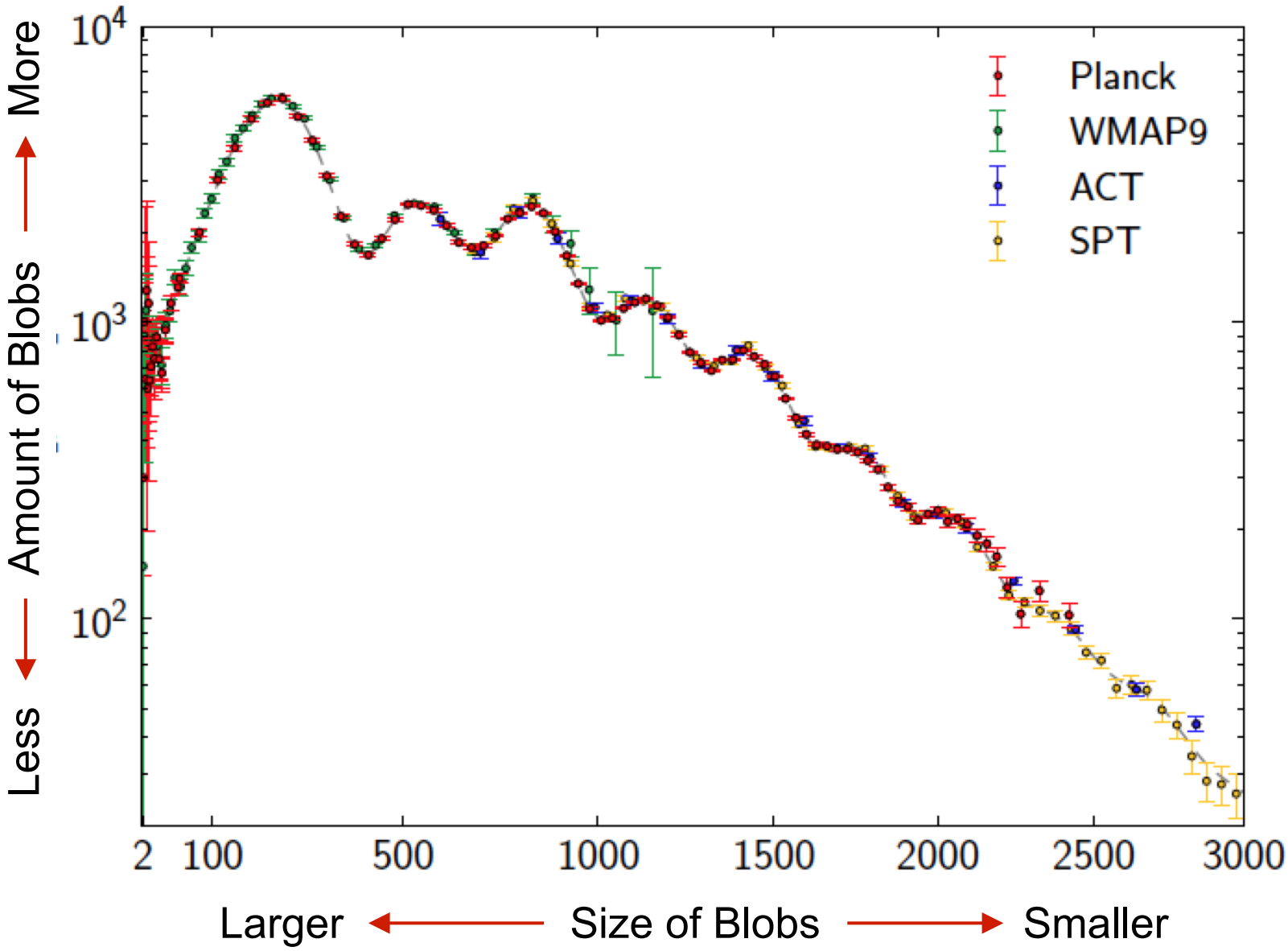

INFLATION
CMB
last scattering
fraction
of a second
379,000
years
first
stars
present
day
~200 million
years
13.7 billion
years

The Cosmic Microwave Background



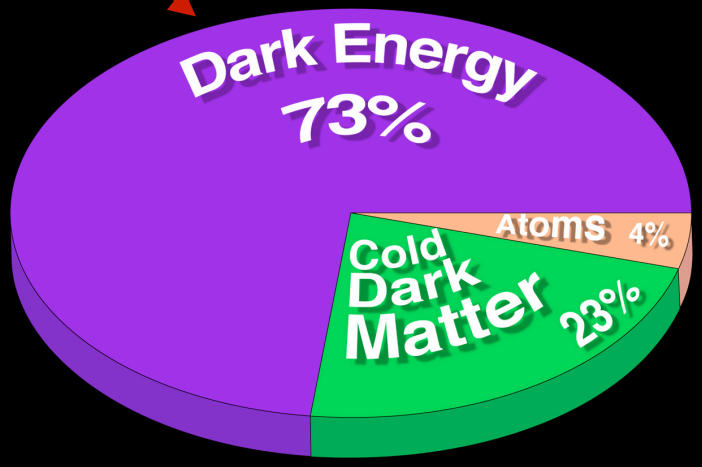
CMB is sample of the density structure on a shell cut through the 380,000 year old Universe

“Lump Sorter” Plot

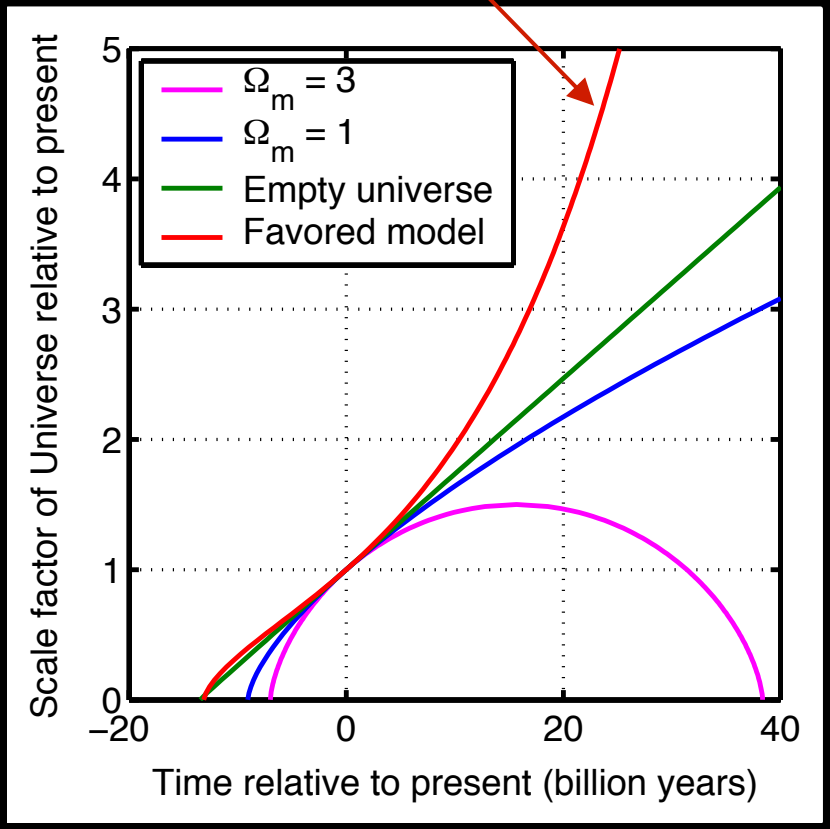


Triumphant/Embarrassing Cosmology

CMB and other data fits GR based model *beautifully* – but it demands that 96% of the Universe is invisible to us



And it implies that the future is runaway expansion…



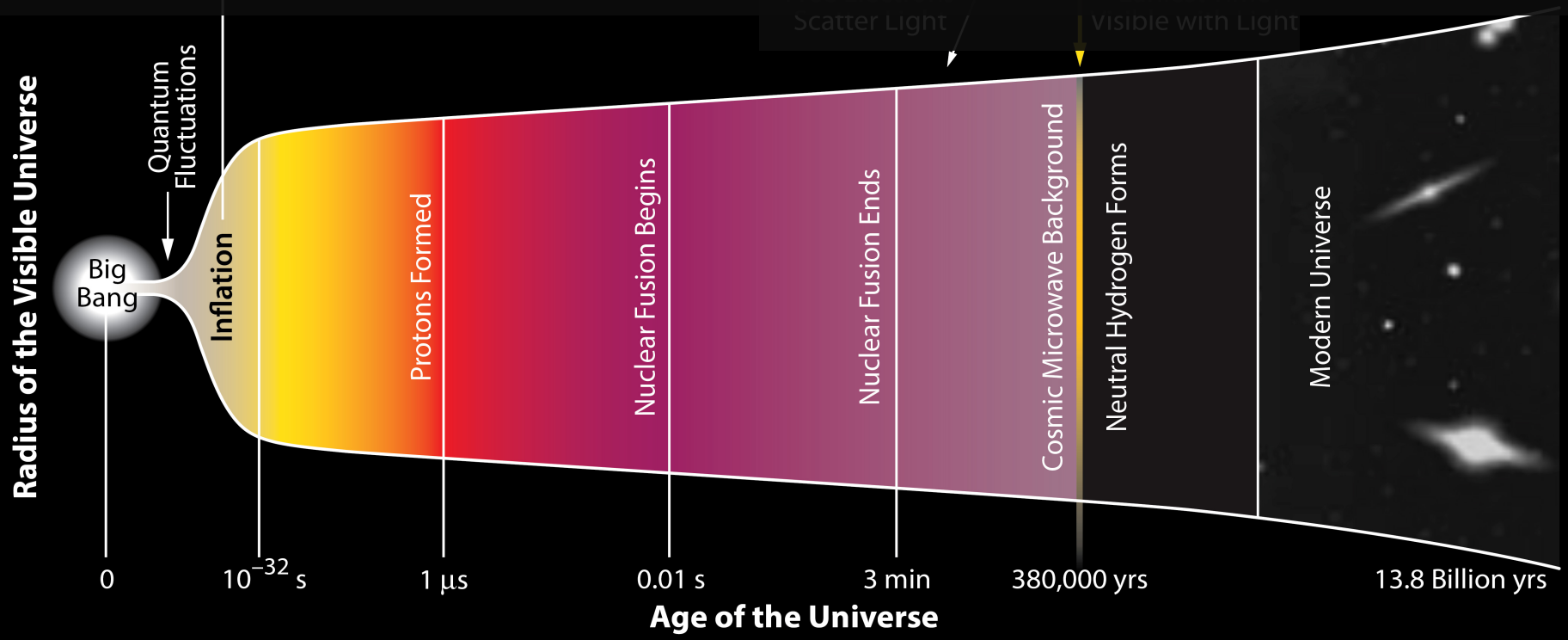
Also it doesn't explain the initial conditions…

History of the Universe

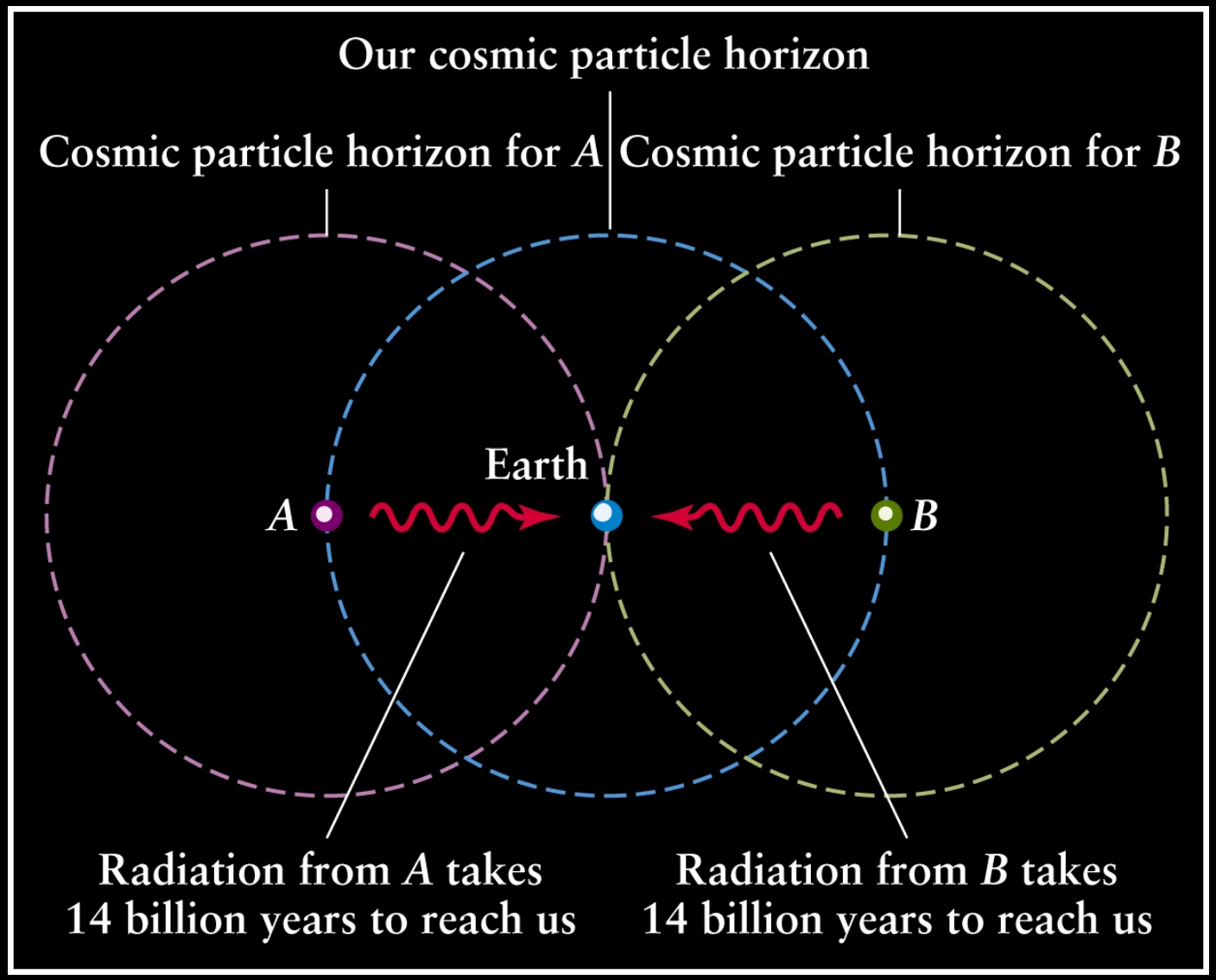
Inflation proposed to explain
Horizon and Flatness problems

Alan Guth

Andrei Linde

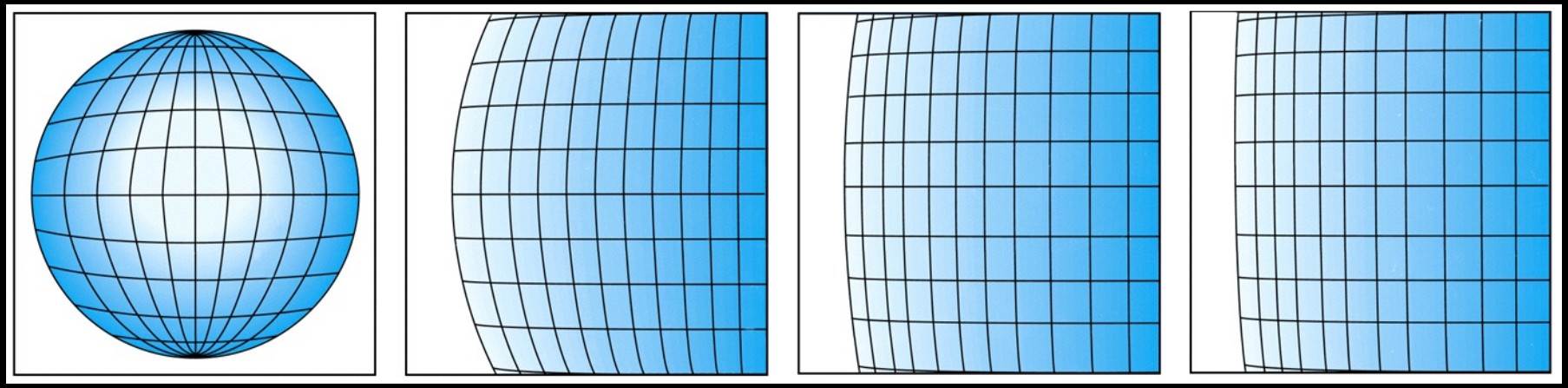


The Horizon Problem



How did points A and B "know" to be at the same temperature at 380,000 years?

Solving the Flatness Problem

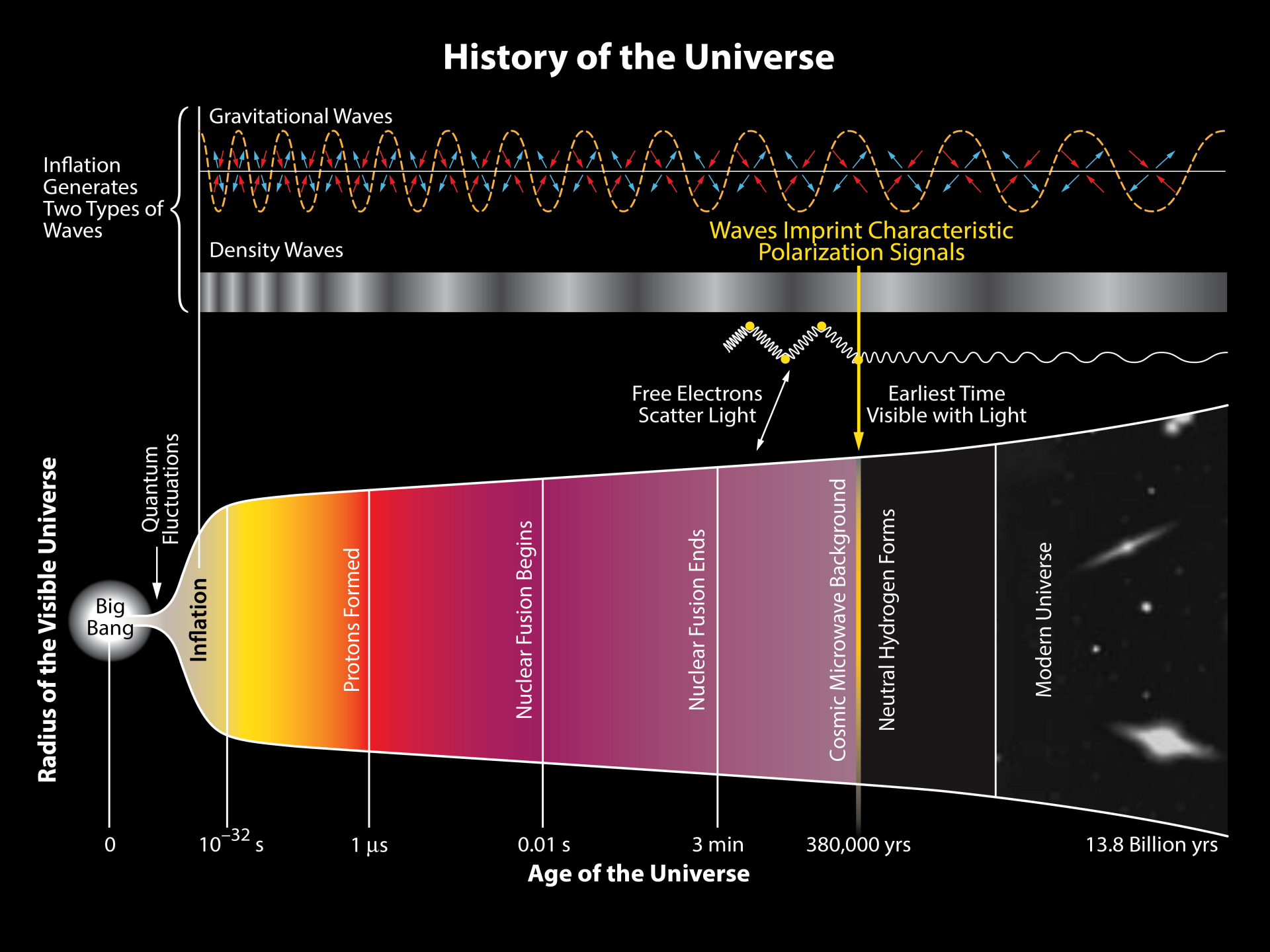


Inflation…

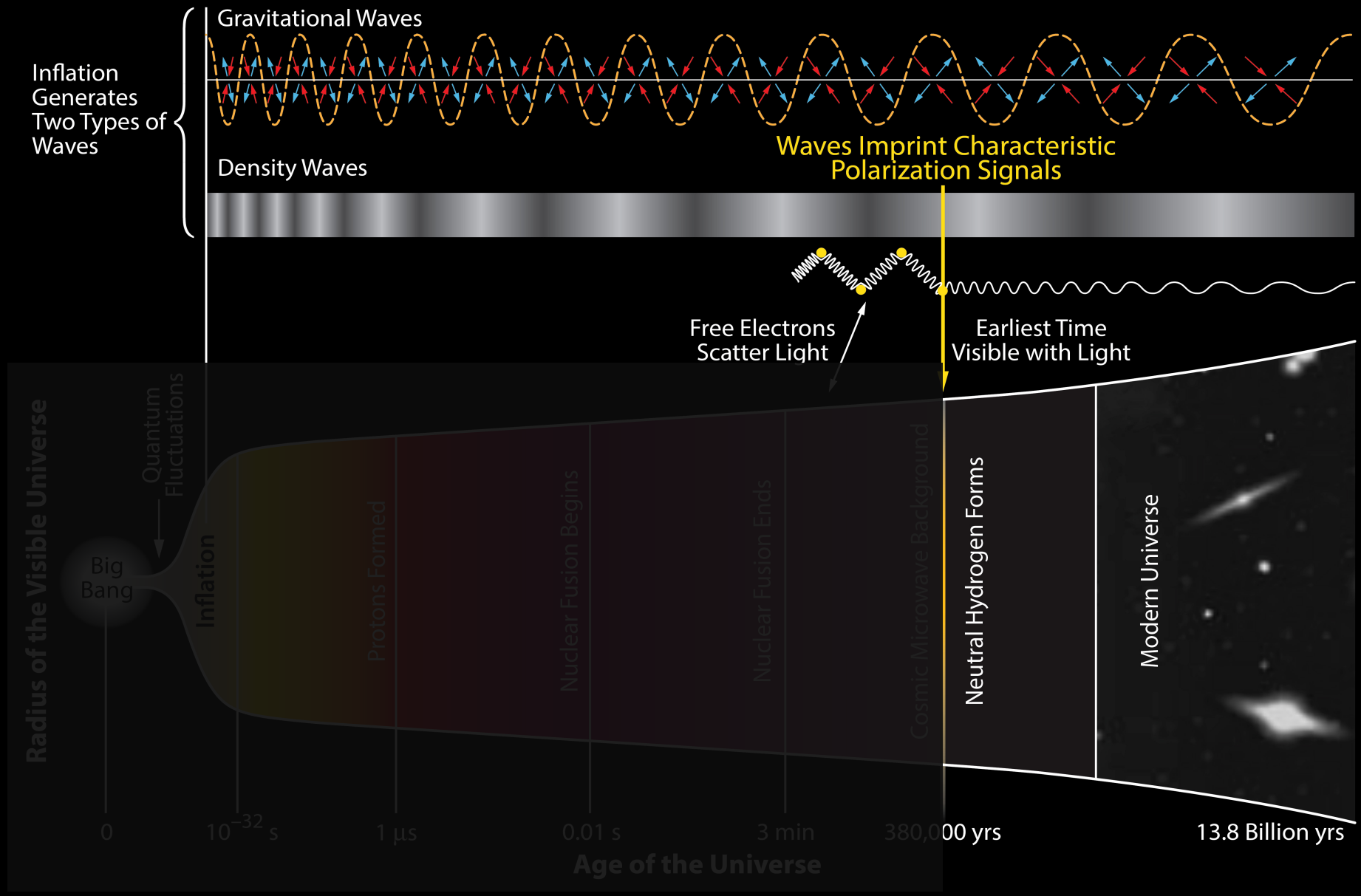
If you take some curved space and blow it up enough pretty soon it is no longer curved on a local scale – like our entire observable Universe!

So nice idea – but how can we get direct evidence if it happened?

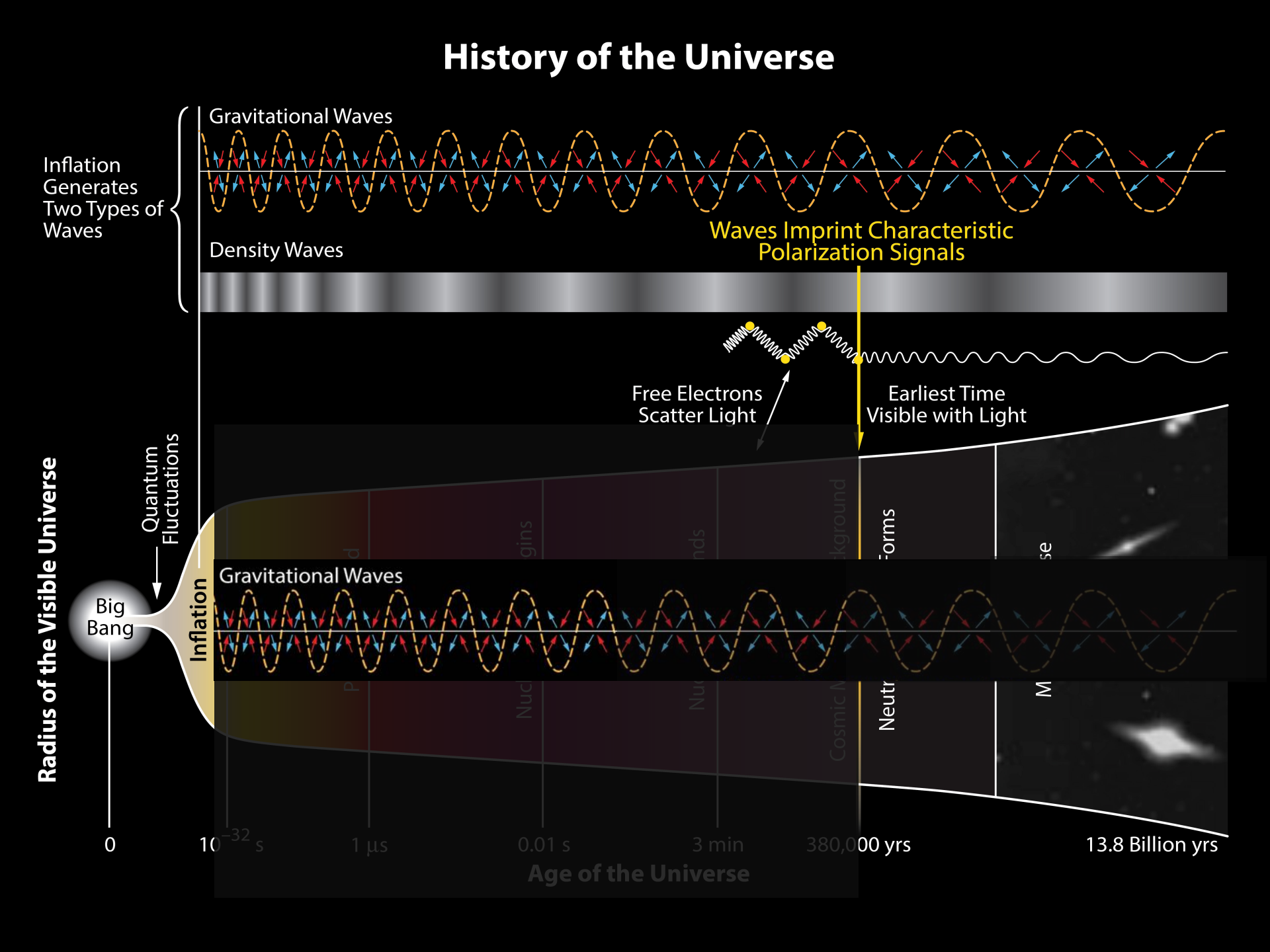
Makes another prediction…


History of the Universe
Inflation Generates Two Types of Waves
Gravitational Waves
Density Waves
Waves Imprint Characteristic Polarization Signals
Free Electrons Scatter Light
Earliest Time Visible with Light
Radius of the Visible Universe
Quantum Fluctuations
Big Bang
Inflation
Protons Formed
Nuclear Fusion Begins
Nuclear Fusion Ends
Cosmic Microwave Background
Neutral Hydrogen Forms
Modern Universe
0
10−32 s
1 μs
0.01 s
3 min
380,000 yrs
13.8 Billion yrs
Age of the Universe

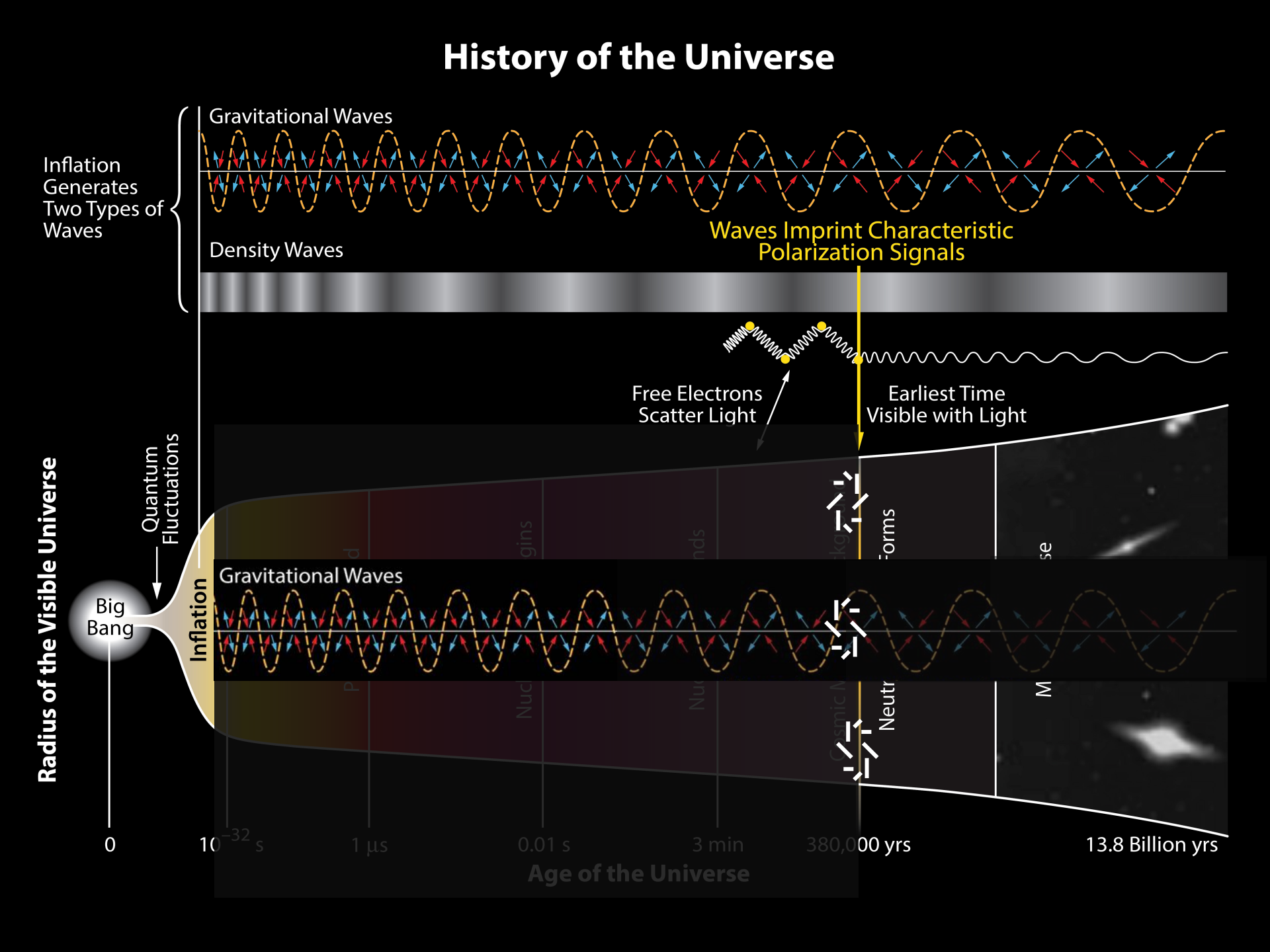
History of the Universe



History of the Universe

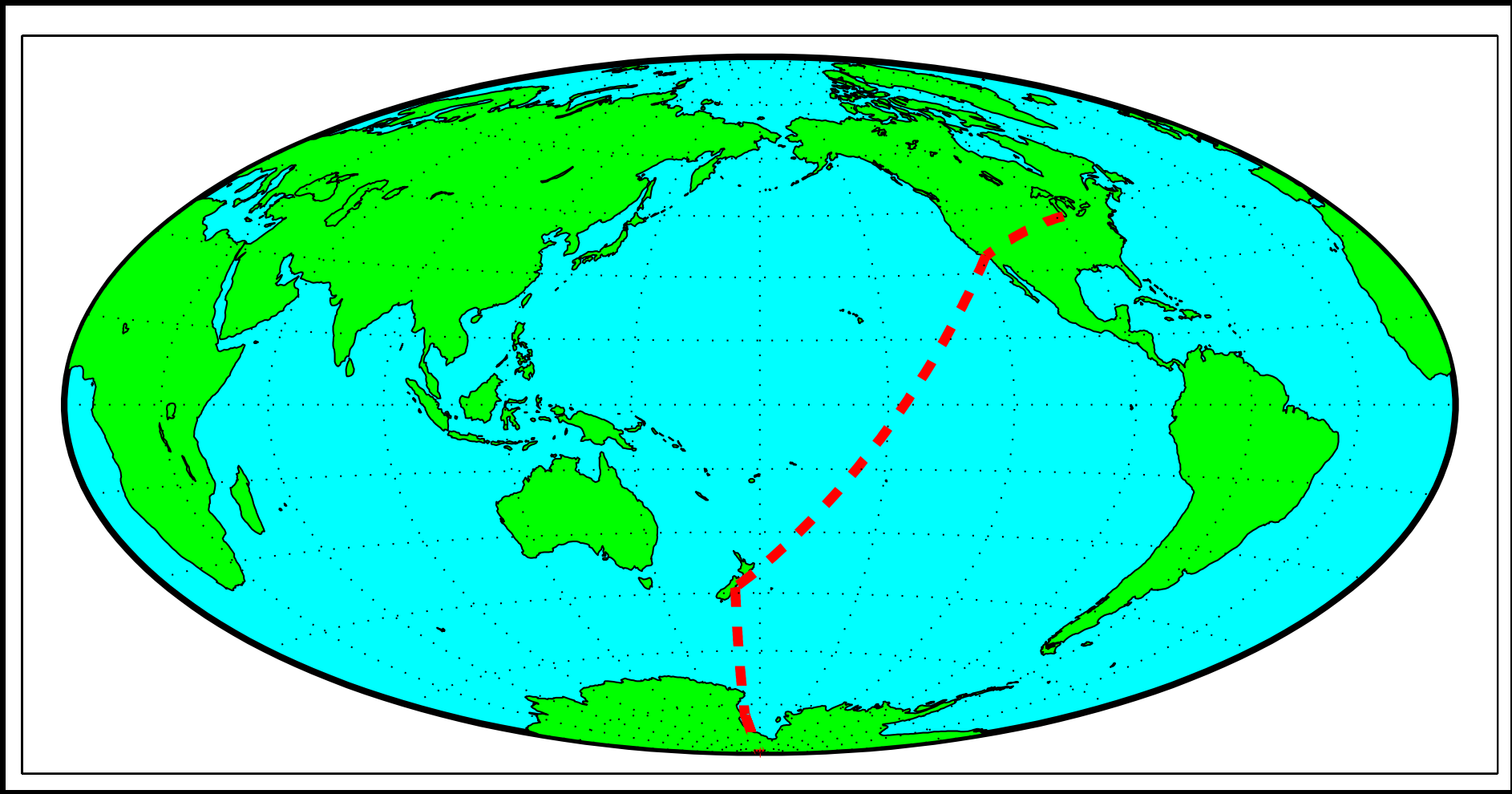


History of the Universe




VE RI TAS
HARVARD
CALIFORNIA INSTITUTE OF TECHNOLOGY
1891
UCSD
JPL
NIST
CARDIFF UNIVERSITY
cea
DE LA RECHERCHE À L'INDUSTRIE
UNIVERSITY OF TORONTO
UBC

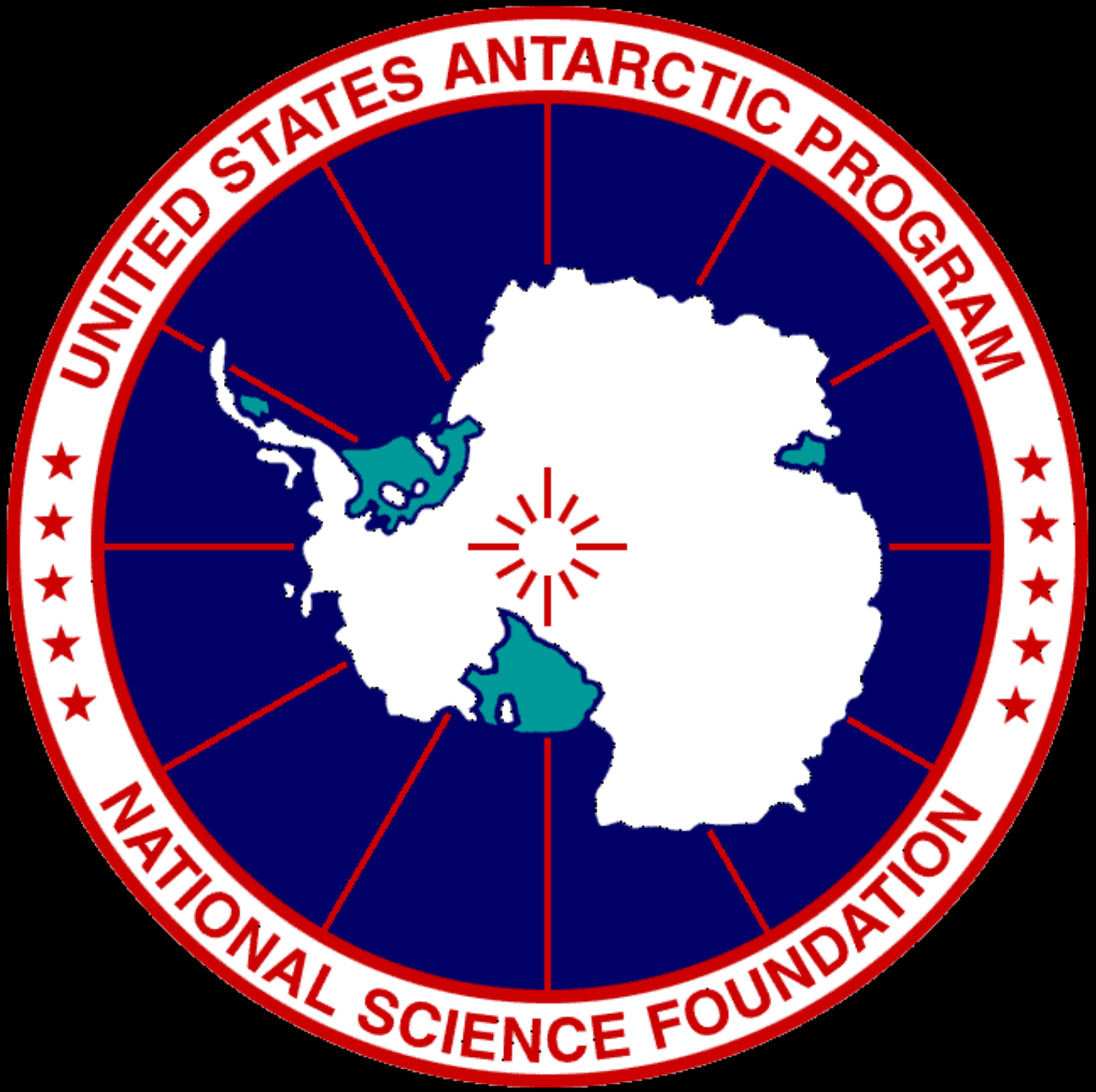
Journey to the South Pole



Minneapolis ->California -> New Zealand -> McMurdo -> South Pole

Antarctic Continent

Larger then the US – Ice sheet two miles thick!


UNITED STATES ANTARCTIC PROGRAM
NATIONAL SCIENCE FOUNDATION

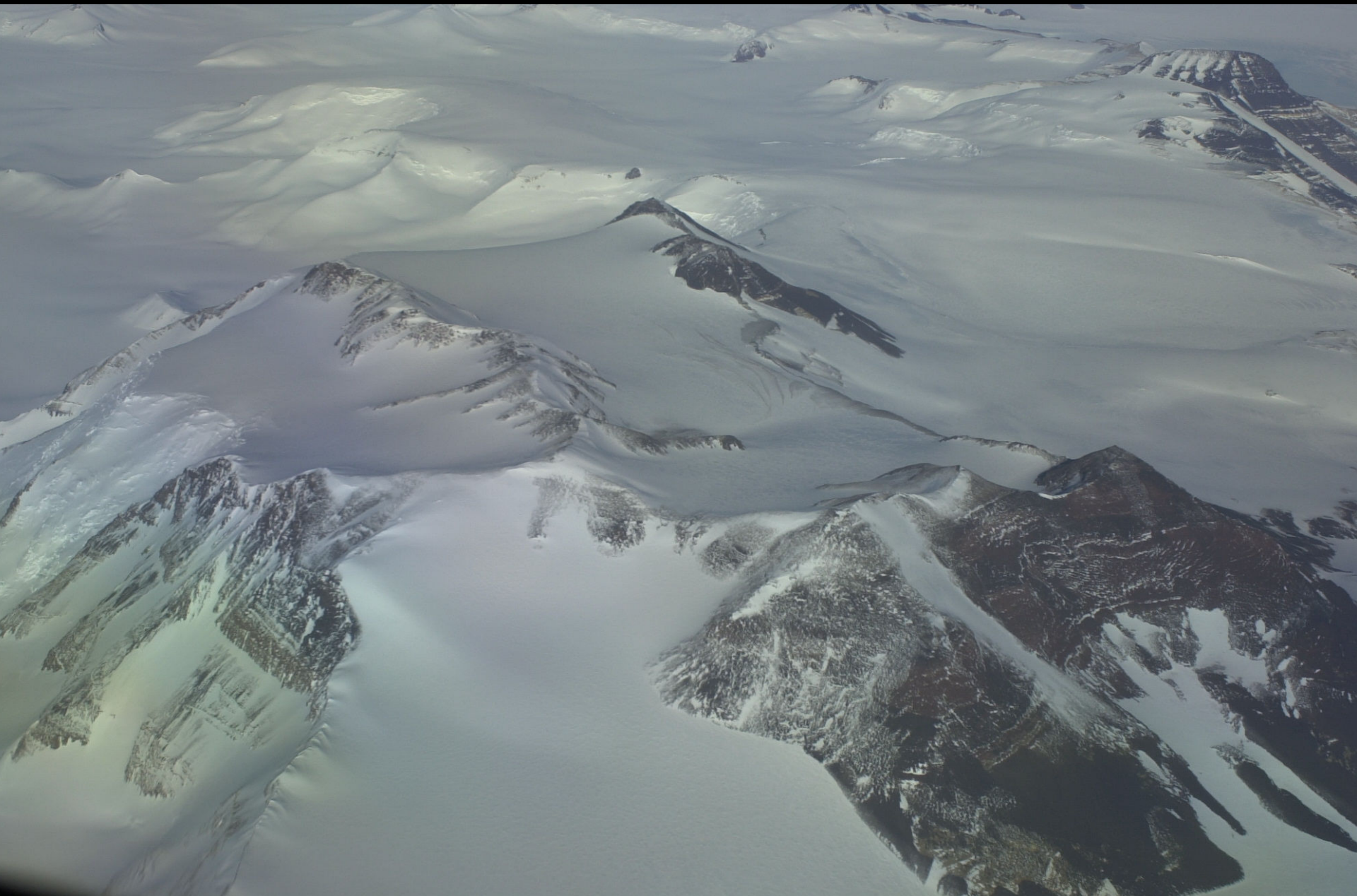
Christchurch New Zealand – Clothing Warehouse

Big Program!

Arrival in Antarctica

McMurdo – base on the coast

On to the Pole – over the Transantarctic Mountains

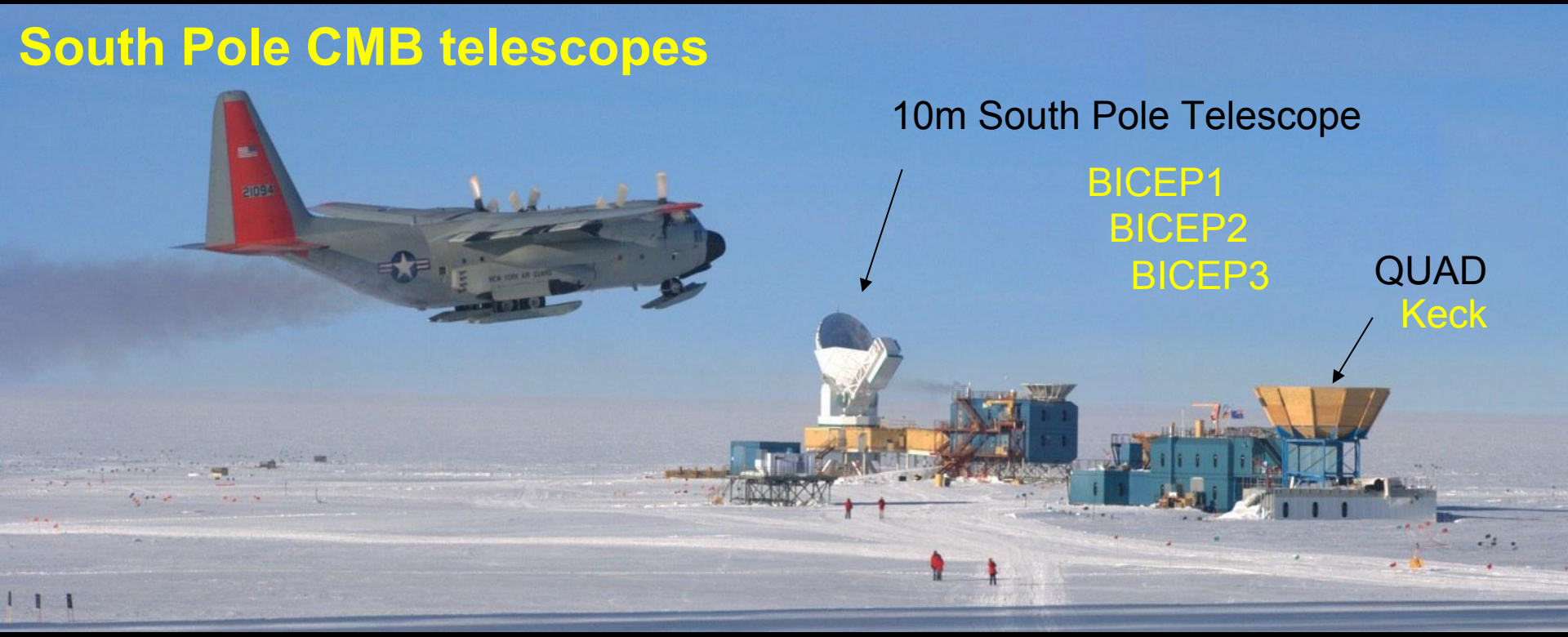


Unloading at Pole

The Actual South Pole

Nothing Out There!

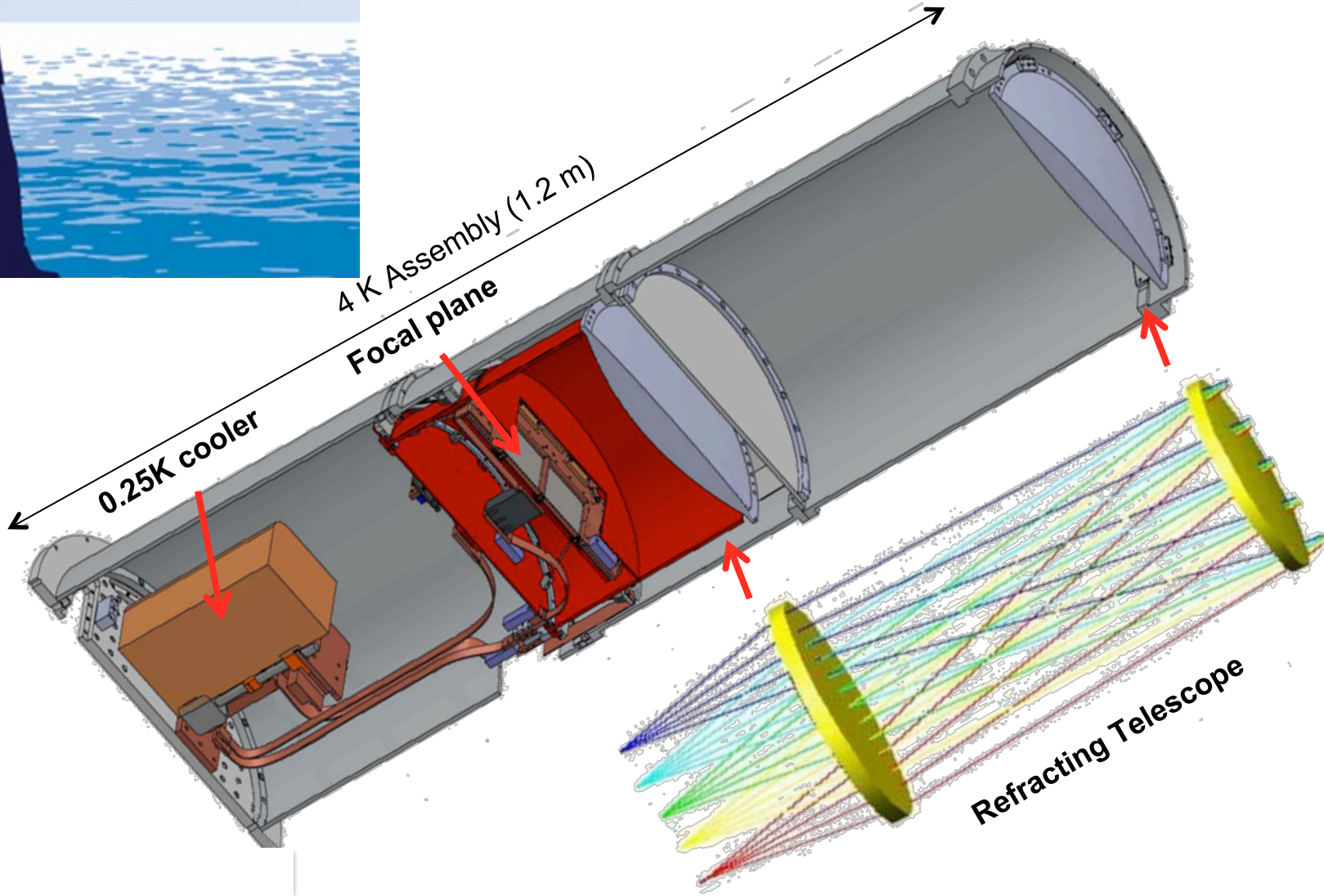
Why do this at the Pole?



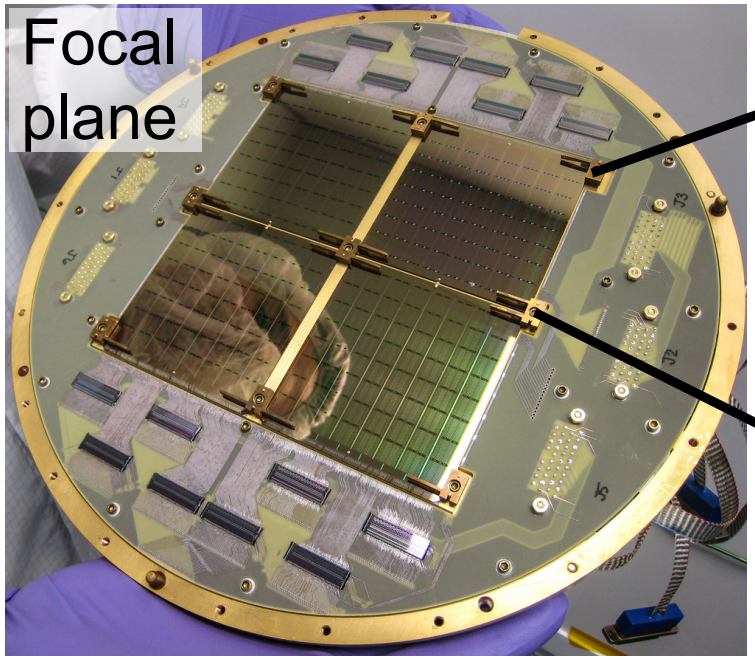
- High and *dry* – see out into space
- On Earth's rotational axis - One day/night cycle per year
  - Long night makes for great quality data
- Good support infrastructure – power, cargo, data comm
- Food and accommodation provided
- Even Tuesday night bingo…

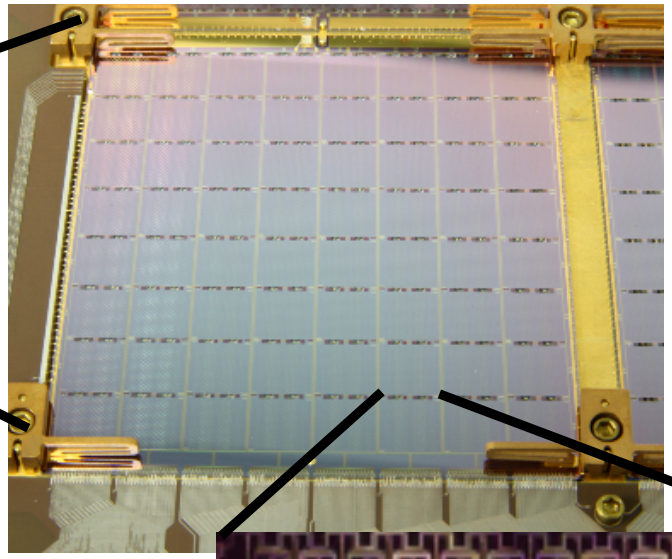
Basic Experiment Design

- Small aperture
- Wide field of view
- Cold refractor



Mass-produced superconducting detectors



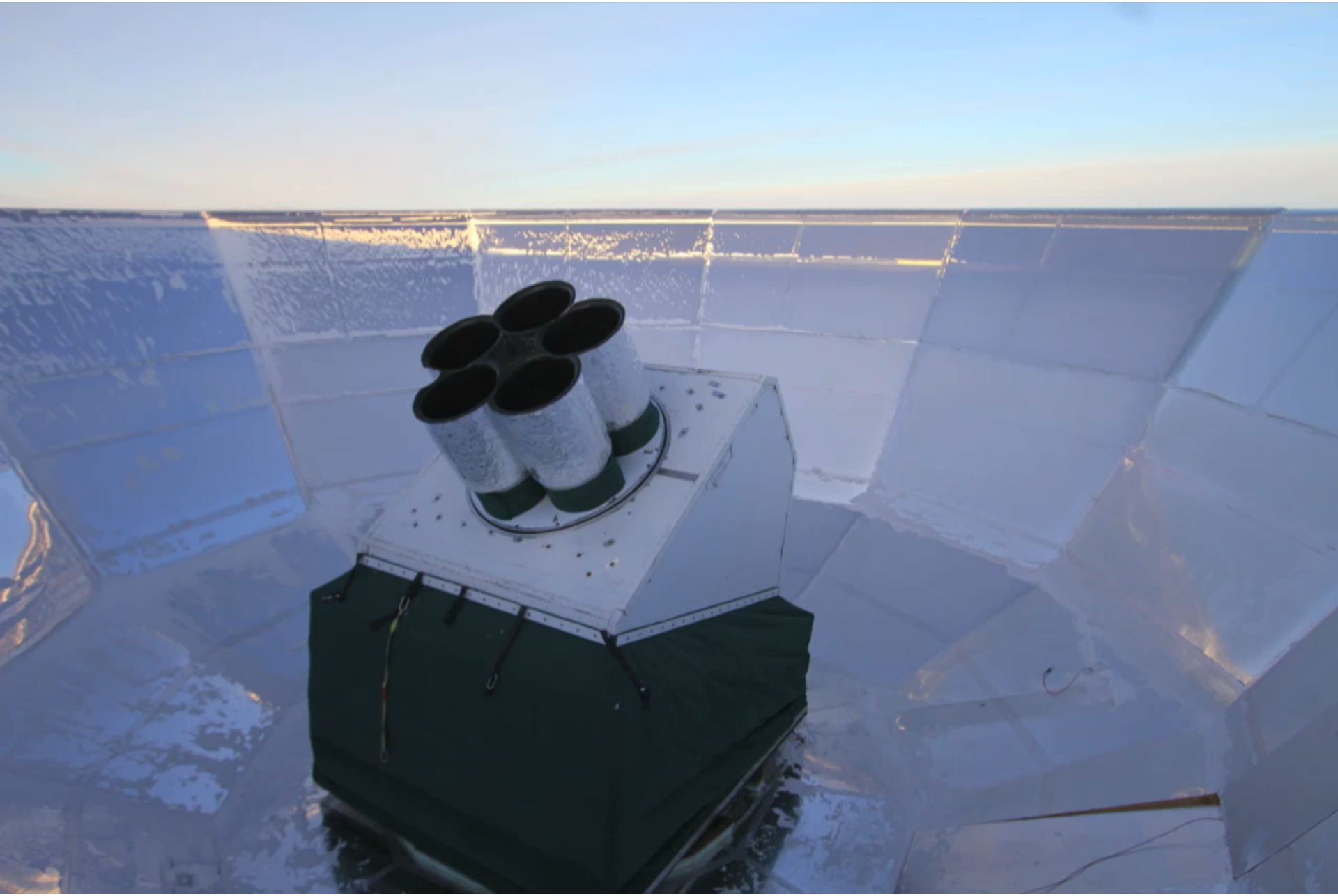


Planar
antenna
array

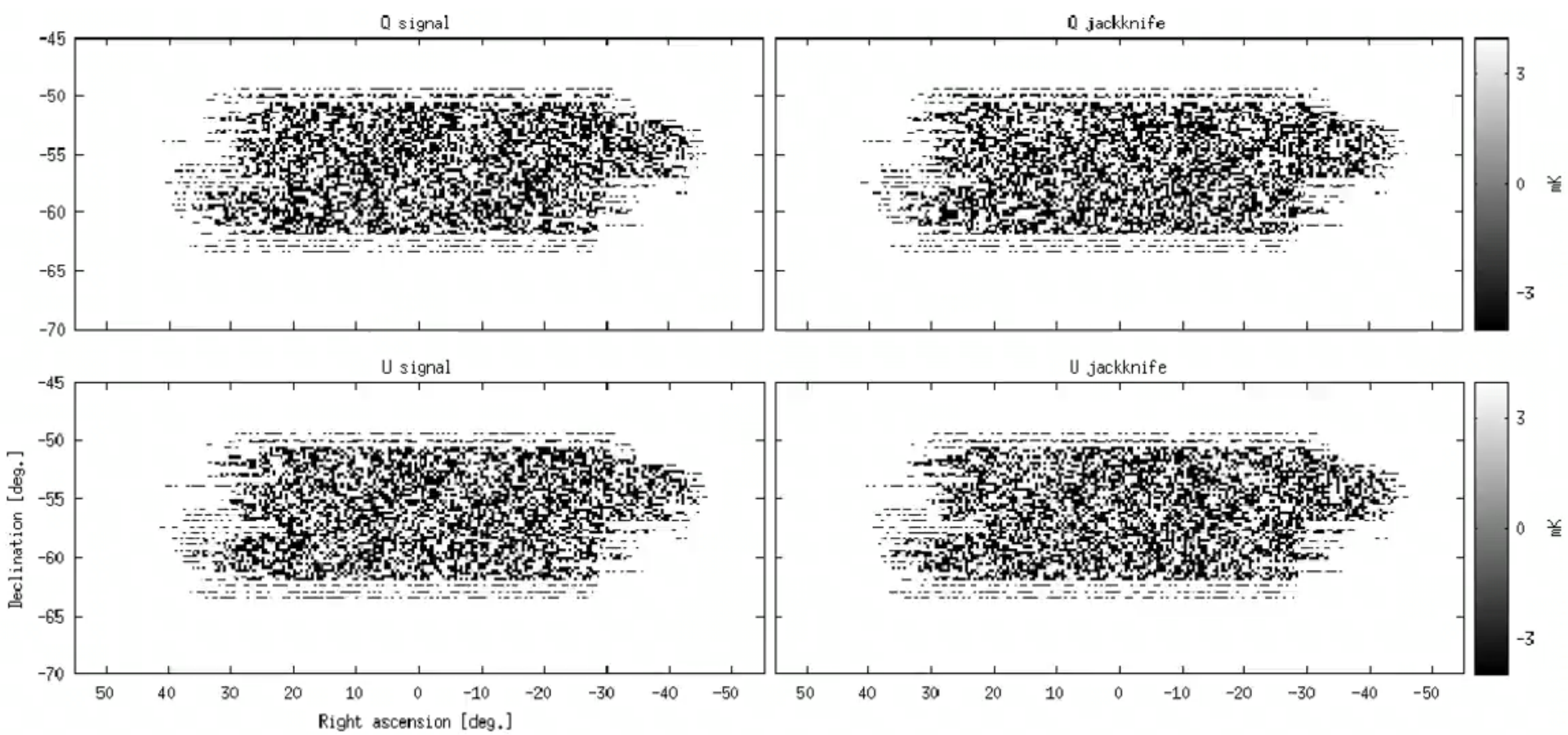
Slot
antennas

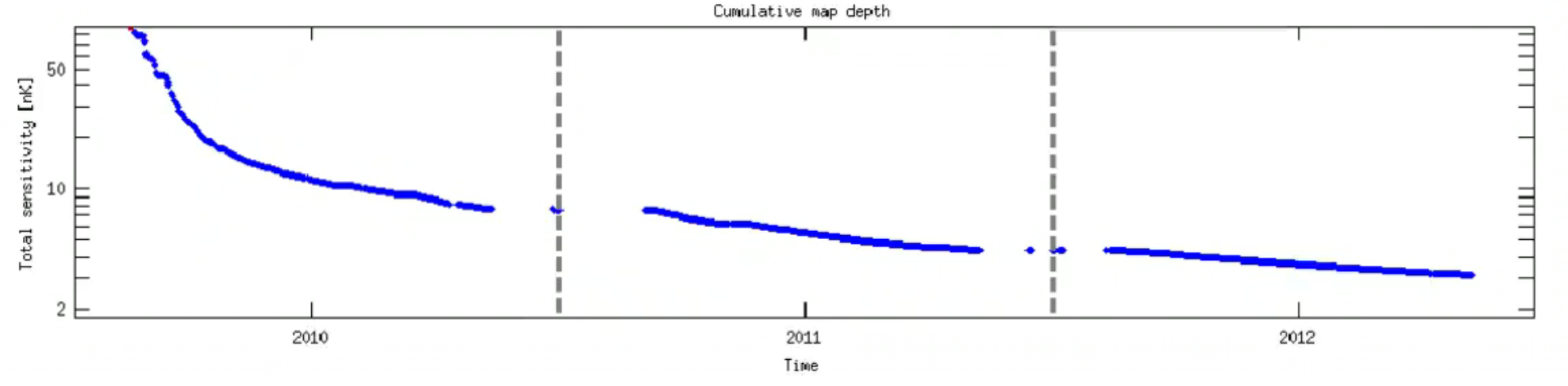
Transition edge sensor

Microstrip filters



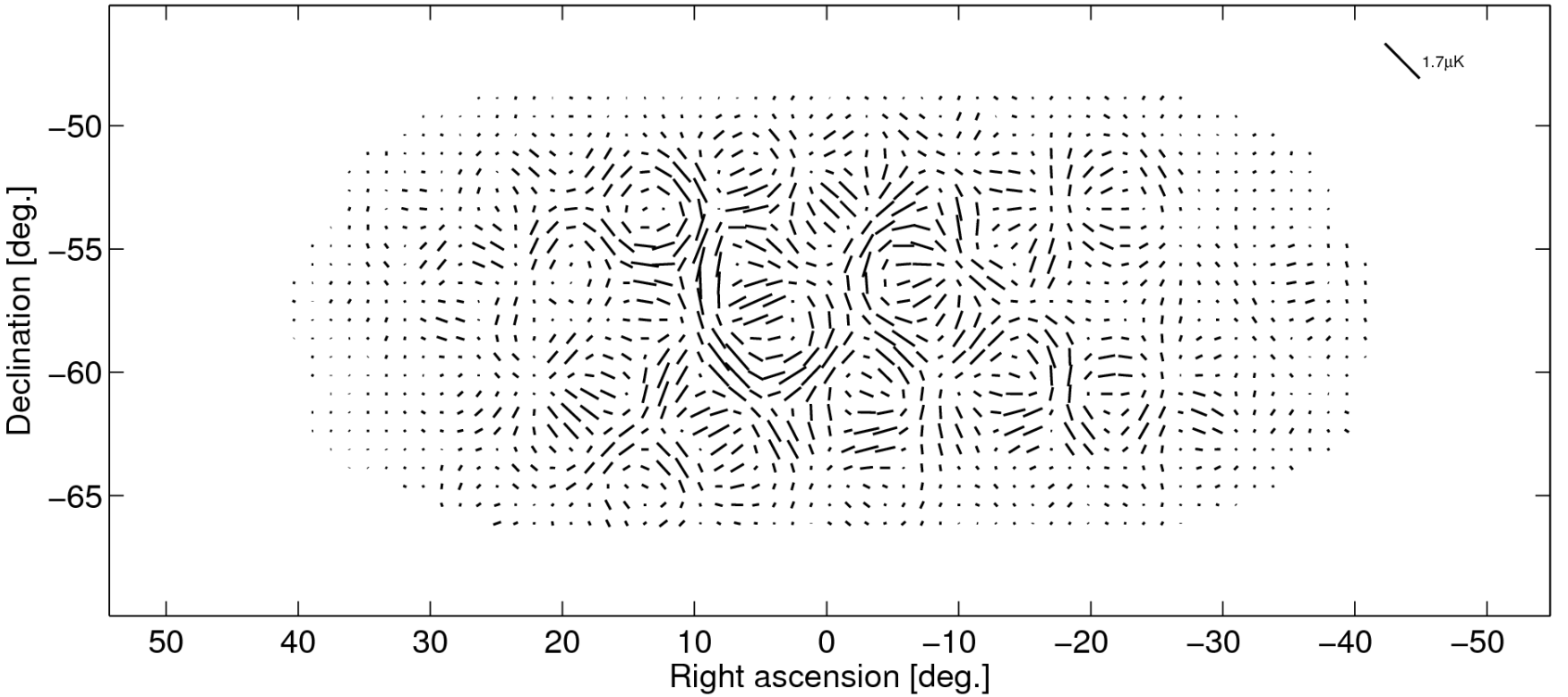
Clem Pryke for The Bicep2 Collaboration


Q signal
Q jackknife
U signal
U jackknife
-45
-50
-55
-60
-65
-70
Declination [deg.]
50
40
30
20
10
0
-10
-20
-30
-40
-50
Right ascension [deg.]
3
0
-3
mK


Cumulative map depth
Total sensitivity [mK]
50
10
2
2010
2011
2012
Time

Total Polarization

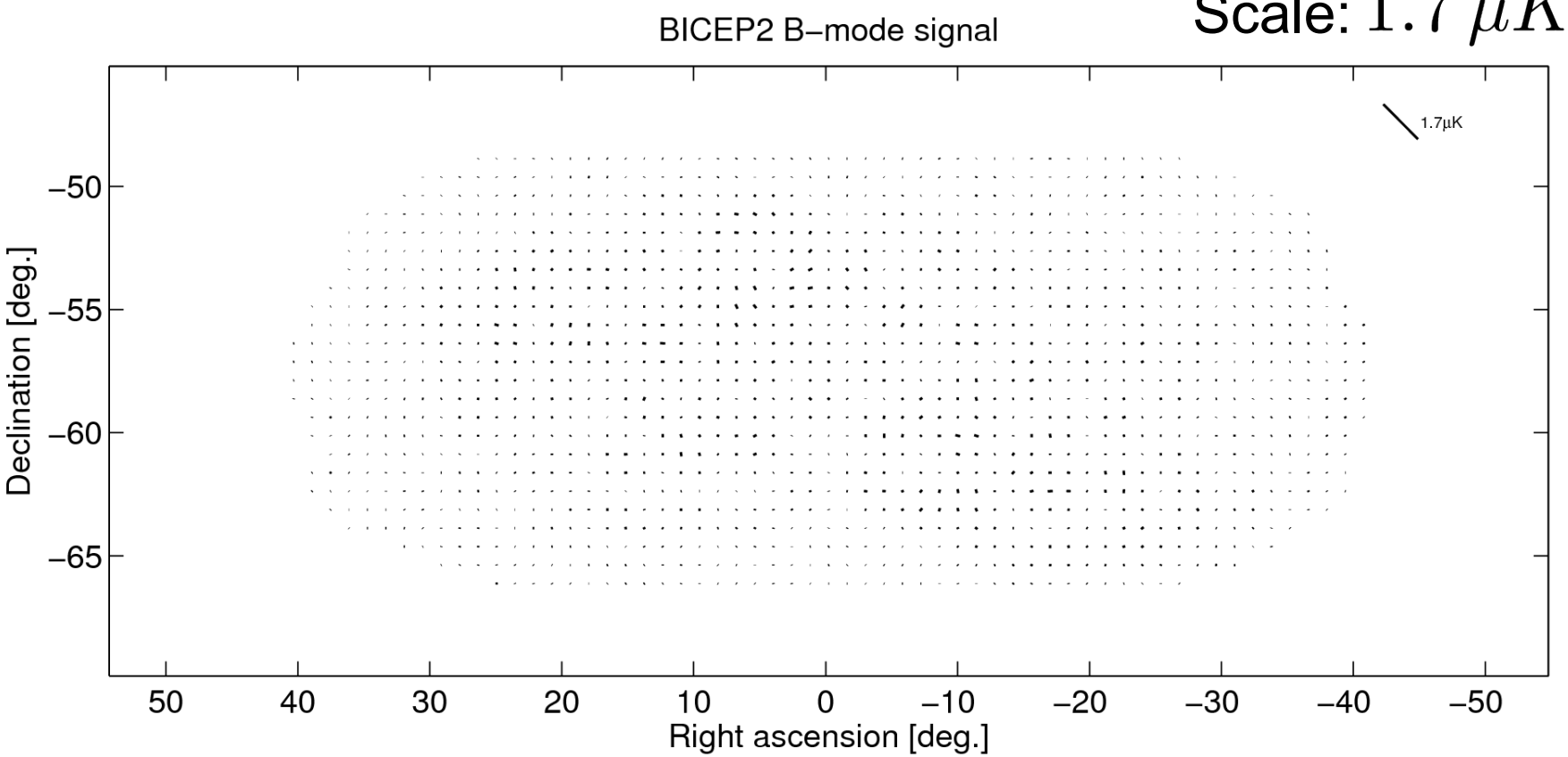
Scale: $1.7\ \mu K$



E-mode dominated pattern – no obvious curl component

B-mode Contribution

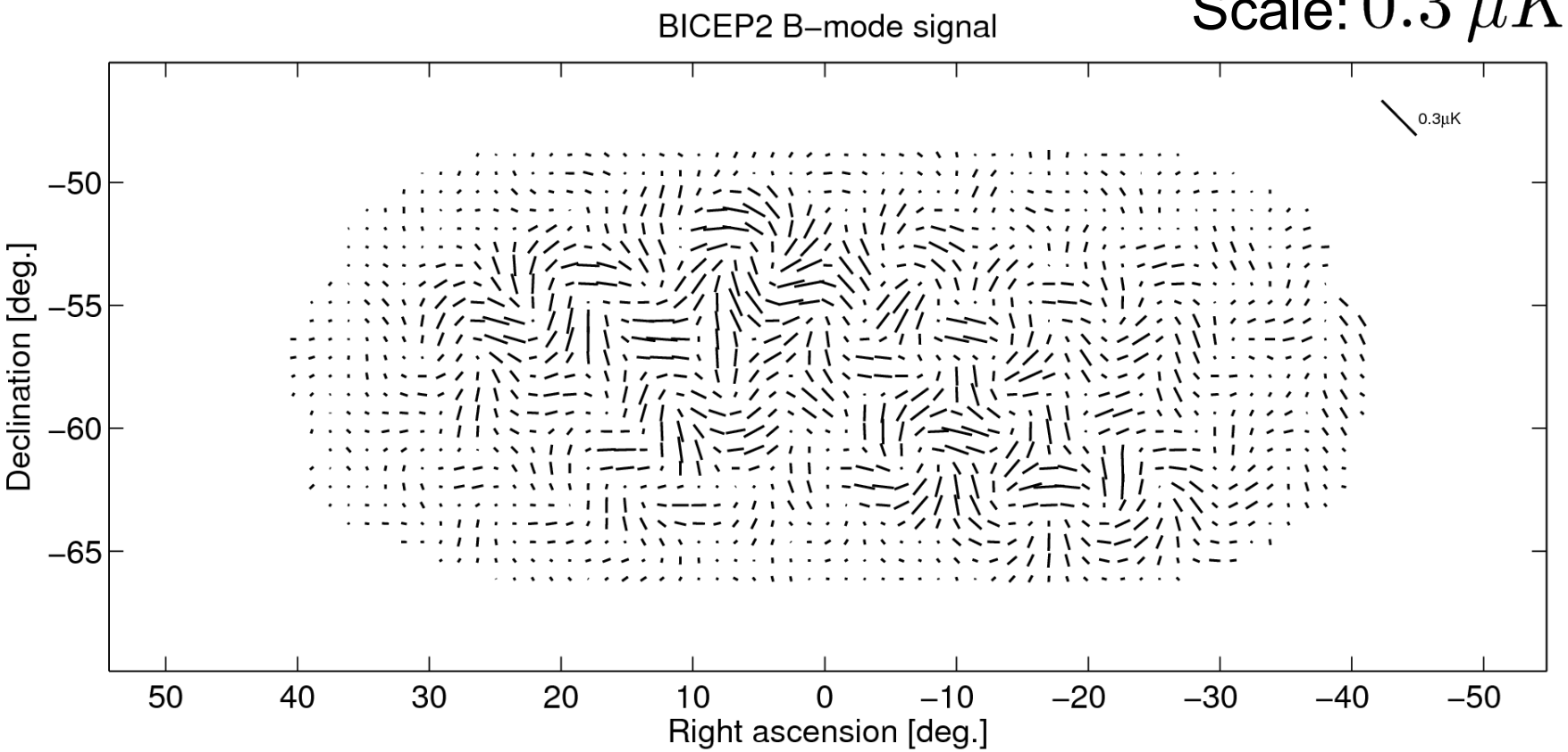
Scale: $1.7\ \mu K$



Apply purification operation which leaves only pure B-modes

B-mode Contribution

Scale: $0.3\,\mu K$



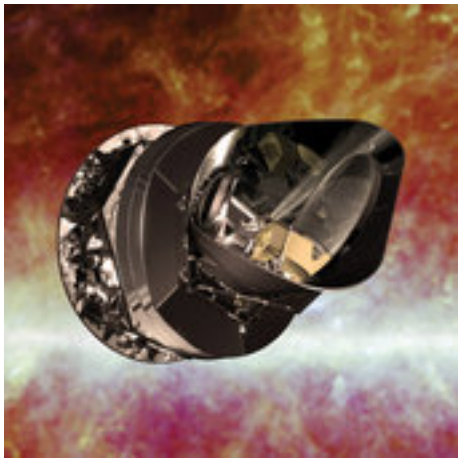
Zoom in by factor 6 – see “swirly” B-mode

Press Conference at Harvard/CfA March 2014

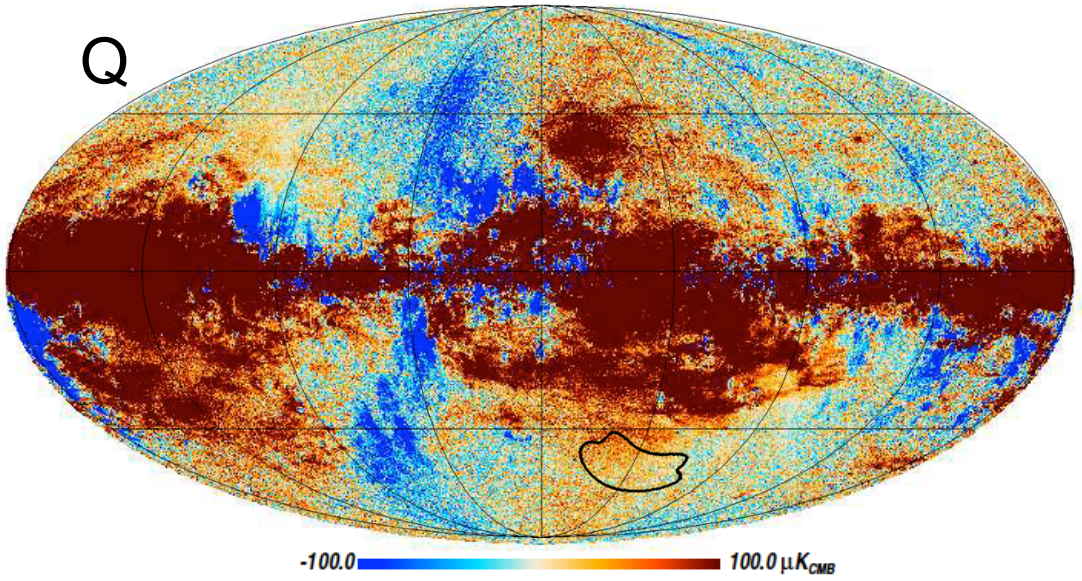
Storm of Media Attention

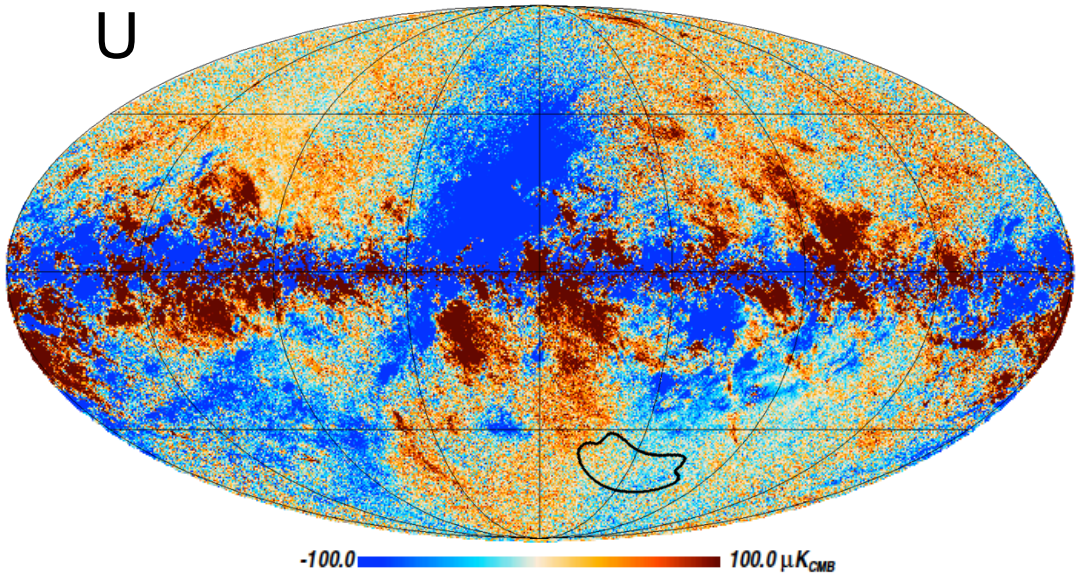
Actually not a lot of fun…

Planck maps of dust emission from our galaxy



Planck was a billion dollar Euro/NASA space mission

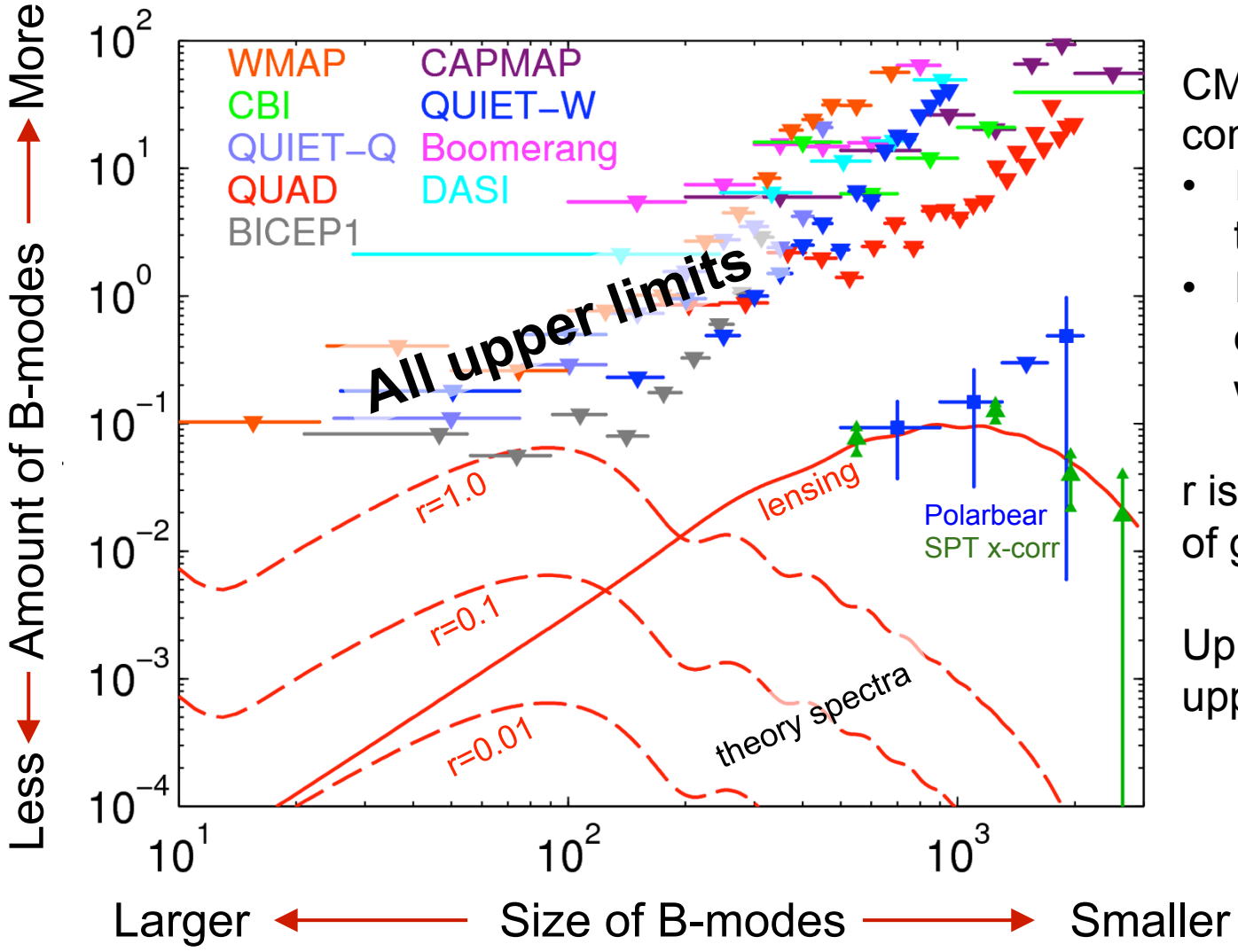




Developments Since…

- We did a joint analysis with the Planck team and released a paper in February of this year
- Unfortunately a large part – and perhaps all – of the signal we have detected is not the cosmic signal we are after – it is emission from dust in our own galaxy
- We are still working hard with our telescopes at the South Pole taking more data
  - If we are lucky we may yet find the signal of cosmic Inflation – if not it is still important to know that it is not there.
- The amount mankind has discovered about the Universe is really quite amazing – and we are not done yet!

The Long Search for Inflationary B-modes



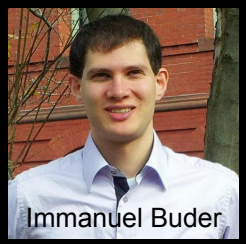
CMB polarization comes in two kinds

- E-modes – vanilla type
- B-modes – (mostly) only from gravity waves from Inflation

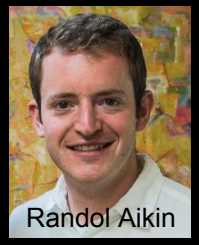
r is measure of amount of gravity waves

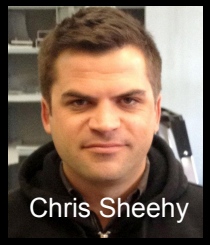
Up until recently only upper limits…

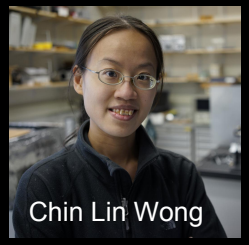
The BICEP2 Postdocs

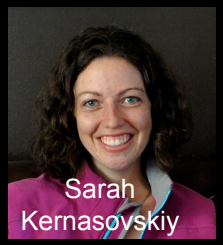


The BICEP2 Graduate Students







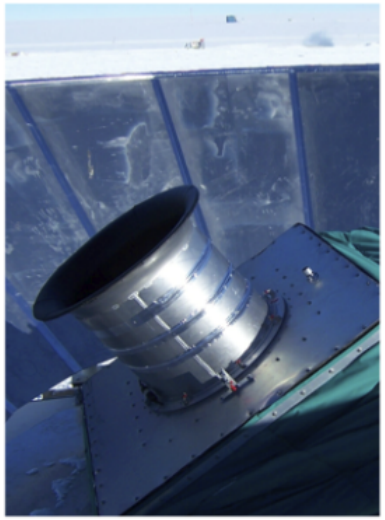
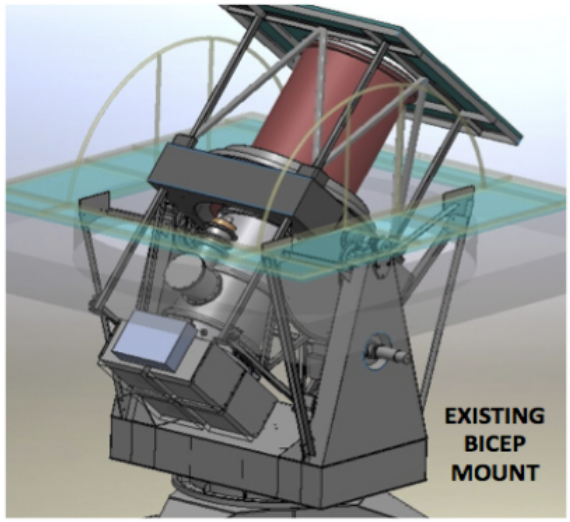
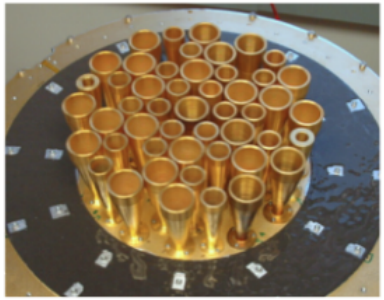
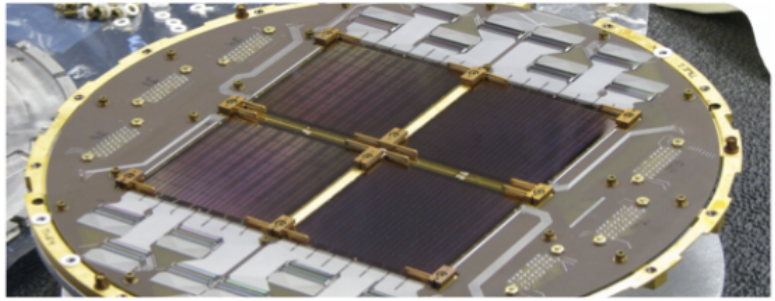
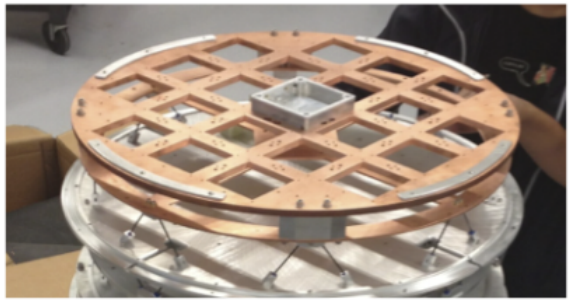
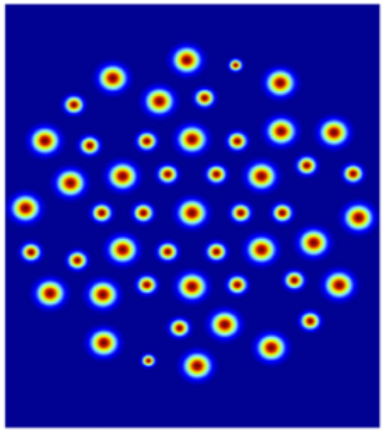
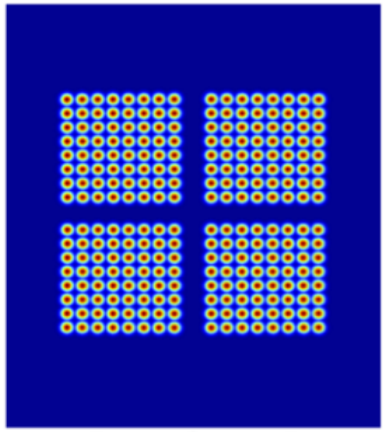
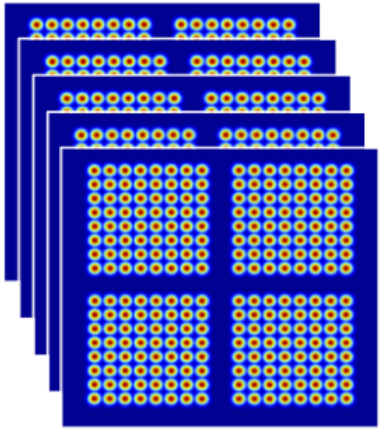
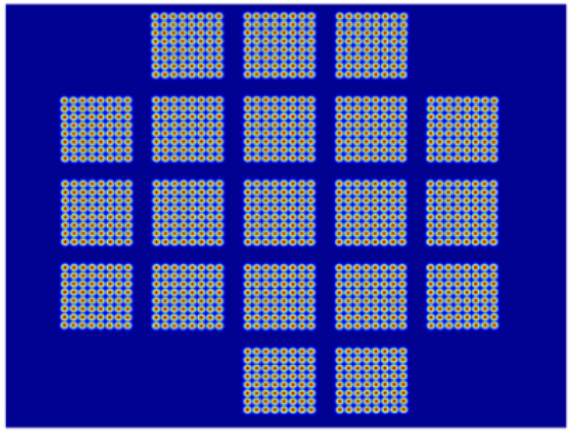


BICEP2 Winterovers

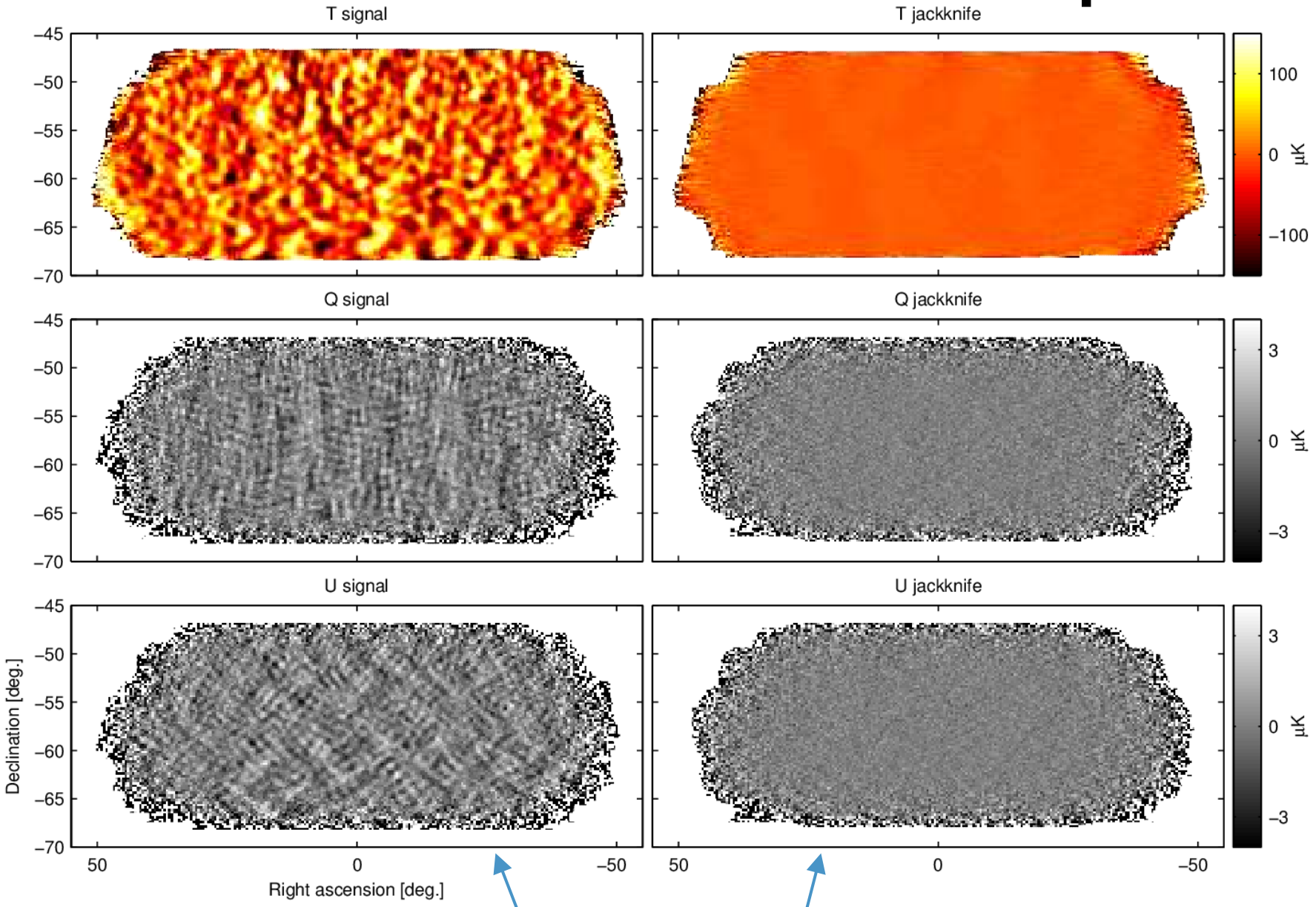
2010

2011

2012

	BICEP1 (2006 - 8)	BICEP2 (2010 - 12)	Keck Array (2011 -)	BICEP3 (2014 -)
Telescope and Mount				
Focal Plane				
Beams on Sky				

BICEP2 T and Stokes Q/U Maps



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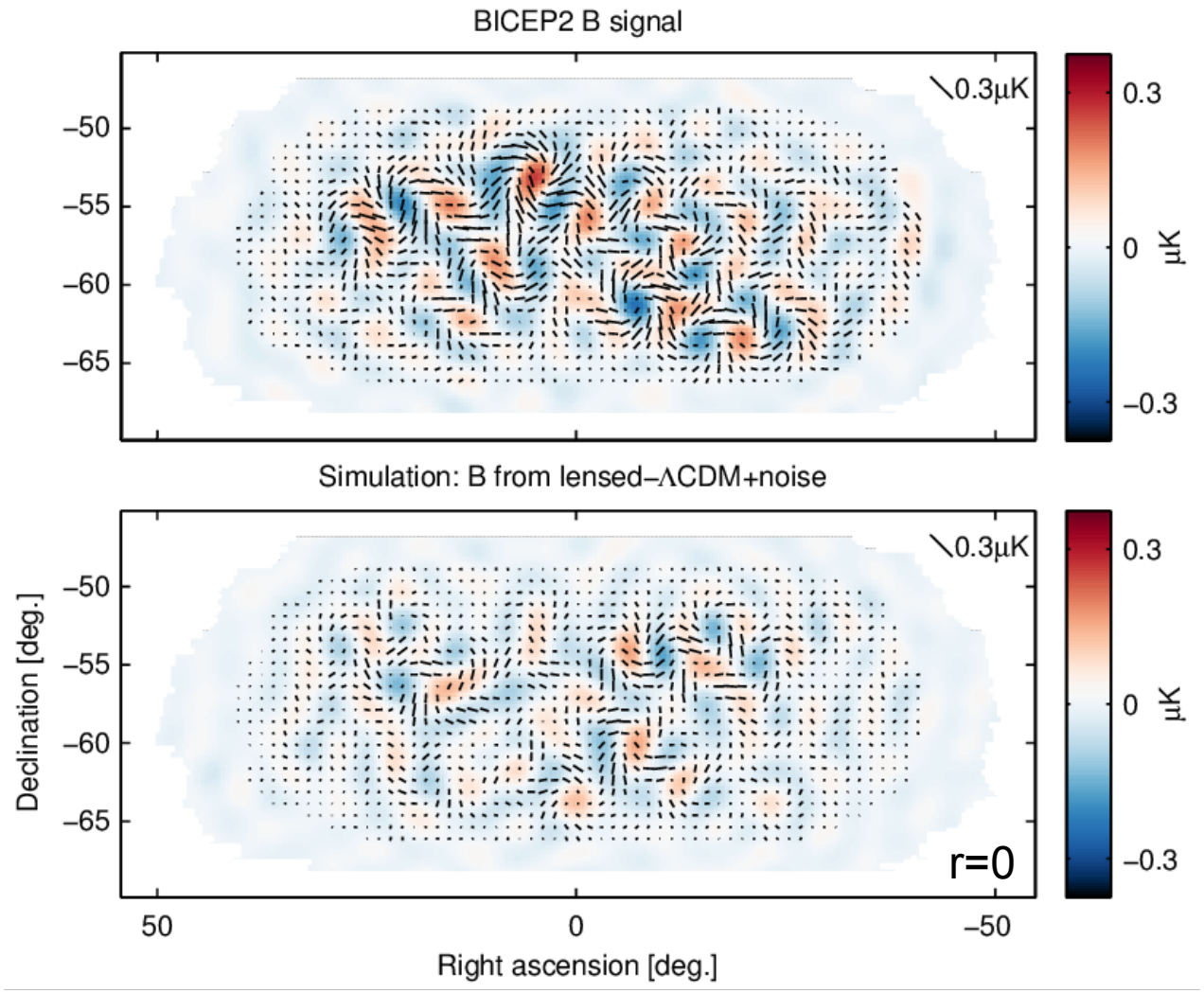
Real B-mode Map vs. Simulation



Way more B-modes in the real map (upper) than in simulations containing vanilla model plus experimental noise (lower)

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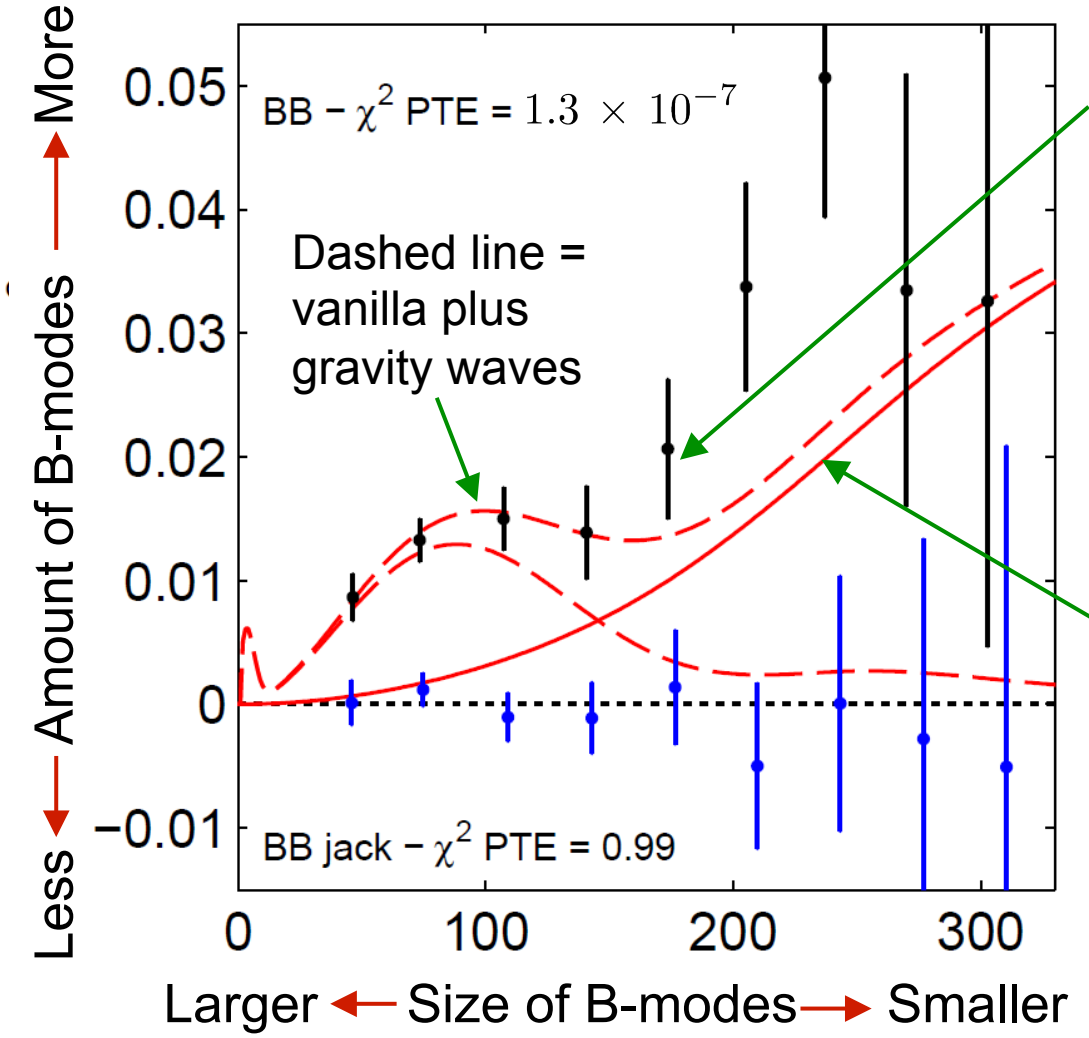
BICEP2 B-mode Power Spectrum



Chance to get data if vanilla model is true: 1 in 10 million

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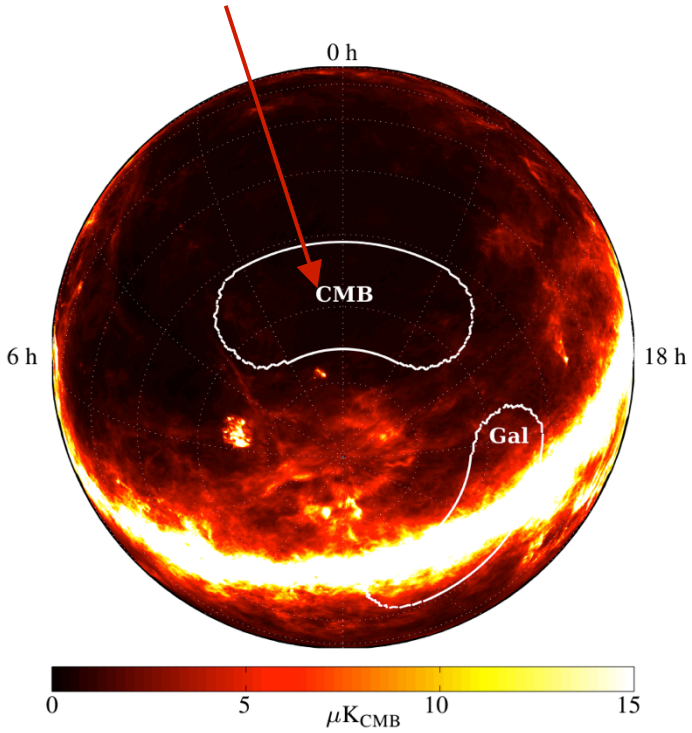
Foreground Contamination from Our Galaxy

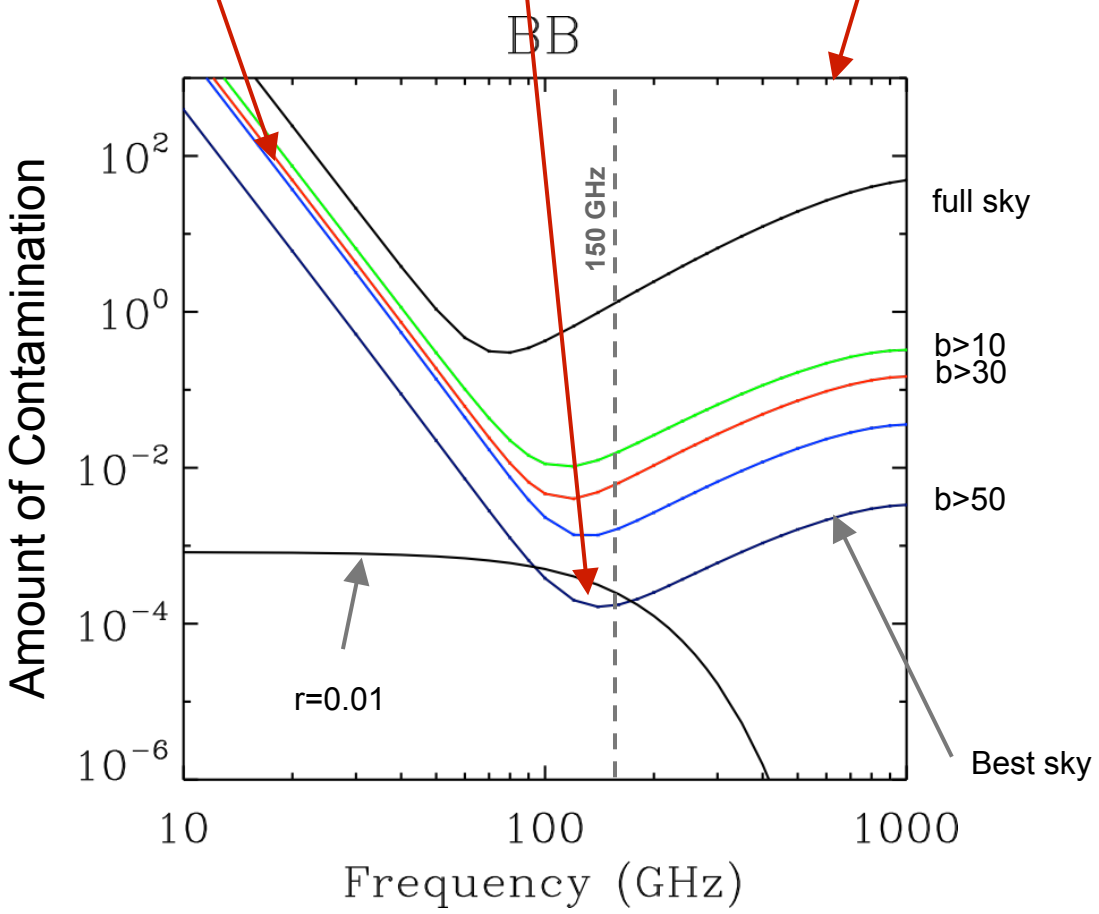
Pick a clean patch of sky



At low frequency synchrotron contamination

Sweetest spot

At high frequency dust contamination



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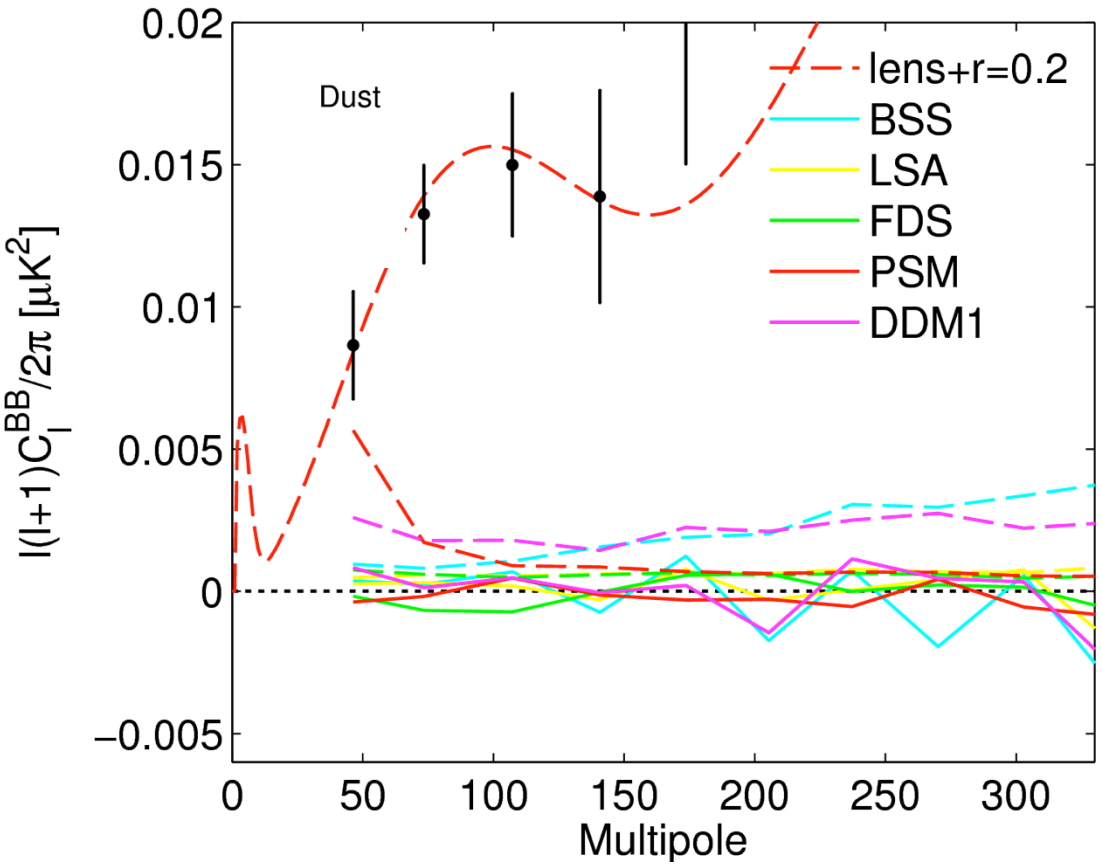
Pre-Planck Polarized Dust Foreground Projections



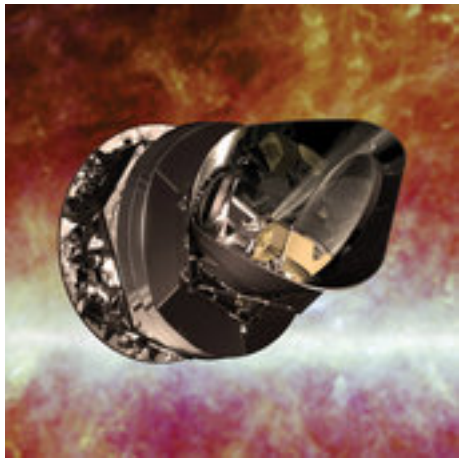
The BICEP2 observation region was chosen on the basis of extremely low unpolarized dust contamination

Used various models of polarized dust emission to estimate dust contamination

Result: All well below observed signal level

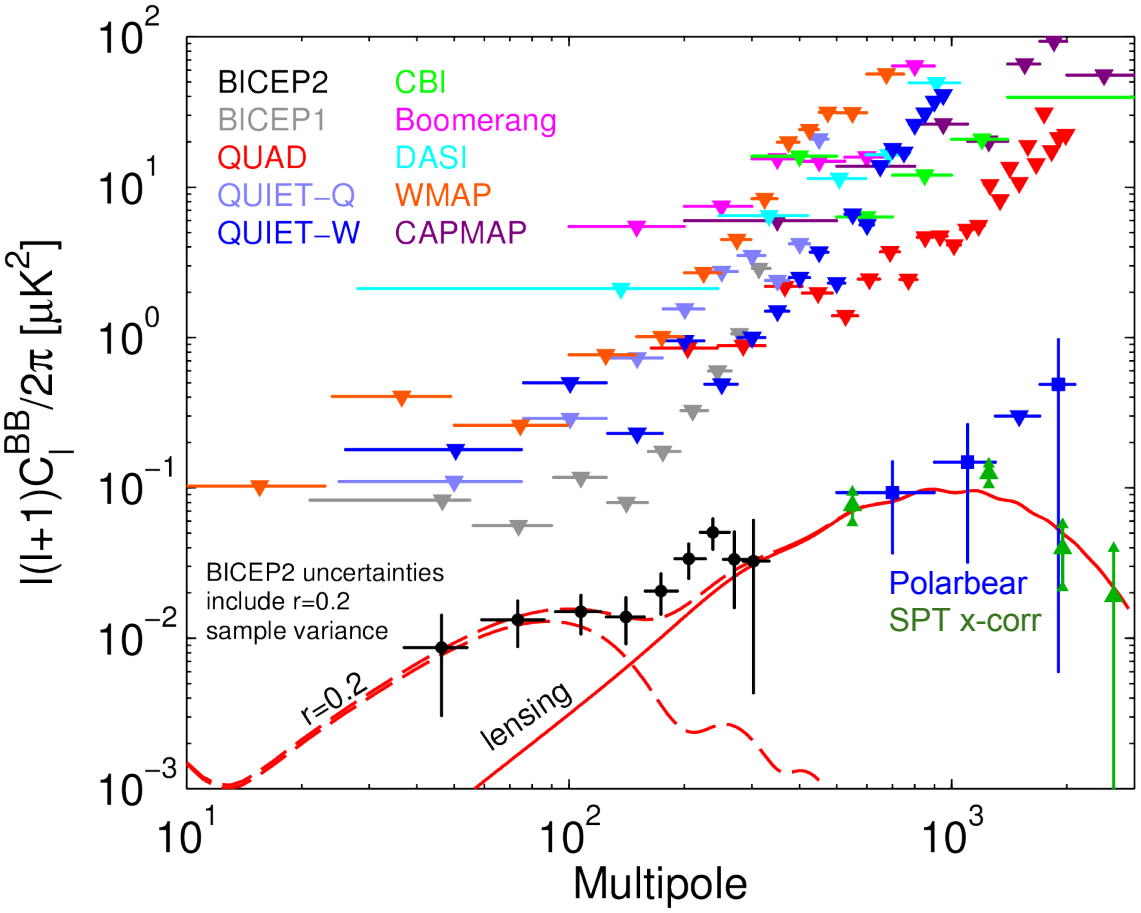
But considerable uncertainty in these models...

Nobody really knew the true level of polarized dust – except the Planck space mission which had taken data but not released it…



Conclusions circa March 17th

BICEP2 and upper limits from other experiments:



http://bicepkeck.org

Really looked like we'd found gravitational waves from inflation

…but a lot of uncertainty about galactic dust polarization remained…