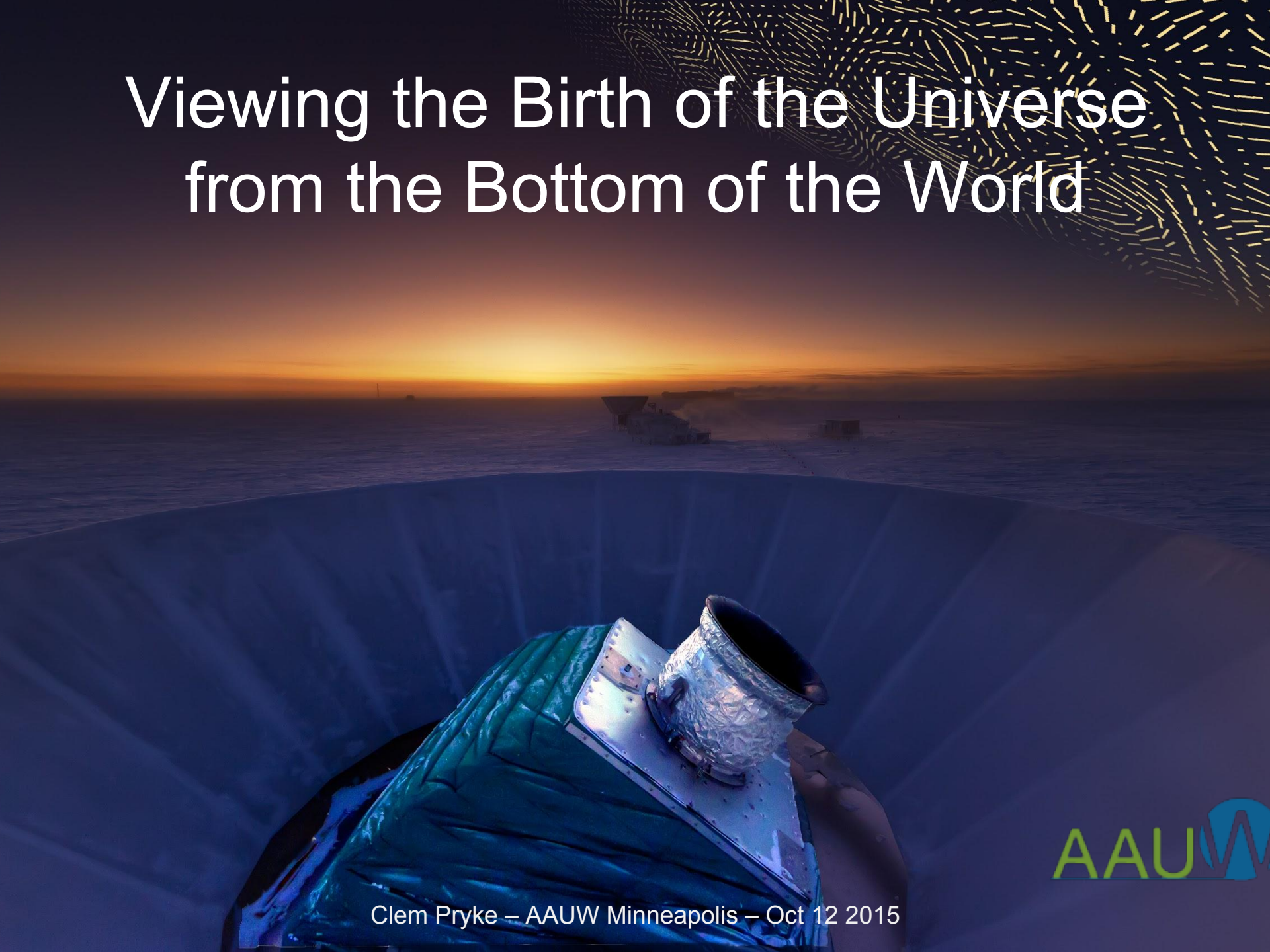
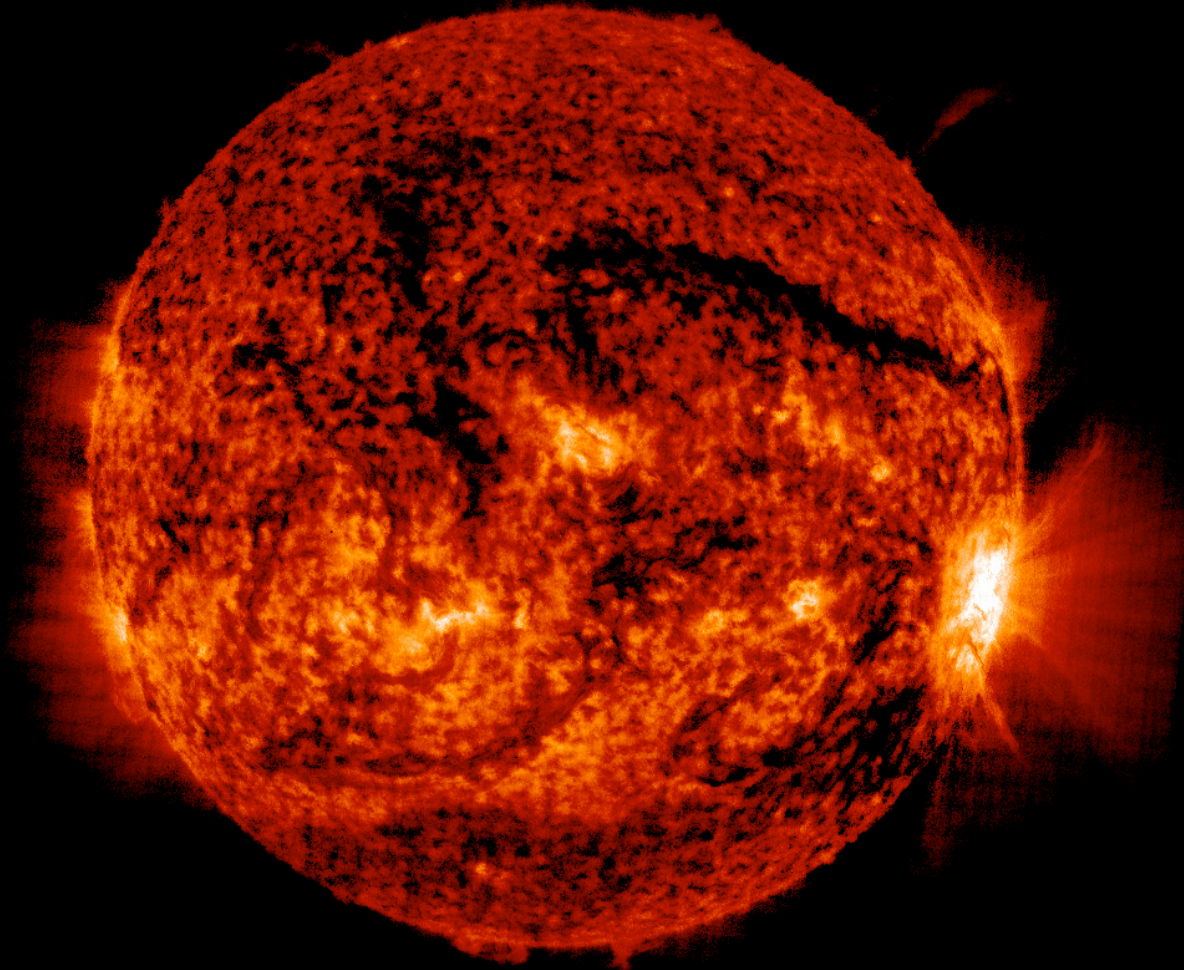




Viewing the Birth of the Universe from the Bottom of the World



Our Sun is a Star

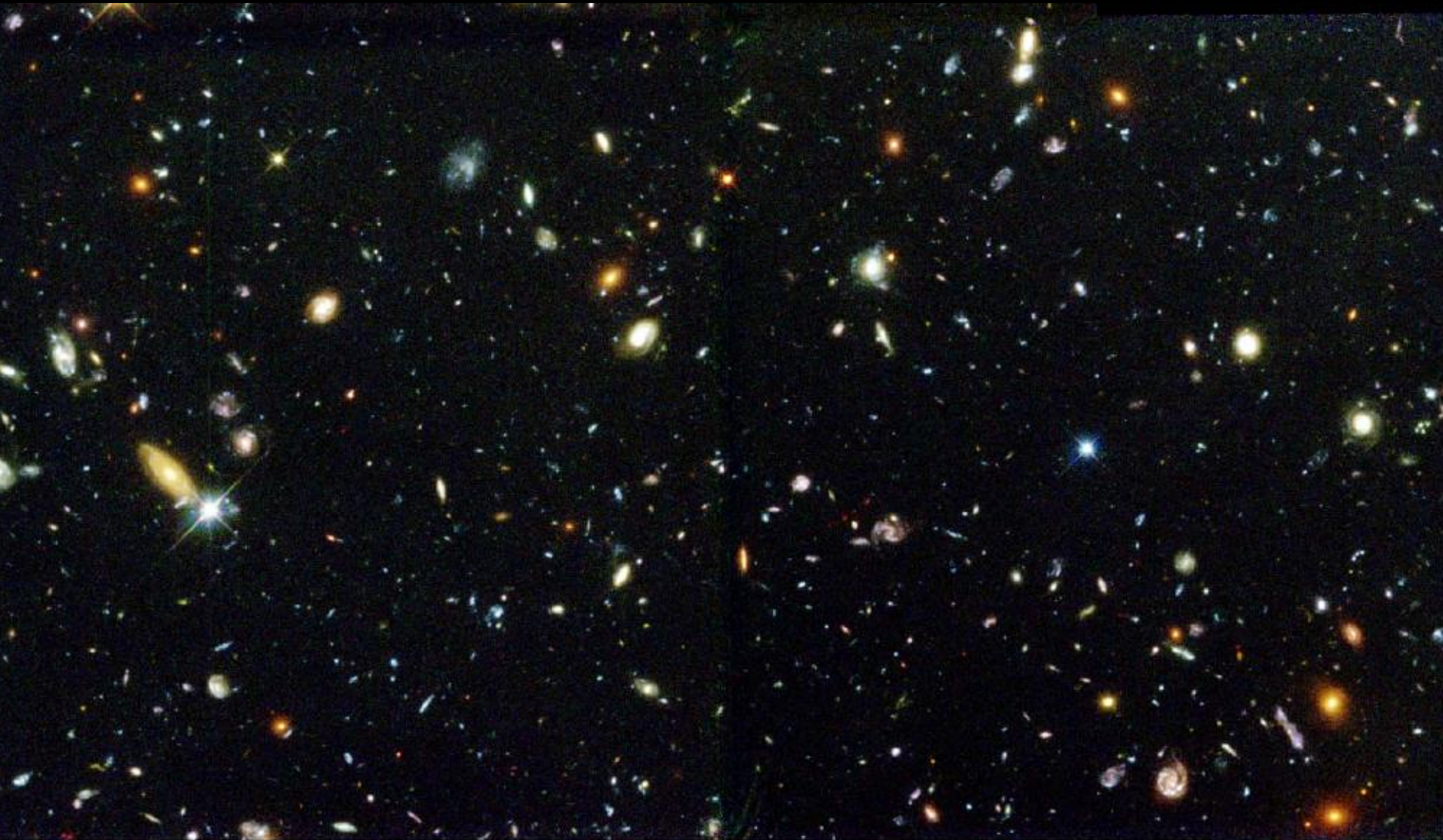


...Many stars make a galaxy...



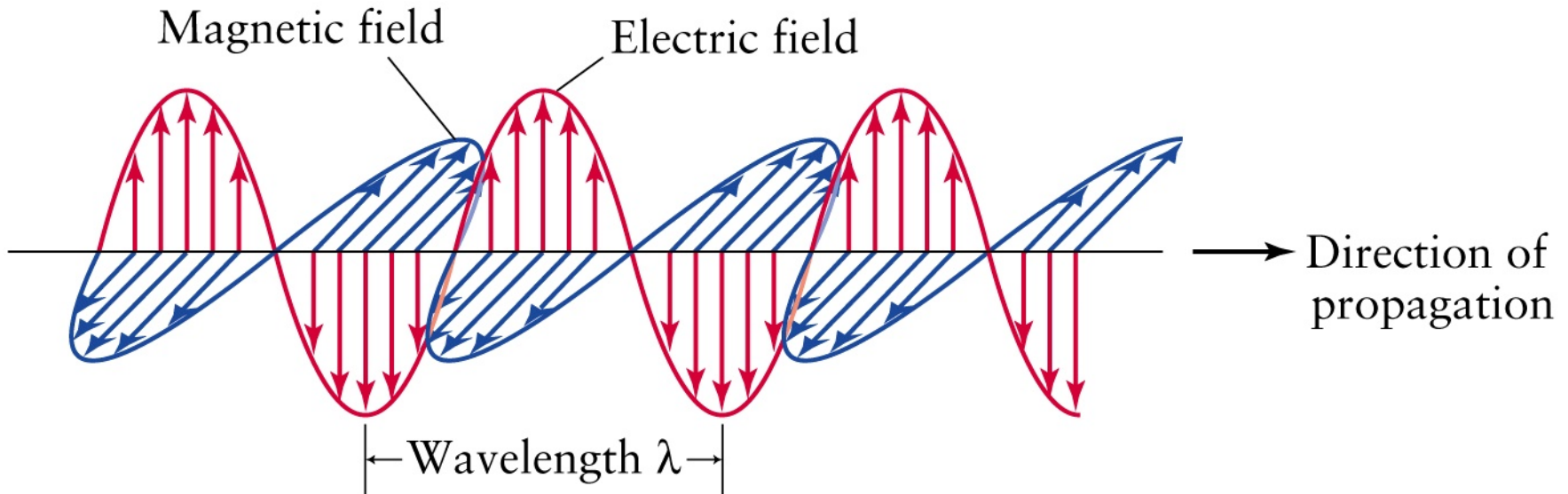
(A nearby galaxy similar to ours)

...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



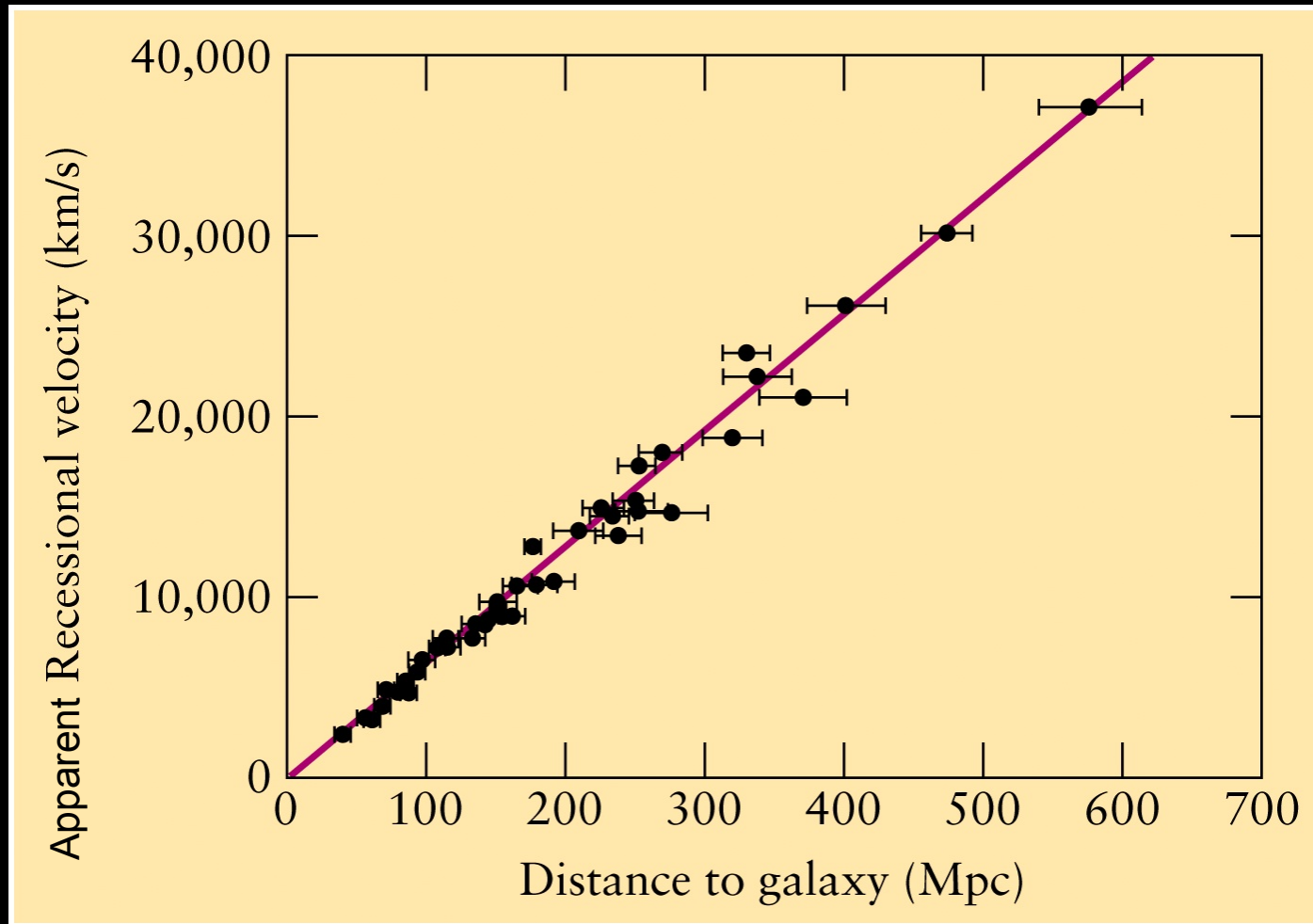
- Imagine 3 stars emitting rays of light of the same “natural” wavelength (color)
- But light moves through space always at the same speed...
- Moving towards us = compressed = bluer
- Moving away from us = stretched = redder

Edwin Hubble “Observing” Distant Galaxies



Mount Wilson Observatory
(LA) 1920's

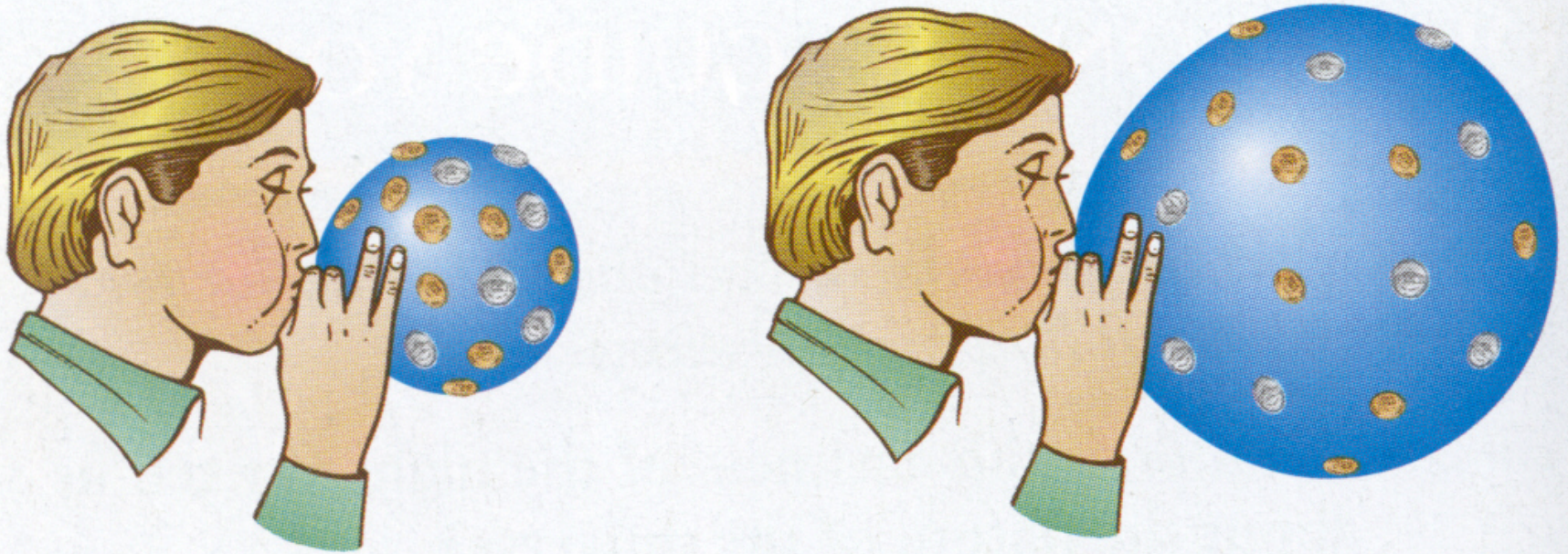
Hubble Diagram



The farther away a galaxy is the faster it *appears* to be moving away from us...

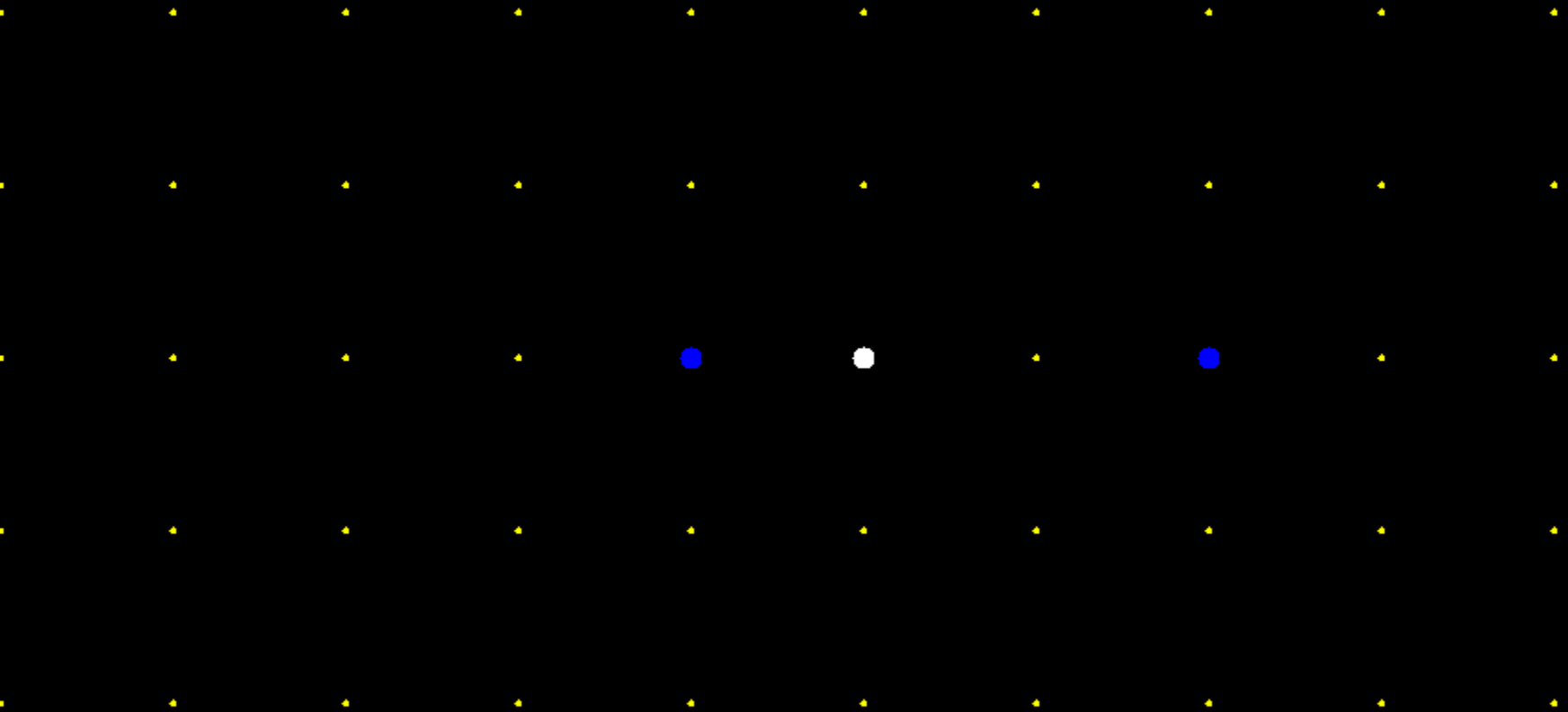
Are we the most unpopular place in the entire Universe?!

Expanding Universe?



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

Cosmological Doppler Effect



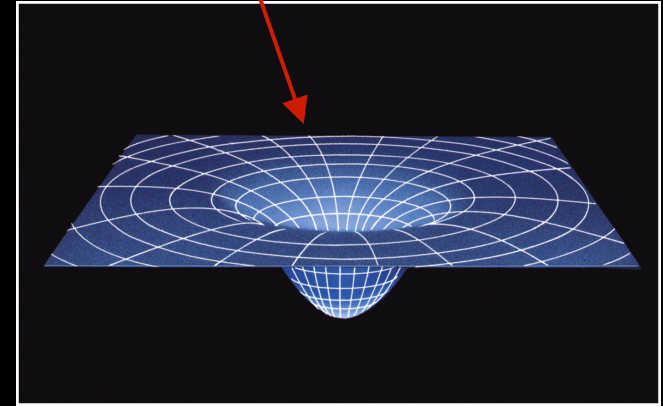
- Light rays stretch with the Universe – called “redshift”
- As we look *out* we look *back* in time

Einstein and General Relativity



↑
In 1915 Albert Einstein
devised the General
Theory of Relativity

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



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

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

Modern cosmology in a nutshell:



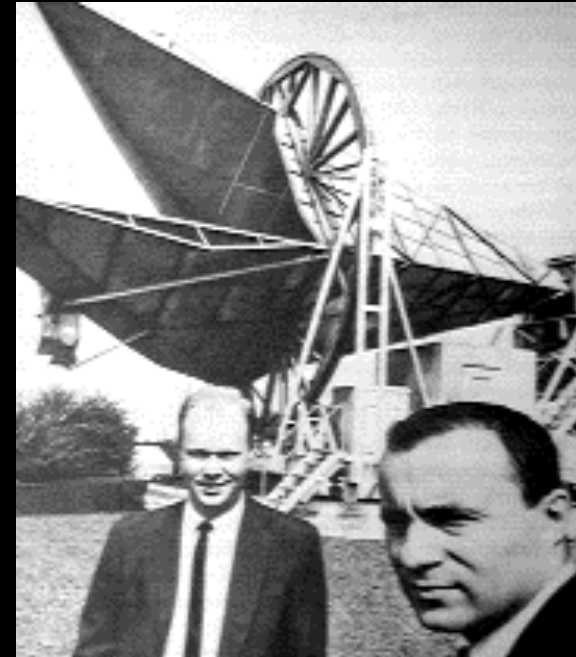
Edwin Hubble

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

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

(Alpher, Gamow, Herman, 1940s)

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



Bob Wilson & Arno Penzias
1978 Nobel Prize

⇒ acceptance of the “HOT BIG BANG”

INFLATION

**CMB
last scattering**

**fraction
of a second**

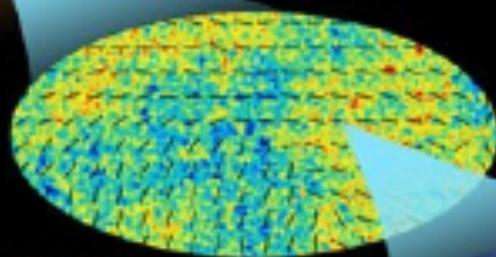
**379,000
years**

**first
stars**

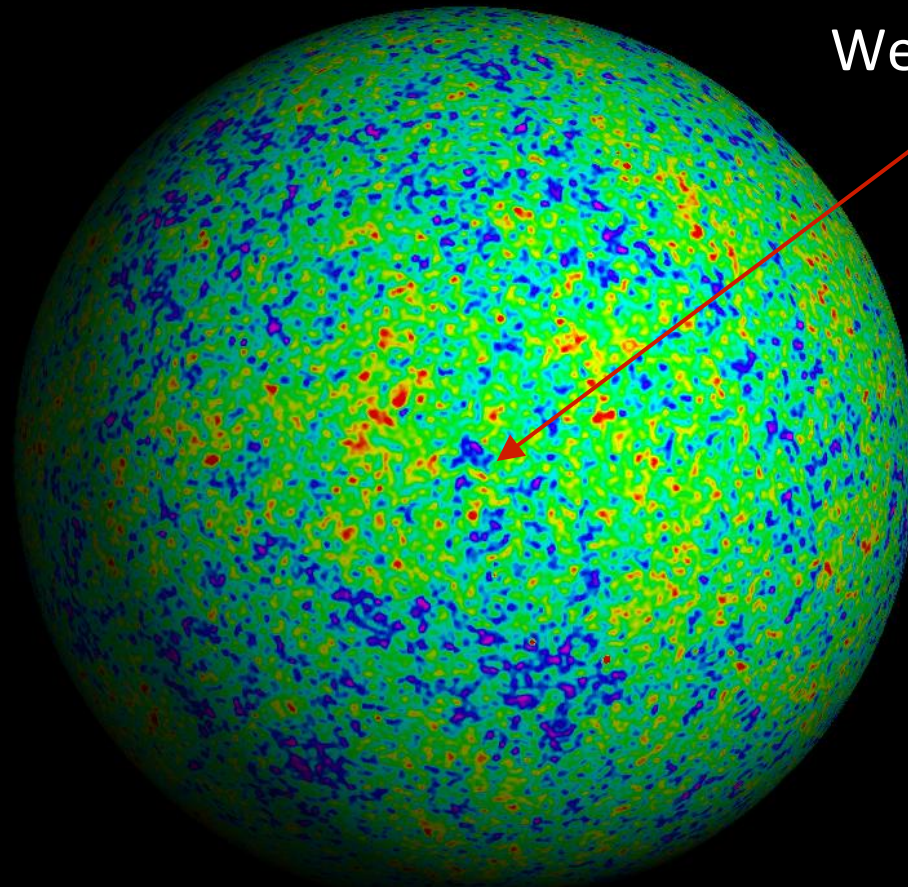
**~200 million
years**

**present
day**

**13.7 billion
years**



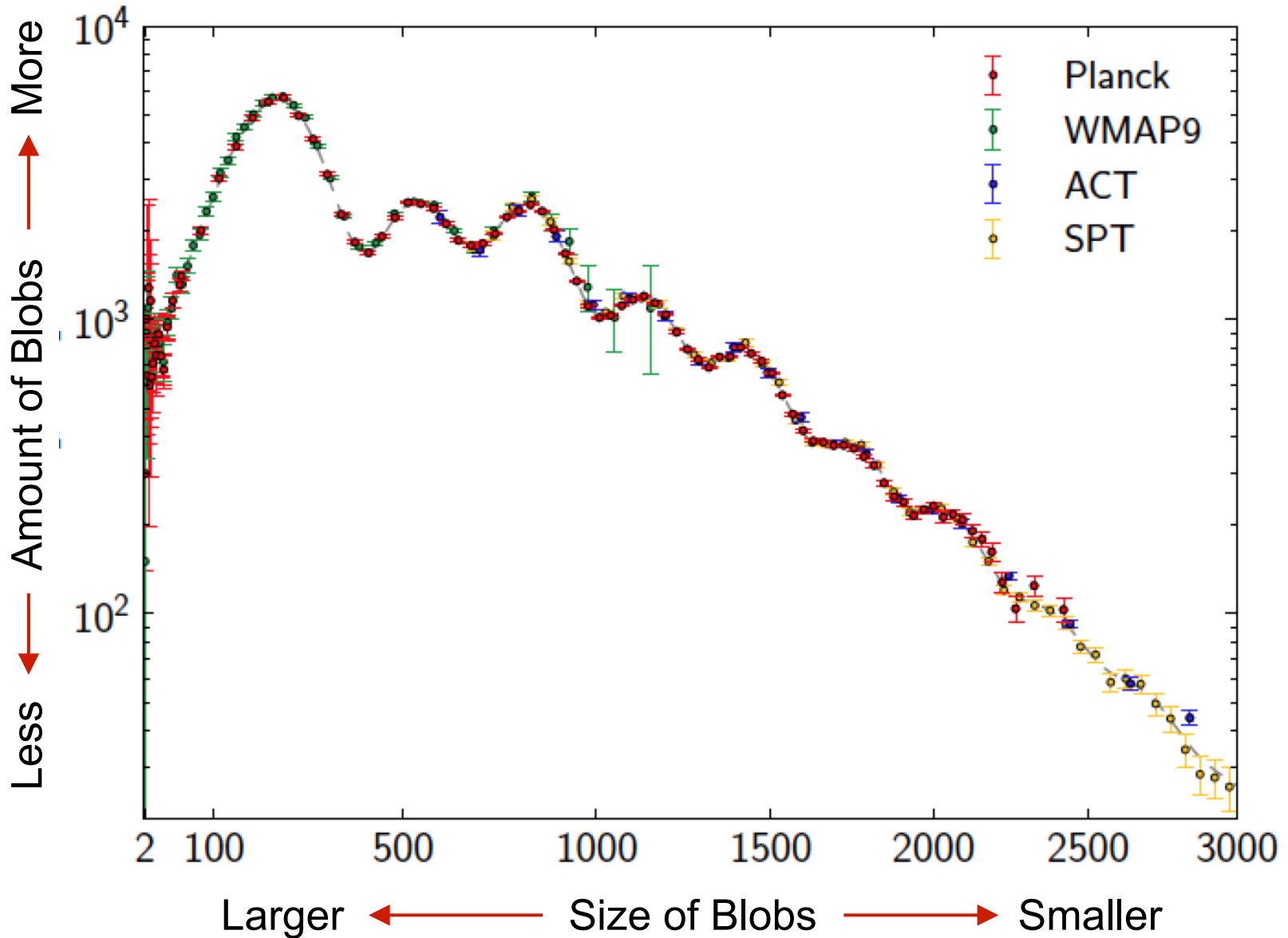
The Cosmic Microwave Background



We are at the center

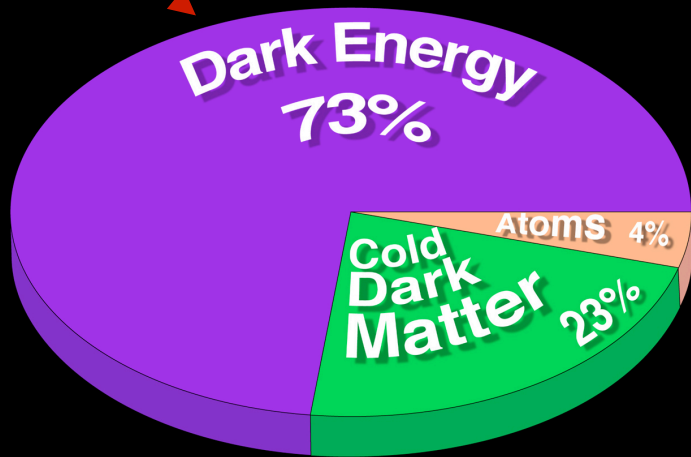
CMB is sample of the density structure on a shell cut through the 380,000 year old Universe

“Lump Sorter” Plot

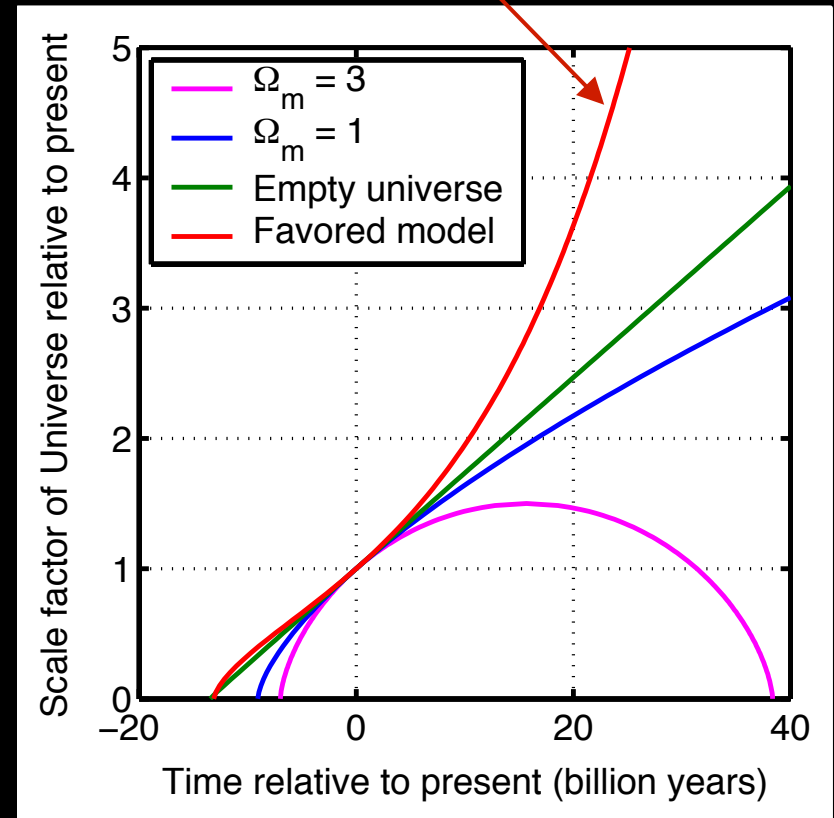


Triumphant/Embarrassing Cosmology

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

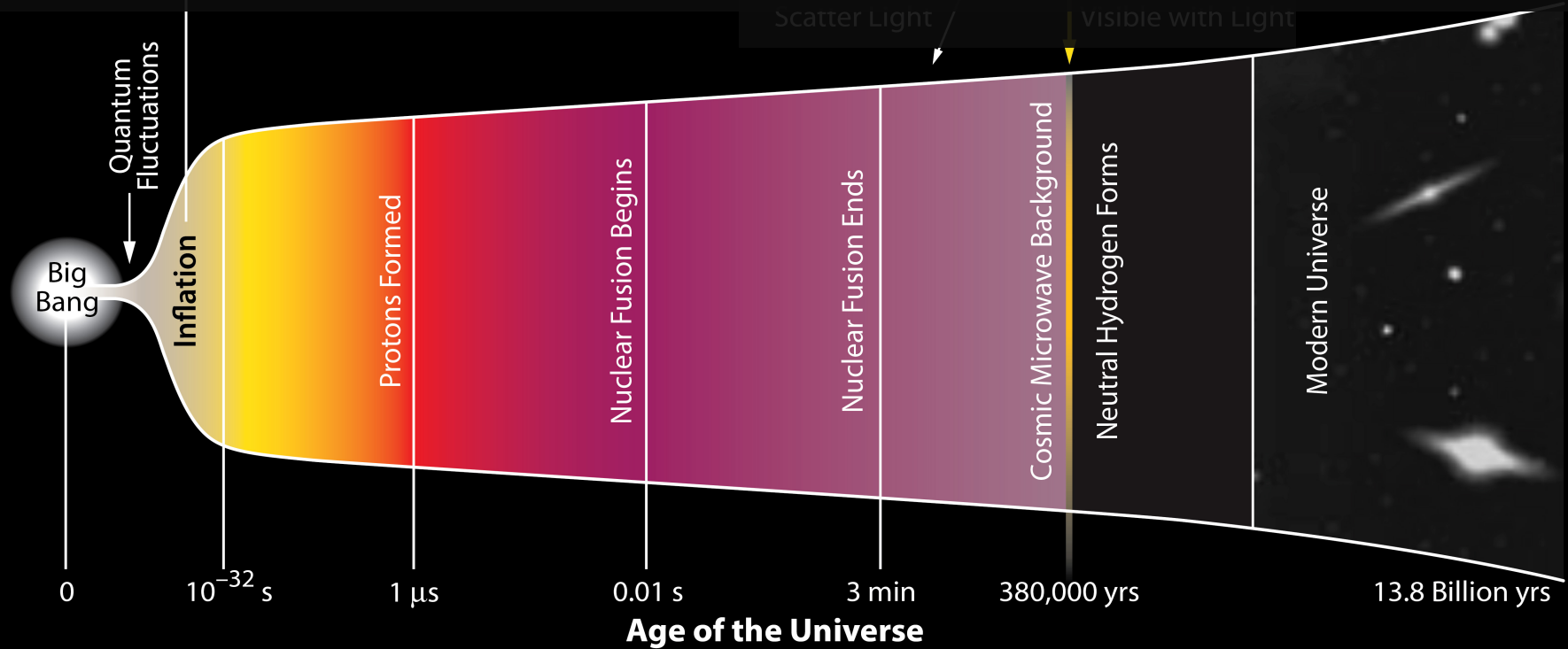


Alan Guth

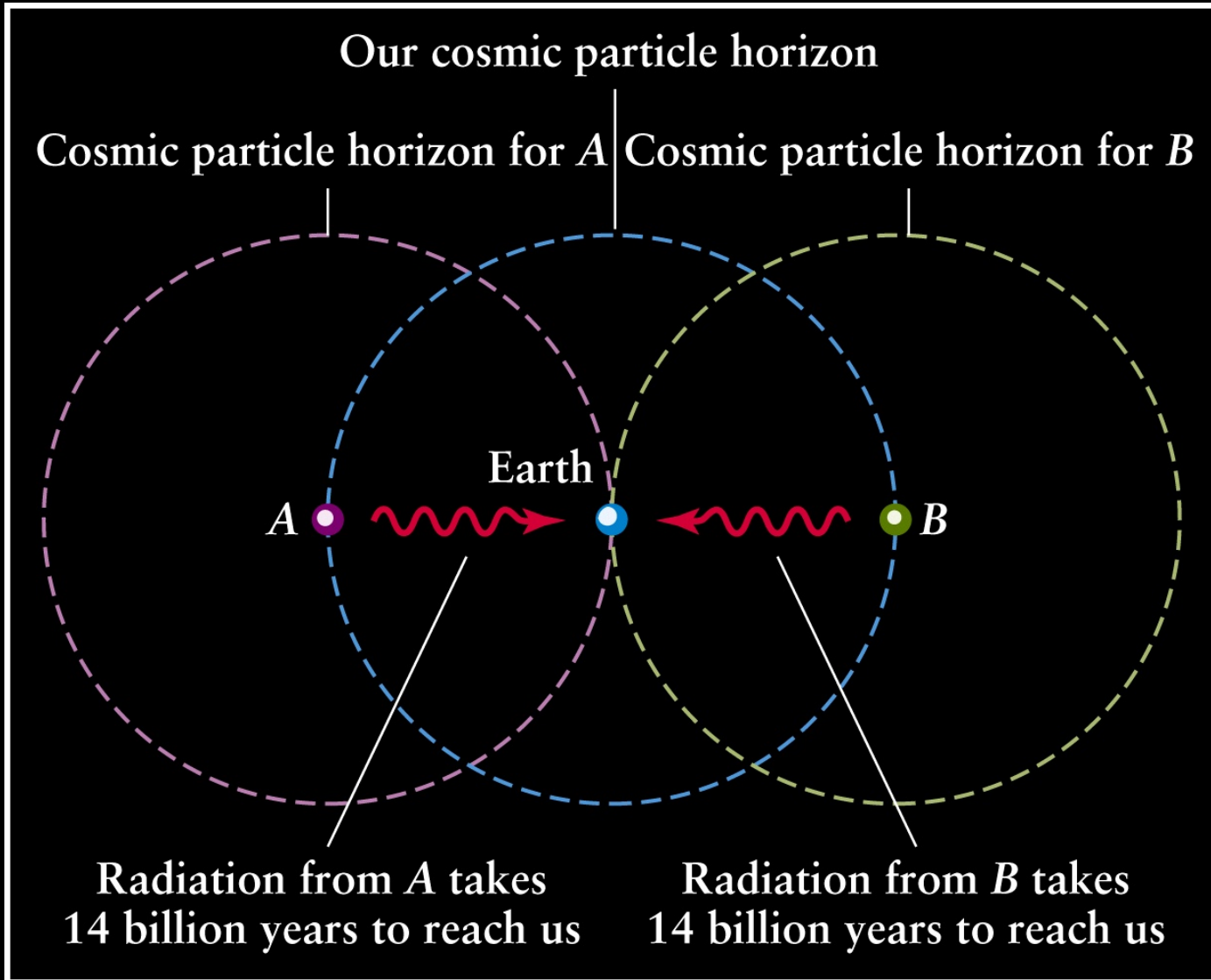


Andrei Linde

Radius of the Visible Universe

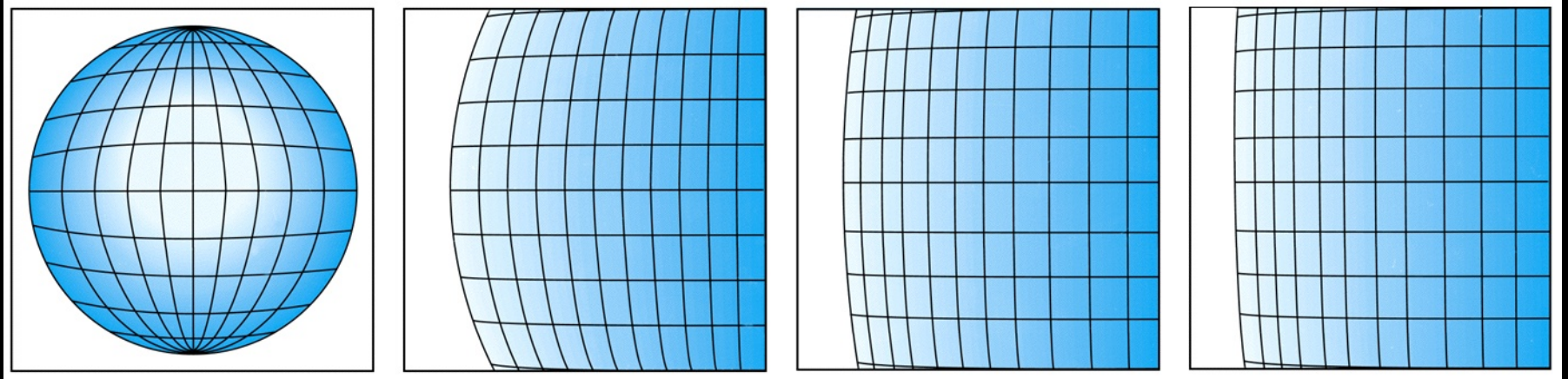


The Horizon Problem



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

Solving the Flatness Problem

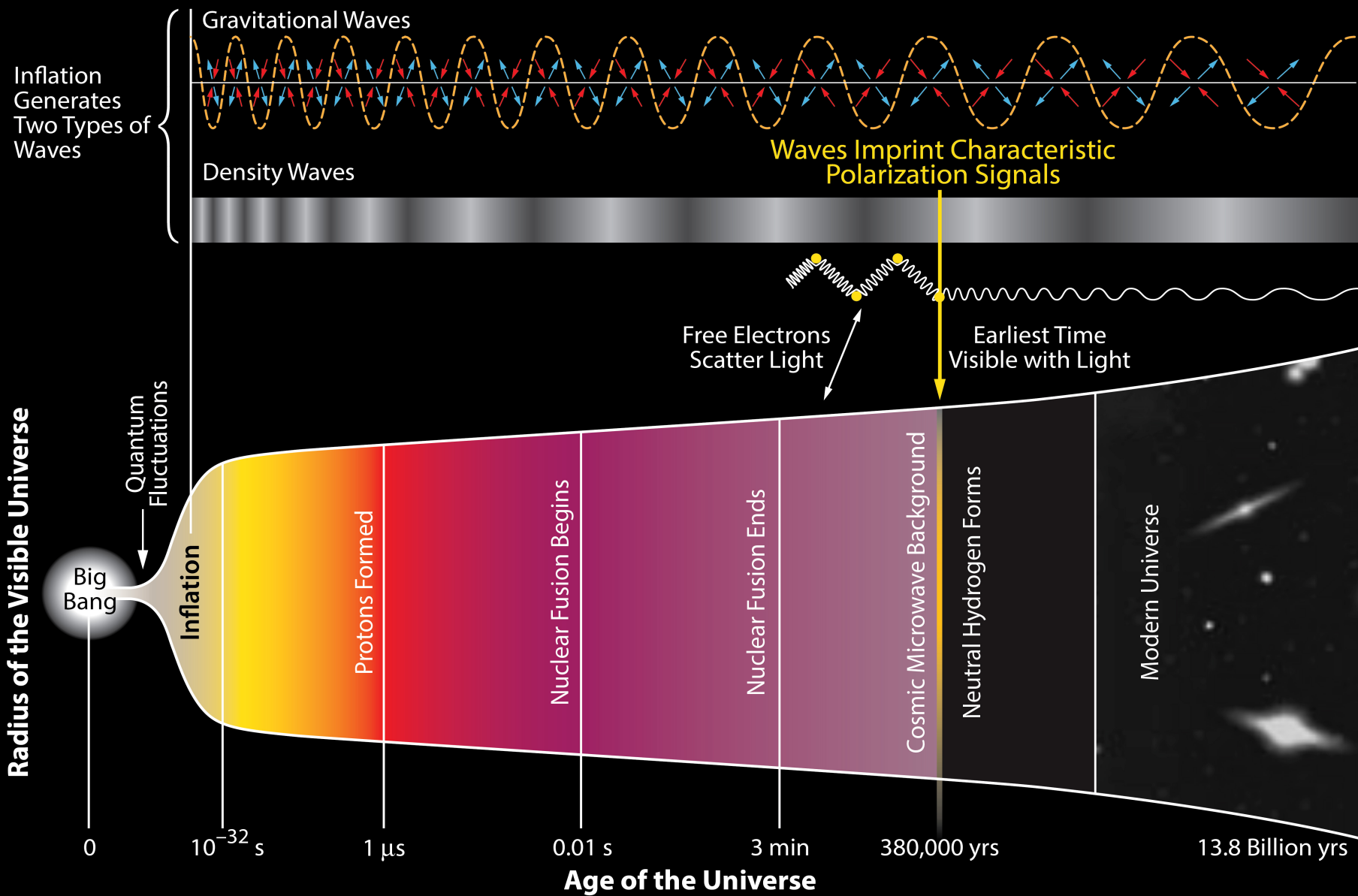


→ Inflation... →

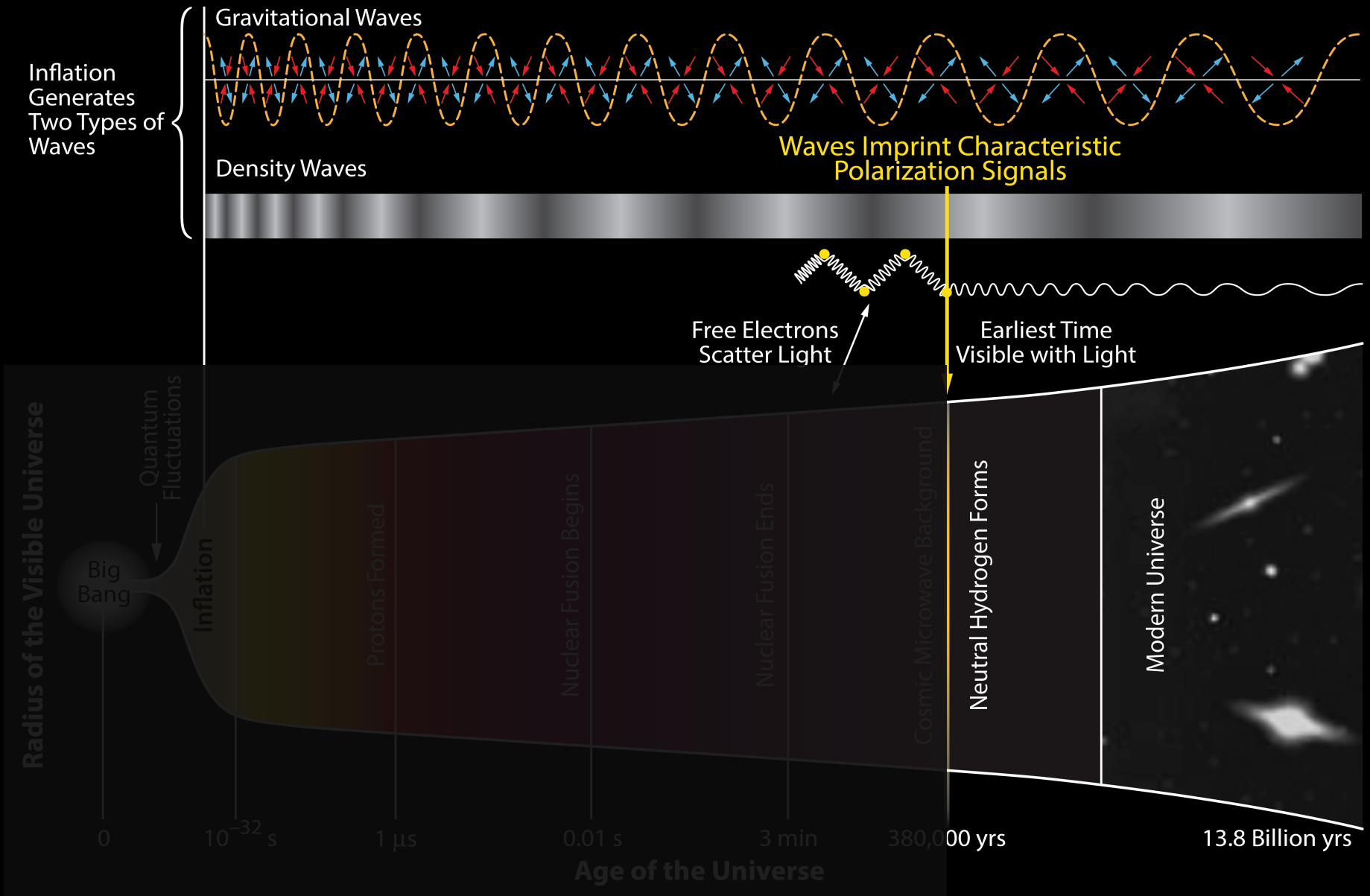
If you take some curved space and blow it up enough pretty soon it is no longer curved on a local scale – like our entire observable Universe!

So nice idea – but how can we get direct evidence if it happened?
Makes another prediction...

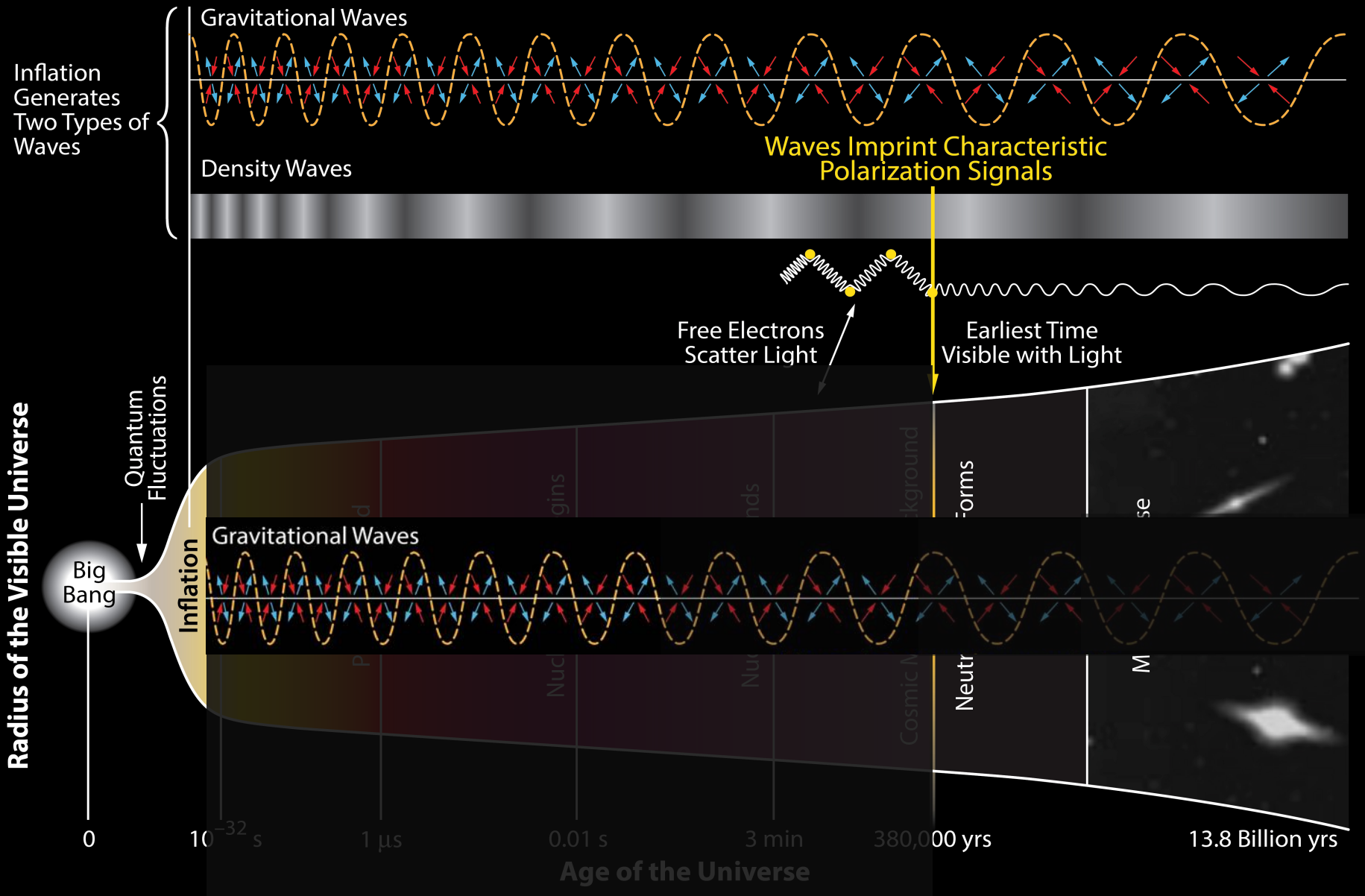
History of the Universe



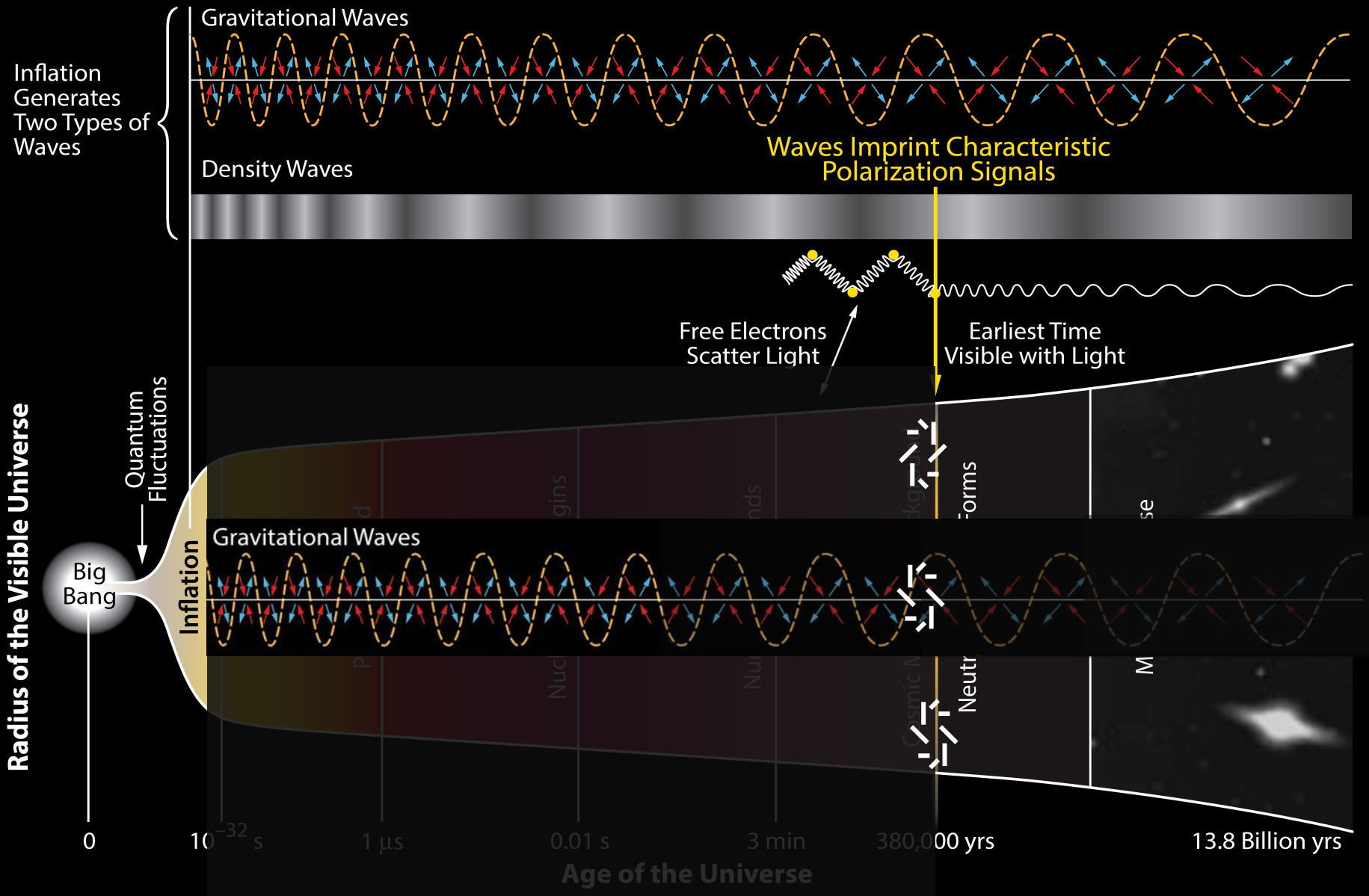
History of the Universe

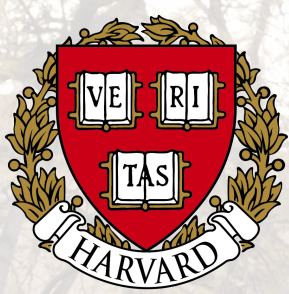


History of the Universe



History of the Universe

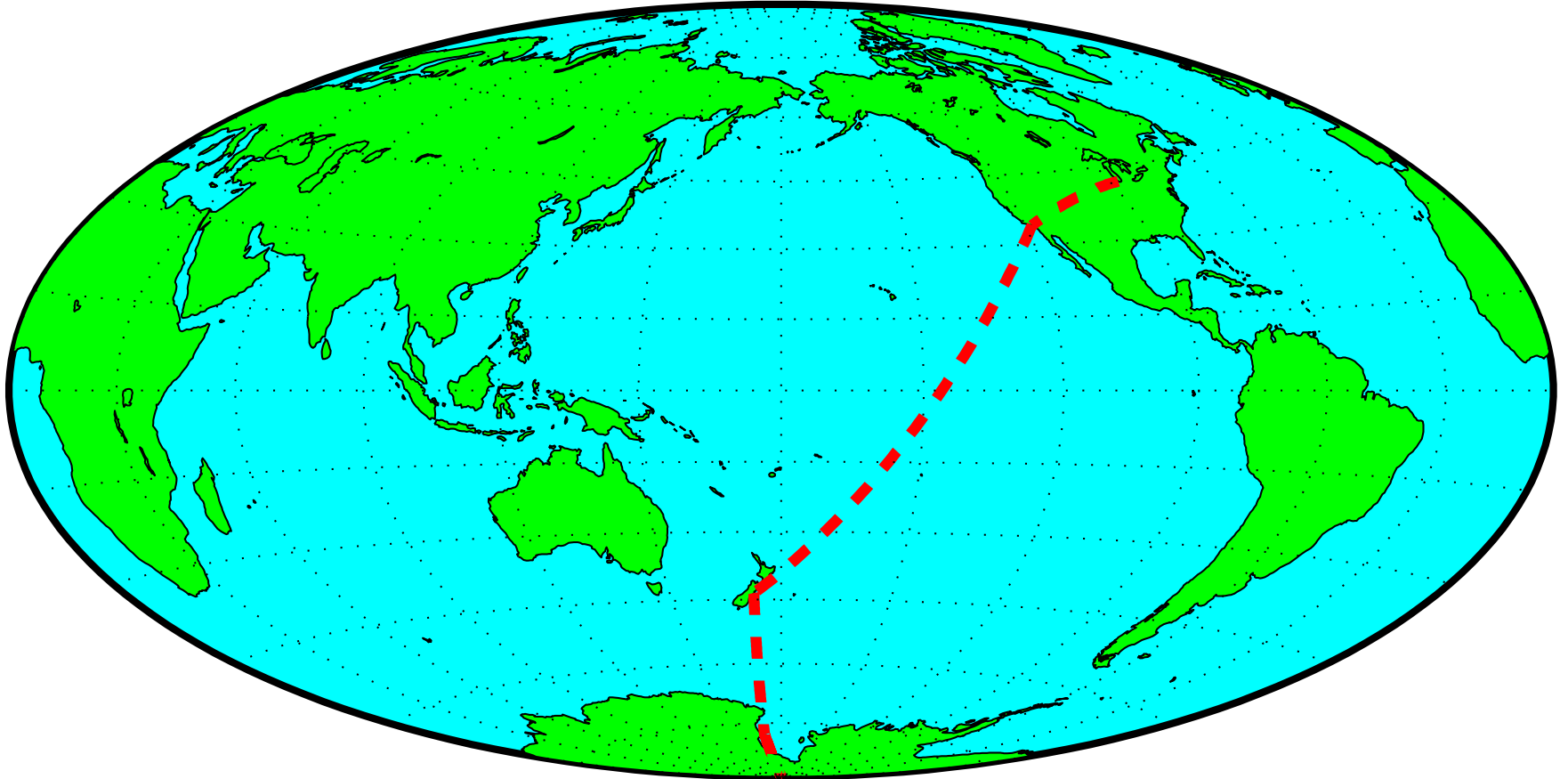




UNIVERSITY OF TORONTO

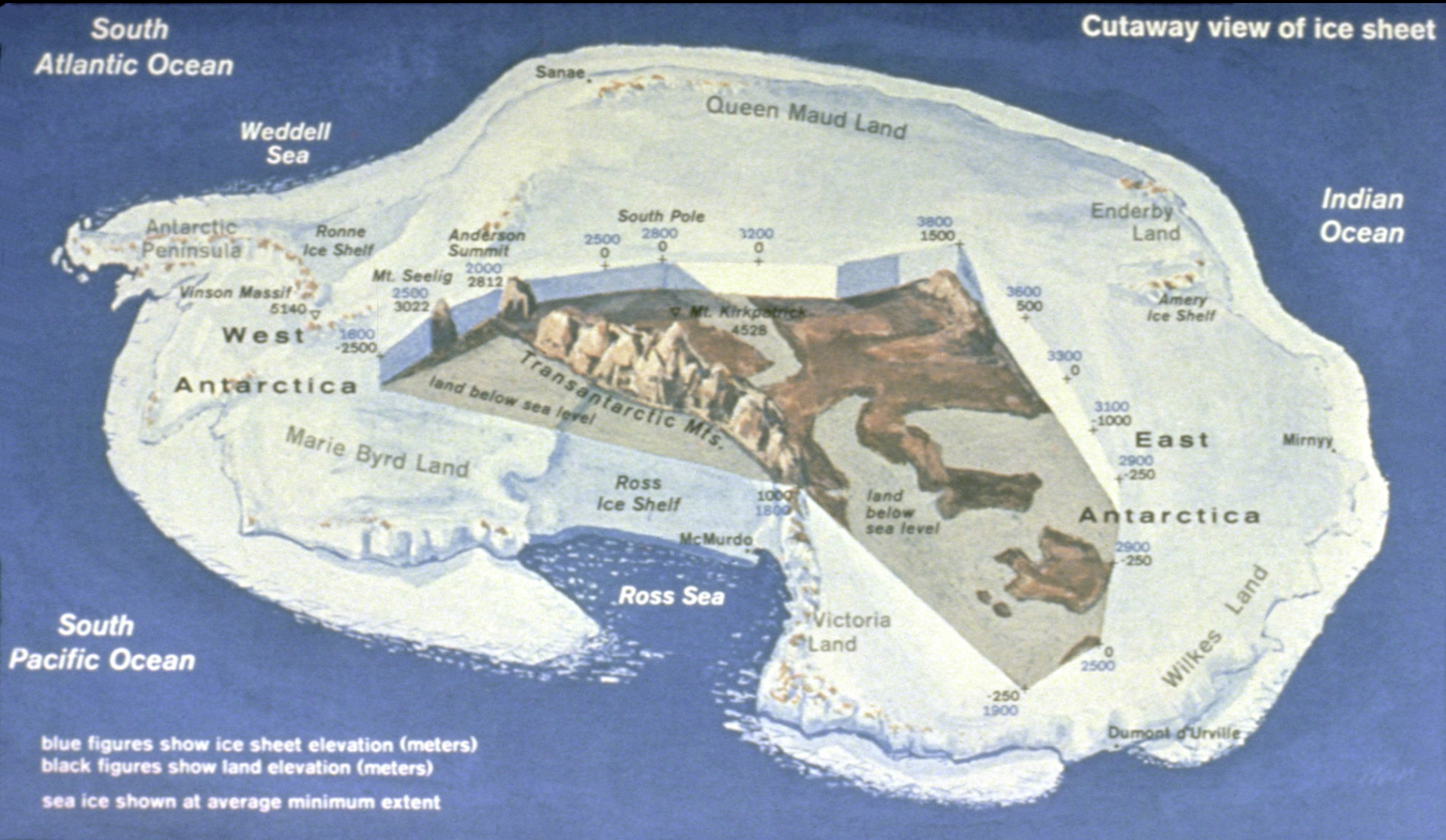


Journey to the South Pole



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

Antarctic Continent



Larger than the US – Ice sheet two miles thick!



Christchurch New Zealand – Clothing Warehouse



Big Program!



Arrival in Antarctica



McMurdo – base on the coast



On to the Pole – over the Transantarctic Mountains



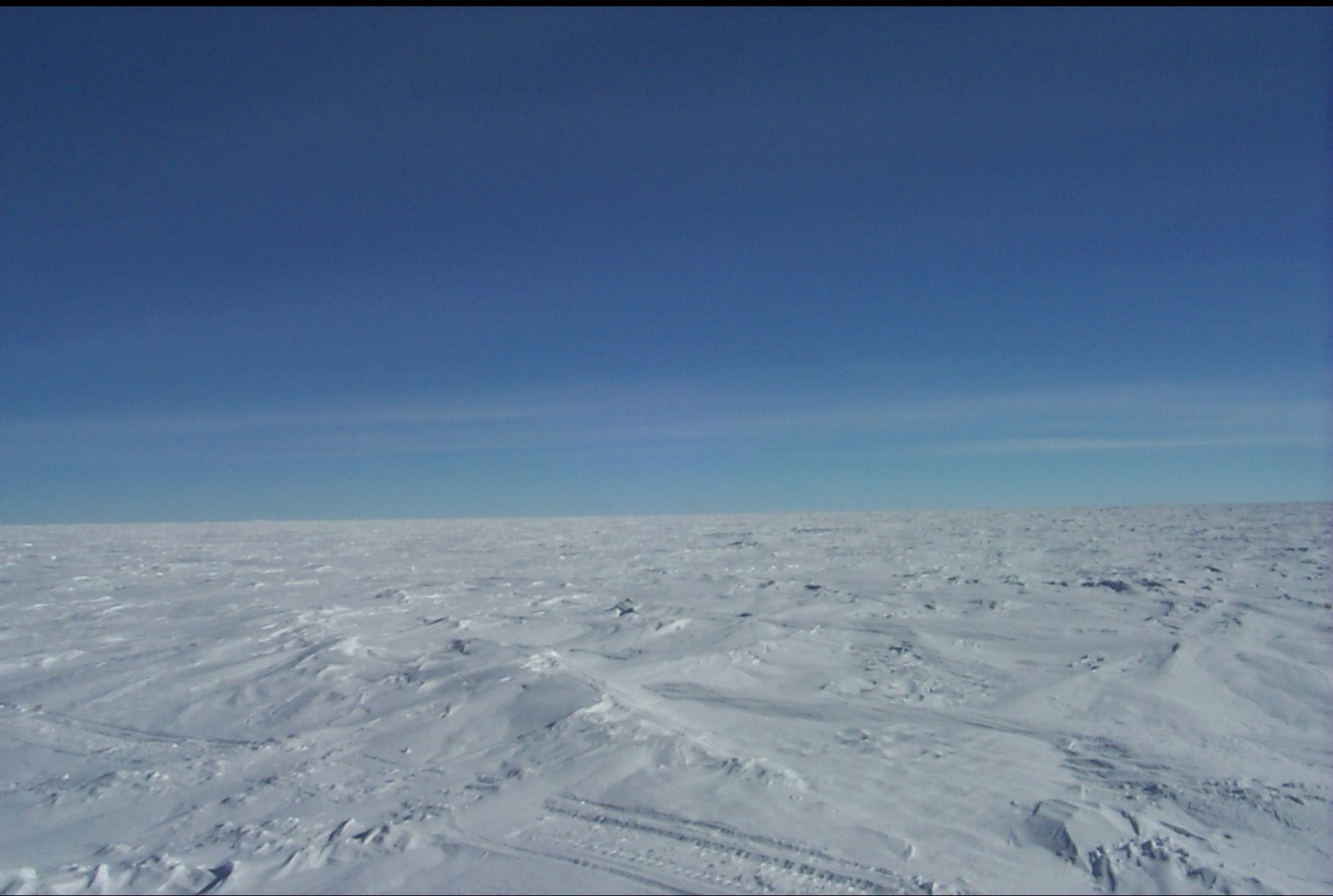
Unloading at Pole



The Actual South Pole



Nothing Out There!



Why do this at the Pole?

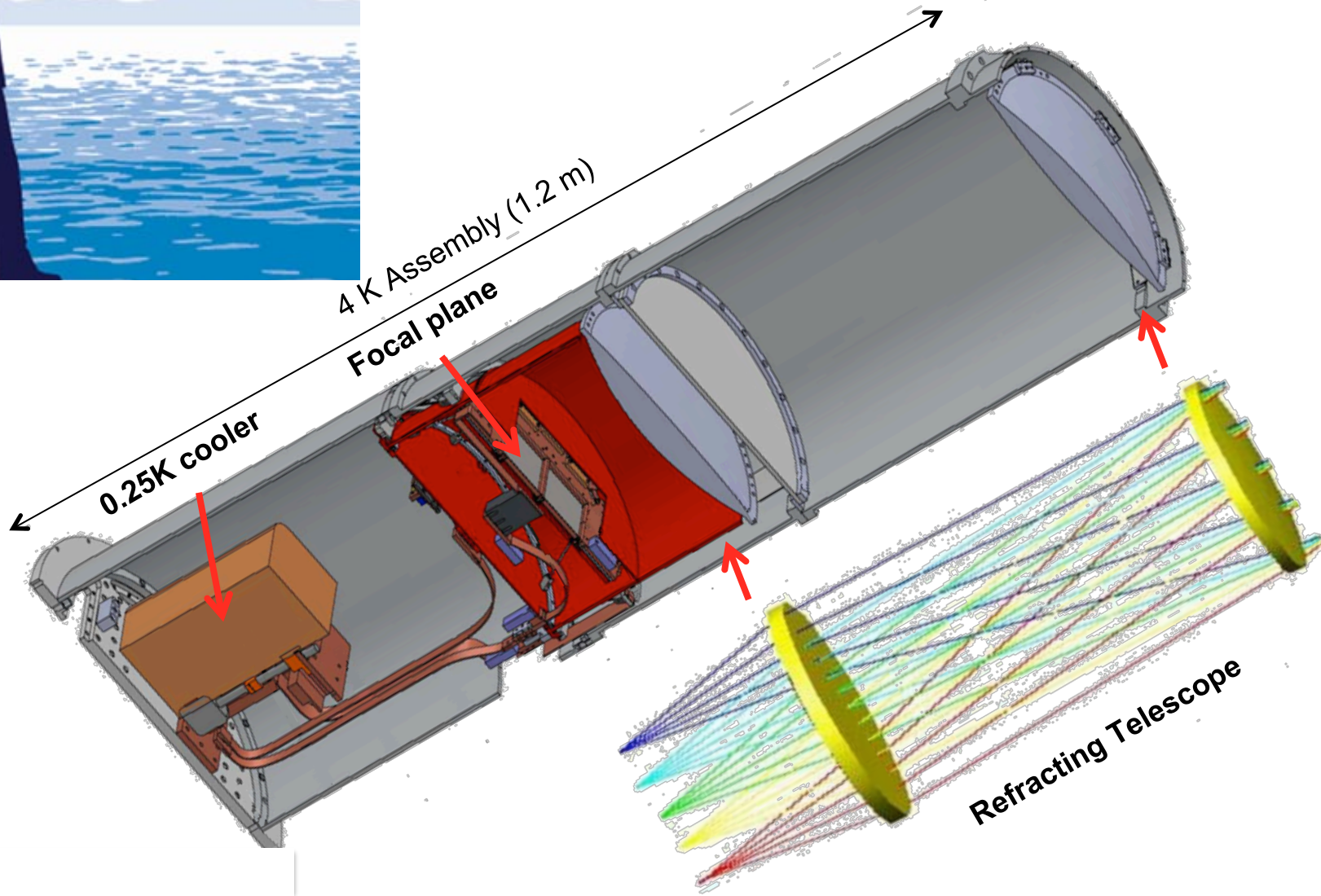
South Pole CMB telescopes



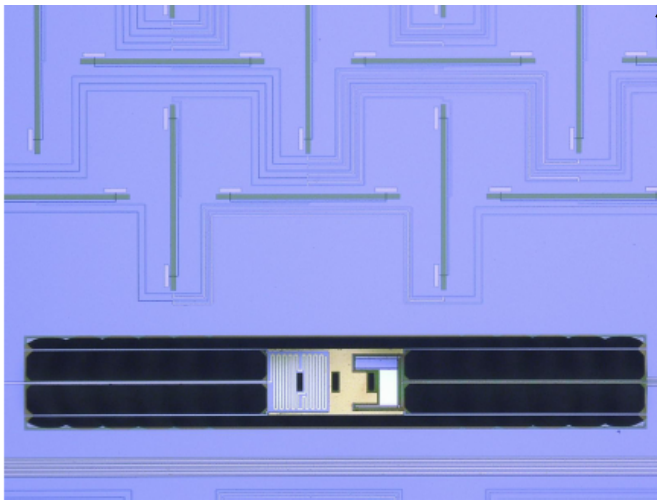
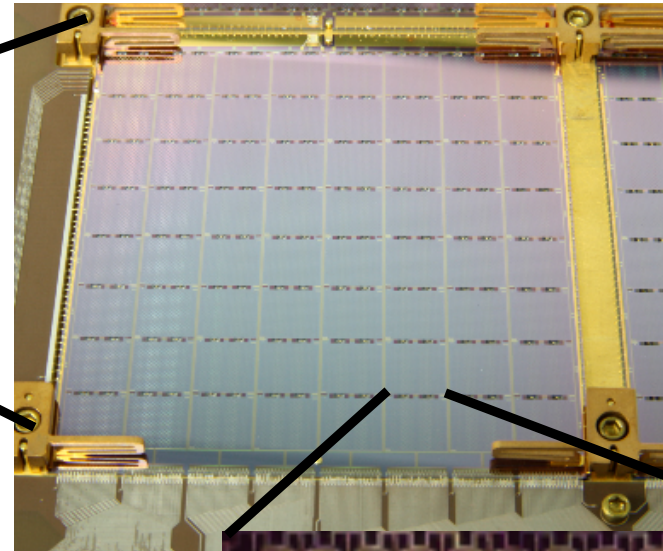
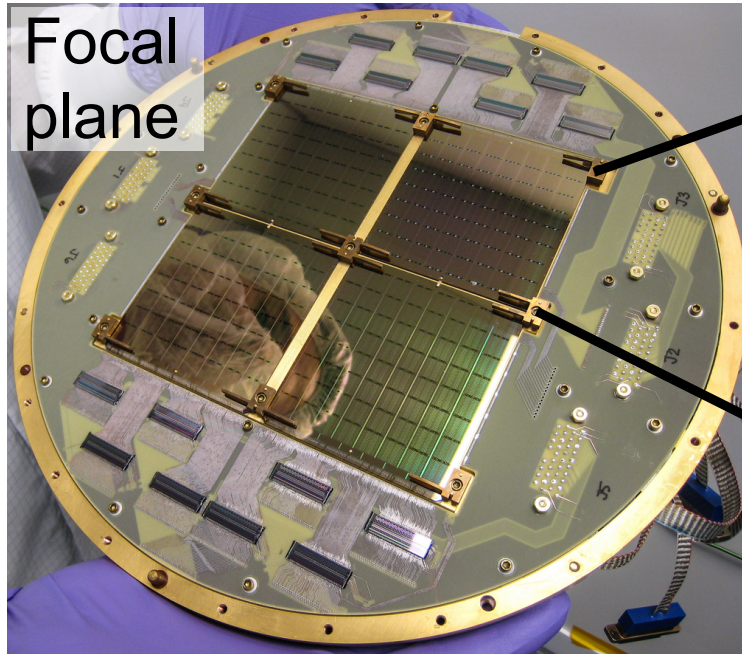
- High and *dry* – see out into space
- On Earth's rotational axis - One day/night cycle per year
 - Long night makes for great quality data
- Good support infrastructure – power, cargo, data comm
- Food and accommodation provided
- Even Tuesday night bingo...

Basic Experiment Design

- Small aperture
- Wide field of view
- Cold refractor



Mass-produced superconducting detectors

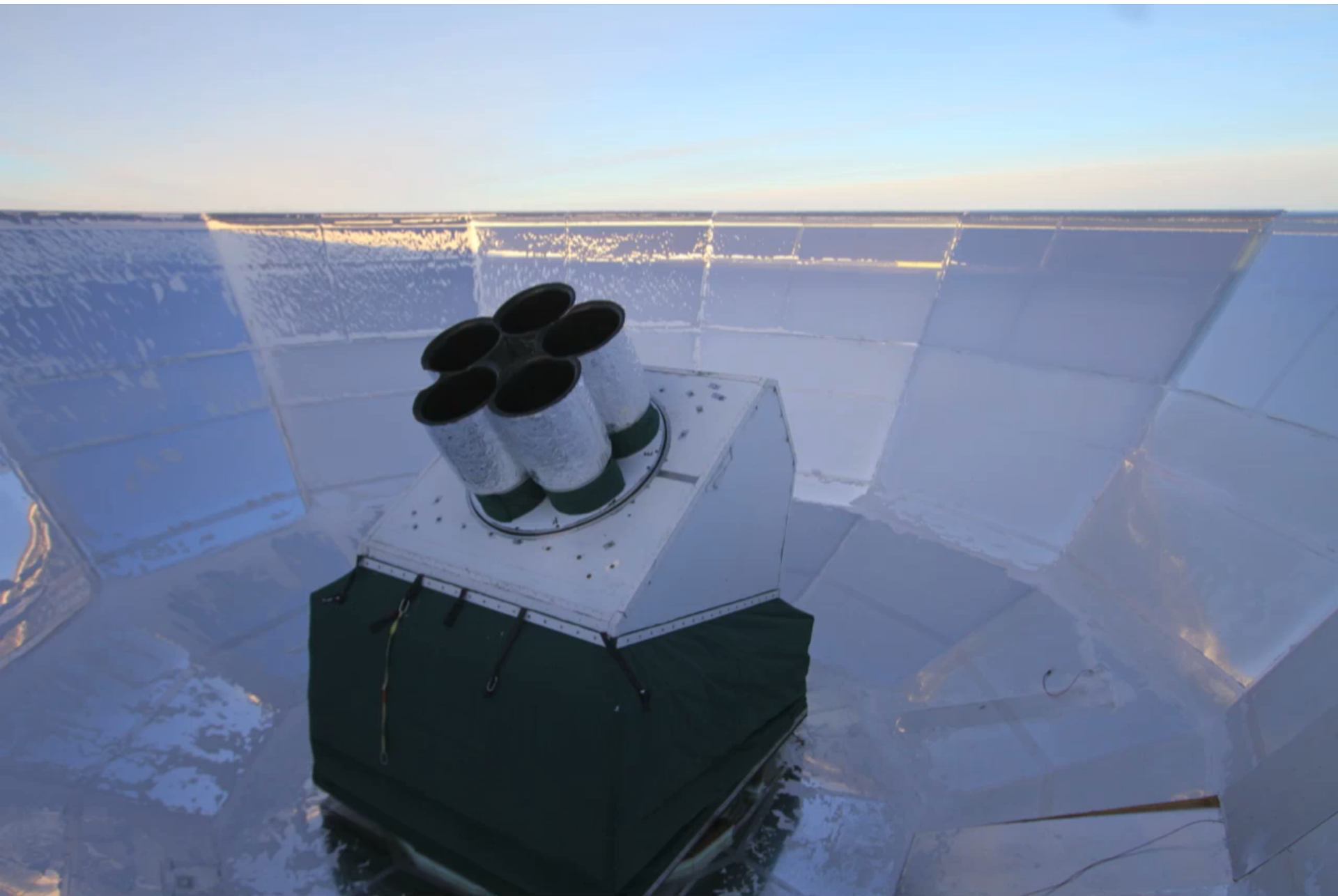


Transition edge sensor

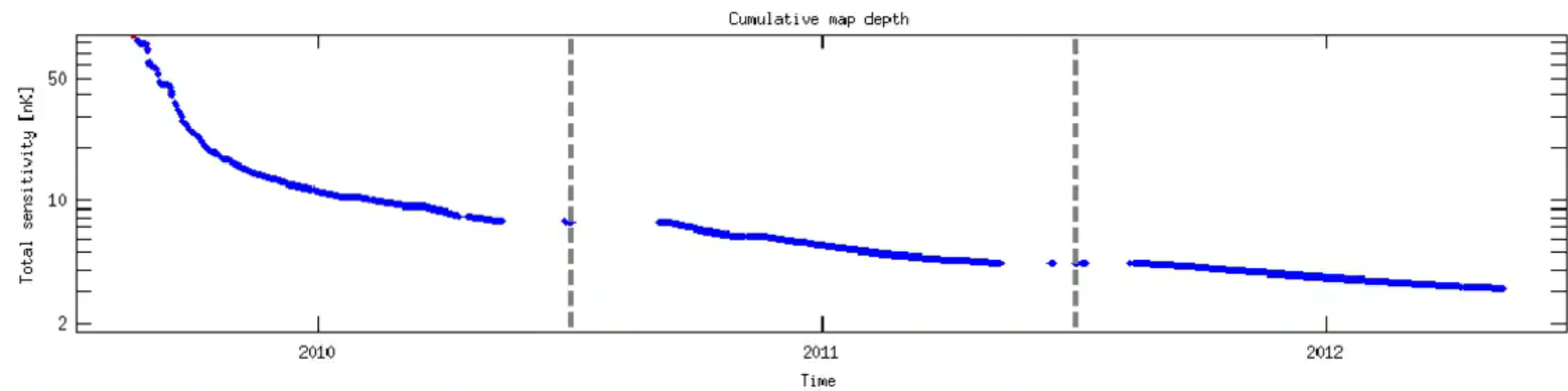
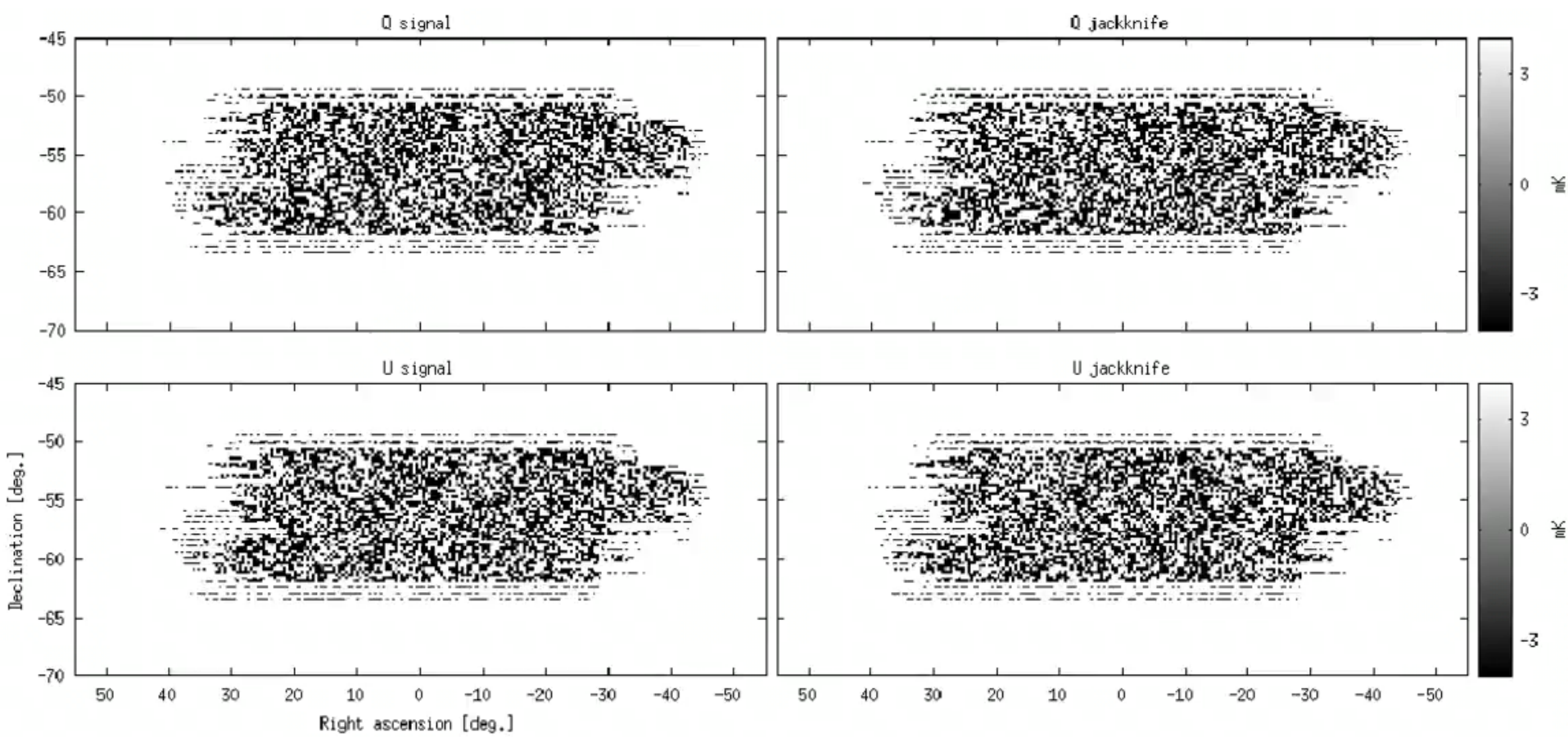
Slot antennas



Microstrip filters



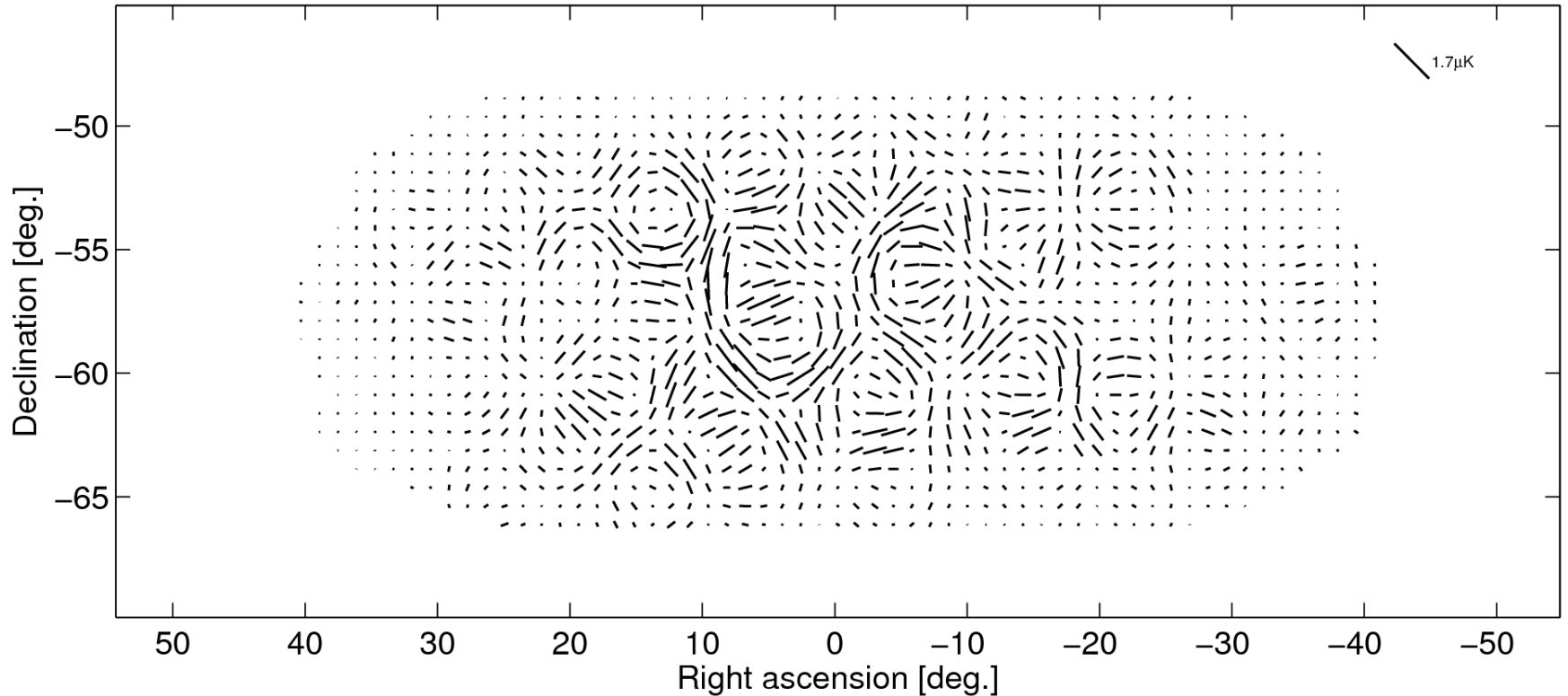
Clem Pryke for The Bicep2 Collaboration



Total Polarization

BICEP2 total polarization signal

Scale: $1.7 \mu K$

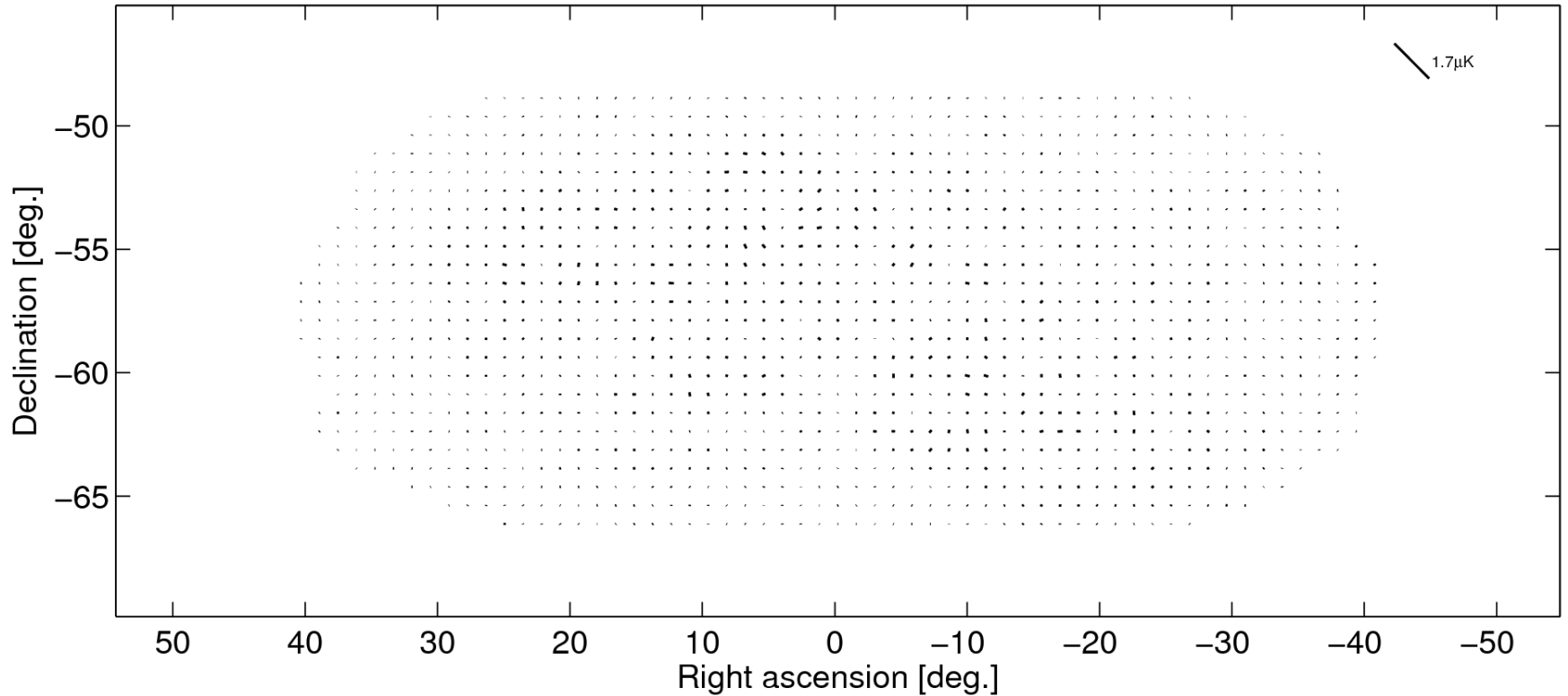


E-mode dominated pattern – no obvious curl component

B-mode Contribution

BICEP2 B-mode signal

Scale: $1.7 \mu K$

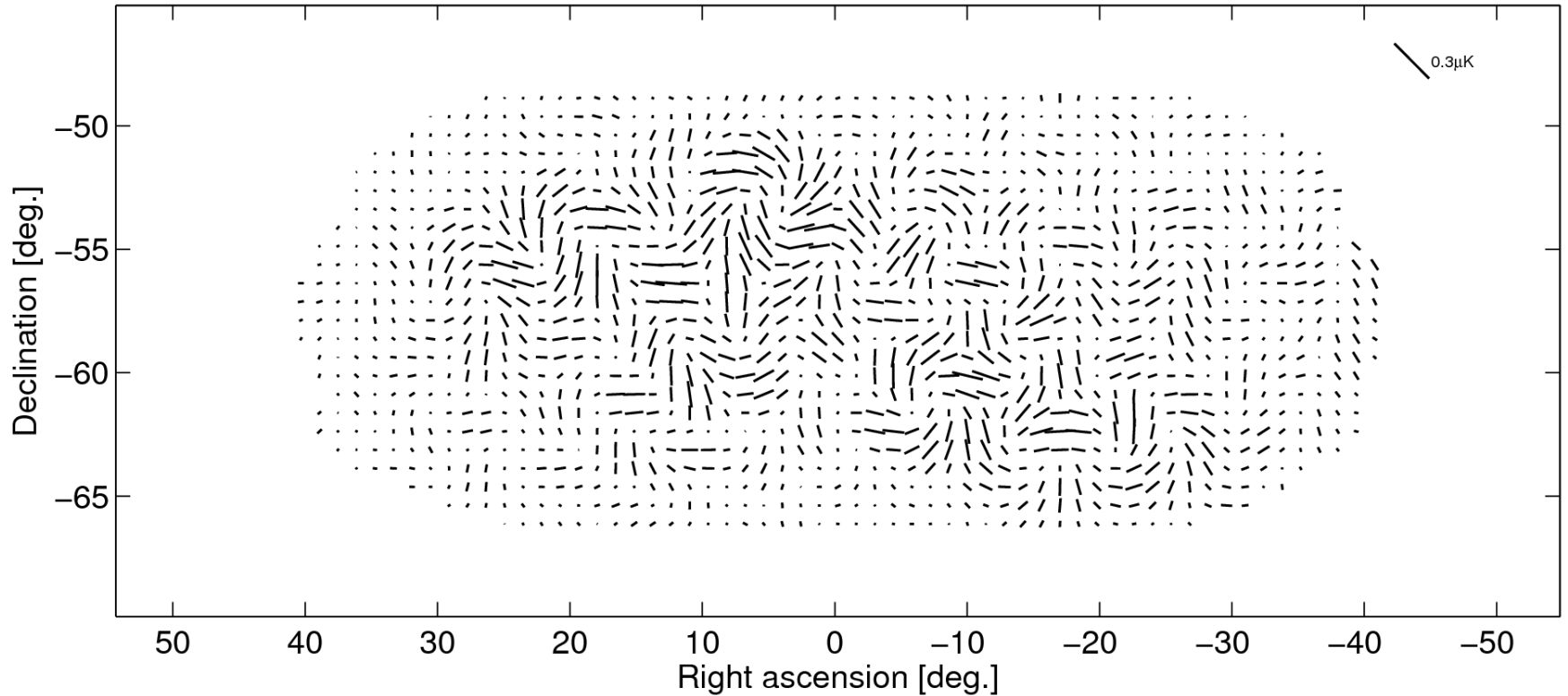


Apply purification operation which leaves only pure B-modes

B-mode Contribution

BICEP2 B-mode signal

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

9.90 THE NETHERLANDS

TUESDAY

USA TODAY
03.18.14

NCAA TOURNAMENT
WHO HAS BEST 'DANCE CARDS'
A look at matchups, players and teams to watch, 5C

UConn tops women's tourney
ANALYSIS, BRACKET, 4C

Putin, U.S. up ante after vote

Sanctions imposed, Ukraine, Russia ready troops as Duma considers Crimea's annexation

'Always hope' missing jet's passengers alive
As search expands to find Malaysia's MH370, Malaysia officials warn that hope of finding plane is faint. **3A**

GM issues three new recalls
New recalls include all plug, cordless systems. GM says recalls affect more than 15 million vehicles. **B**

Homework load unchanged
Despite parents' concerns about more work, study finds burden has barely changed over 30 years. **3A**

How Angela earned her big, bad wings
To play 'Mad Max: Fury Road' to glory, actress Jessica Chastain had to go 'to the bone' on a diet that nearly cost her her sanity. **2B**

SOUTH POLAR VIEW
The best place to view comets, the South Pole offers a unique view of the southern sky. **2B**

HOME DELIVERY
1-800-877-3000
MAILORDERMAGAZINES.COM

Prisons hire drugs, use study pharmacies, try untested medicines
Gregg Groves
Prisons should not do this. **6C**

EXERCISE METHODS SINCE 1976
They were called aerobics, but the fitness craze has evolved into a billion-dollar industry. **2C**



"All the News, That Fits Ya!"

The New York Times

Vol. CLXXIII, No. 56,444 TUESDAY, MARCH 18, 2014 \$2.50



RUSSIAN PRESIDENT Vladimir Putin (left) and Chinese Premier Li Keqiang (right) meet with other leaders at the BRICS summit in Beijing. **Page A8.**

Lost Jet's Path Seen as Altered

Via a Computer

By PATRICK L. WALSH and PHILIP J. SCHWARTZ
WASHINGTON — The first serious view that the missing Malaysia Airlines plane was altered in its path from the crash site to the island of Sumatra, Indonesia, was revealed by a computer program that traced the flight path of the plane. The program, which was developed by a team of researchers, found that the plane's path was altered in a way that suggests it was hijacked. The researchers believe that the plane was hijacked by a group of people who were trying to reach the island of Sumatra. The researchers also found that the plane was flying at a lower altitude than it should have been, which suggests that it was being controlled by someone on the ground. The researchers believe that the plane was hijacked by a group of people who were trying to reach the island of Sumatra. The researchers also found that the plane was flying at a lower altitude than it should have been, which suggests that it was being controlled by someone on the ground.

Space Ripples Reveal Big Bang's Smoking Gun

By DENNIS OVERBYE
CAMBRIDGE, Mass. — The light left in 2013 an important piece of evidence that the Big Bang really happened. Scientists have found a "smoking gun" in the form of space ripples that were created by the Big Bang. The ripples, which are called B-modes, were discovered by a team of researchers using a satellite called Planck. The researchers found that the ripples were created by the Big Bang, which is the strongest evidence yet that the Big Bang really happened. The researchers also found that the ripples were created by the Big Bang, which is the strongest evidence yet that the Big Bang really happened.

PUTIN RECOGNIZES CRIMEA SECESSION, DEFYING THE WEST

Decree Increases Fears of Annexation by Russia, Despite More Sanctions

By STEVEN LEVITSKY and PETER BAKER
Moscow and The Hague, Netherlands — Vladimir Putin's decree on Tuesday recognizing Crimea's secession from Ukraine and its annexation by Russia was a major step toward the annexation of the peninsula, which has been a major goal of Russian foreign policy since 2012. The decree, which was signed by Putin, recognized the independence of Crimea and transferred the peninsula to Russian control. The move was widely expected, but it was still a significant step toward the annexation of the peninsula. The move was widely expected, but it was still a significant step toward the annexation of the peninsula. The move was widely expected, but it was still a significant step toward the annexation of the peninsula.

FINANCIAL TIMES

The Apple alumni
Steve Jobs' acolytes are taking over the world, Page 8

The trouble with tinkering with textbooks
Gideon Rachman, Page 7

Sanctions hit Russian top brass

EU and US take action • More severe measures prepared • Putin lays out Crimea demands

By Chris Chantler in Brussels and David S. Johnston in London
The European Union and the United States have imposed sanctions on a number of Russian officials, including members of the Russian government and military. The sanctions are aimed at punishing those who are responsible for the annexation of Crimea. The sanctions include freezing assets and banning travel. The sanctions are aimed at punishing those who are responsible for the annexation of Crimea. The sanctions include freezing assets and banning travel. The sanctions are aimed at punishing those who are responsible for the annexation of Crimea. The sanctions include freezing assets and banning travel.

Bicep 2's 'ripples' add muscle to Big Bang

By Chris Chantler in London
The discovery of space ripples in the Cosmic Microwave Background radiation adds to the evidence that the Big Bang really happened. The ripples, which are called B-modes, were discovered by a team of researchers using a satellite called Planck. The researchers found that the ripples were created by the Big Bang, which is the strongest evidence yet that the Big Bang really happened. The researchers also found that the ripples were created by the Big Bang, which is the strongest evidence yet that the Big Bang really happened.

New dawn for breakfast as disease and speculation push price rises

By Colin Tappin in London
The price of breakfast cereals has risen sharply in recent months, due to a combination of factors. One of the main reasons is the increase in the price of wheat, which is used to make cereals. Another reason is the increase in the price of sugar, which is also used in cereals. The price of cereals is expected to continue to rise in the coming months. The price of cereals is expected to continue to rise in the coming months.



Gravitational waves are detected by the LIGO observatory. **Page 2B.**

宇宙急速膨張の証拠、検出される

Telescope captures view of gravitational waves

宇宙の急速な膨張を示す証拠が、重力波の観測によって見つけられました。重力波は、時空の歪みによって生じる波であり、光速で伝わるため、遠くまで伝わるようになります。重力波の観測は、宇宙の急速な膨張を示す重要な証拠です。重力波の観測は、宇宙の急速な膨張を示す重要な証拠です。重力波の観測は、宇宙の急速な膨張を示す重要な証拠です。重力波の観測は、宇宙の急速な膨張を示す重要な証拠です。



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PHYSICAL REVIEW LETTERS

Articles published week ending 20 JUNE 2014

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PHYSICAL REVIEW LETTERS

20 JUNE 2014

Actually not a lot of fun...

PHYSICAL REVIEW LETTERS

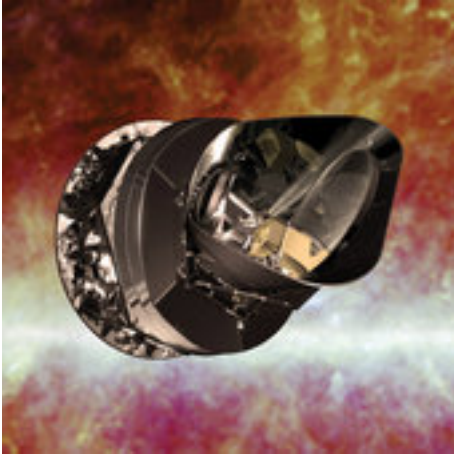
Articles published week ending 20 JUNE 2014

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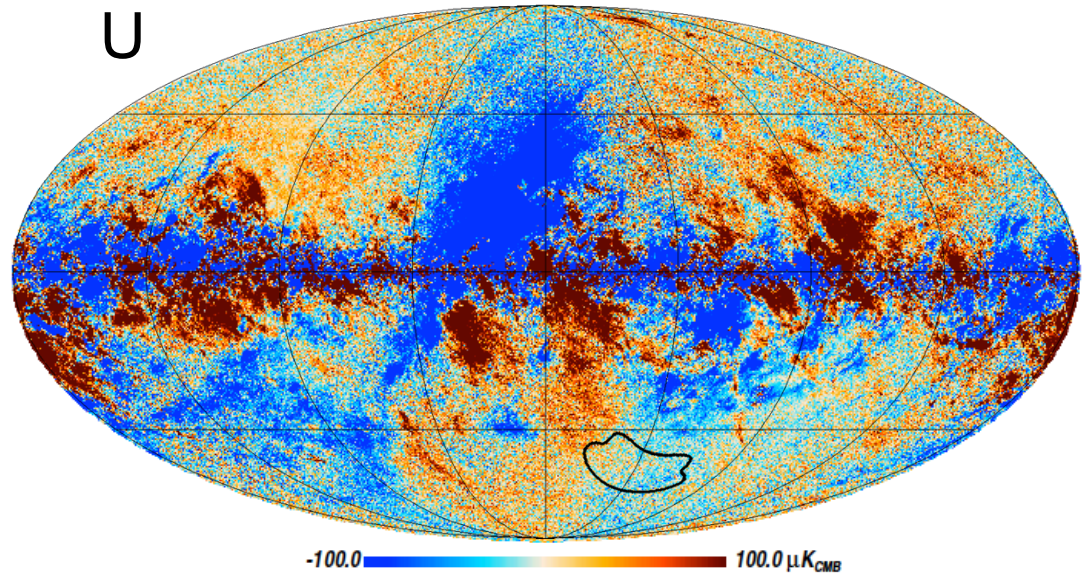
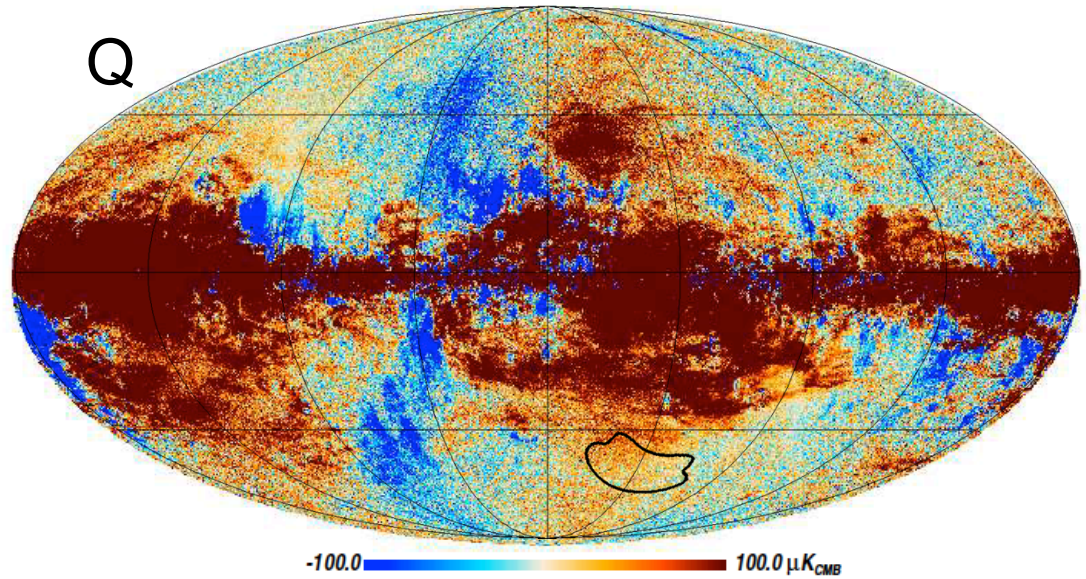
PHYSICAL REVIEW LETTERS

20 JUNE 2014

Planck maps of dust emission from our galaxy



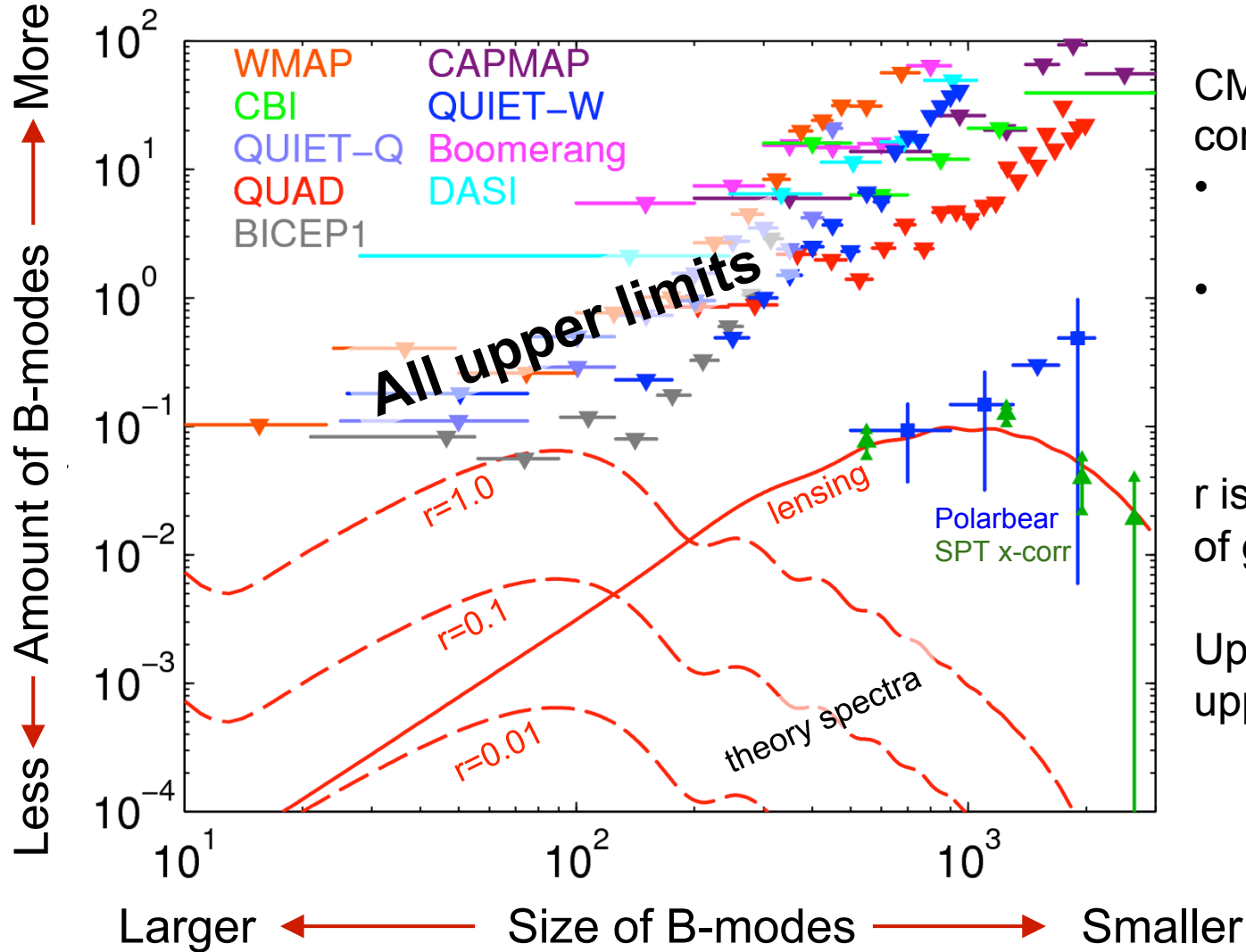
Planck was a billion dollar Euro/NASA space mission



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



Colin Bischoff



Jeff Filippini



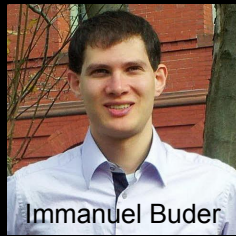
Martin Lueker



Walt Ogburn



Abigail Viereggs



Immanuel Buder



Stefan Fliescher



Roger O'Brient



Angiola Orlando



Zak Staniszewski

The BICEP2 Graduate Students



Randol Aikin



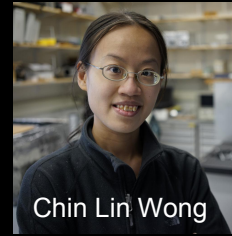
Justus Brevik



Chris Sheehy



Grant Teply



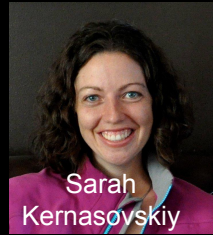
Chin Lin Wong



Kirit Karkare



Jon Kaufman



Sarah
Kernasovskiy



Jamie Tolan

BICEP2 Winterovers



Steffen Richter

2010



Steffen Richter

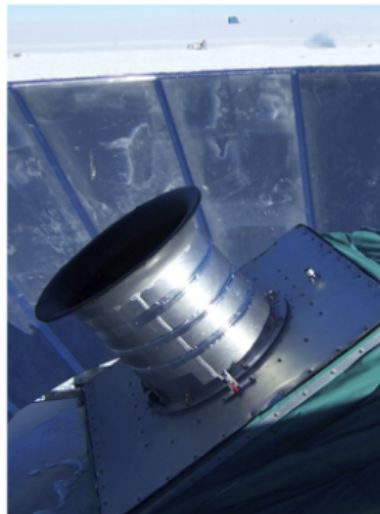
2011



Steffen Richter

2012

BICEP1
(2006 - 8)



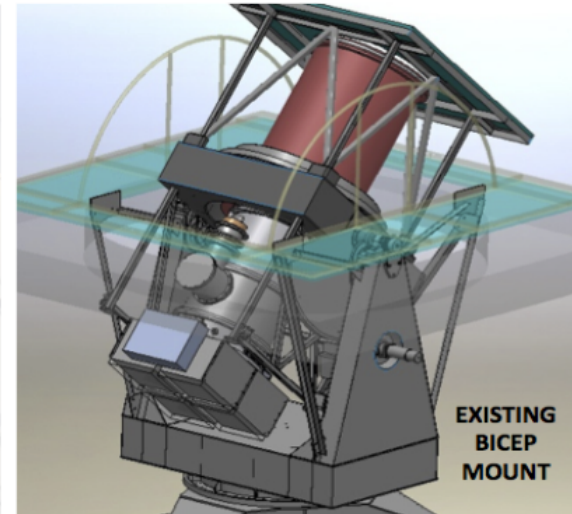
BICEP2
(2010 - 12)



Keck Array
(2011 -)

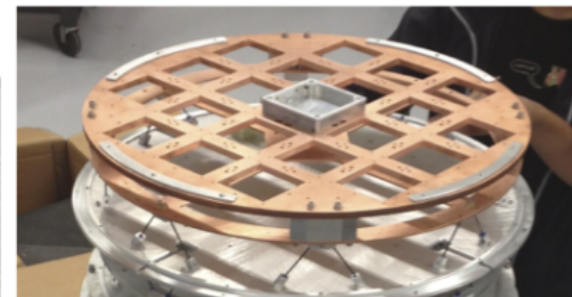
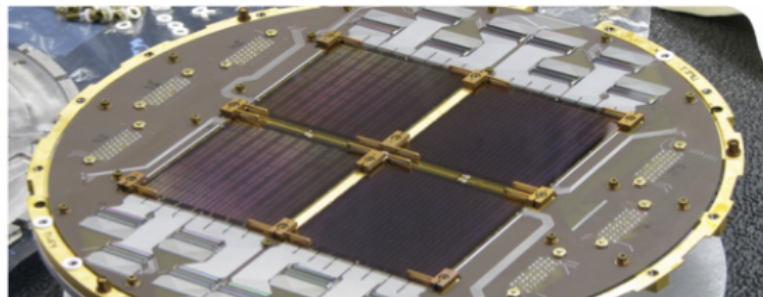
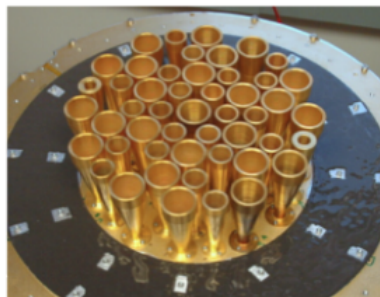


BICEP3
(2014 -)

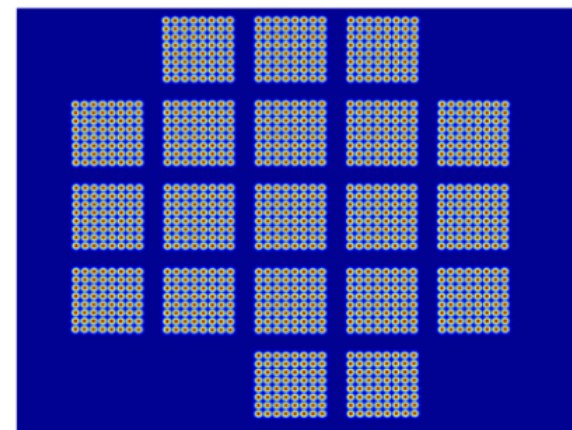
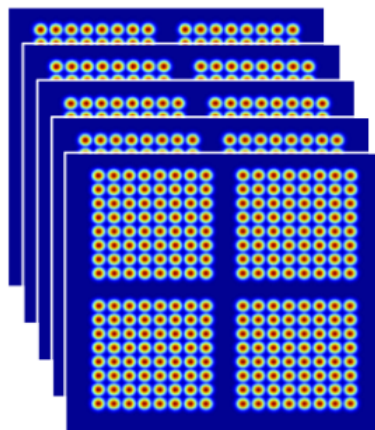
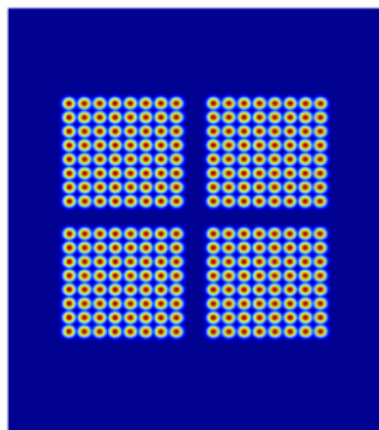
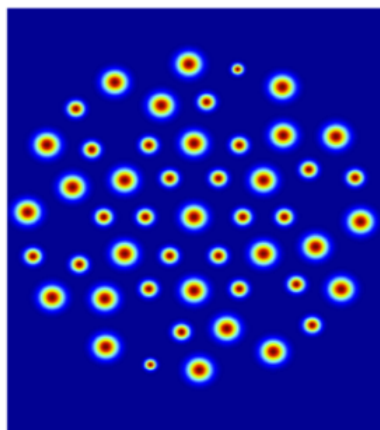


Telescope and Mount

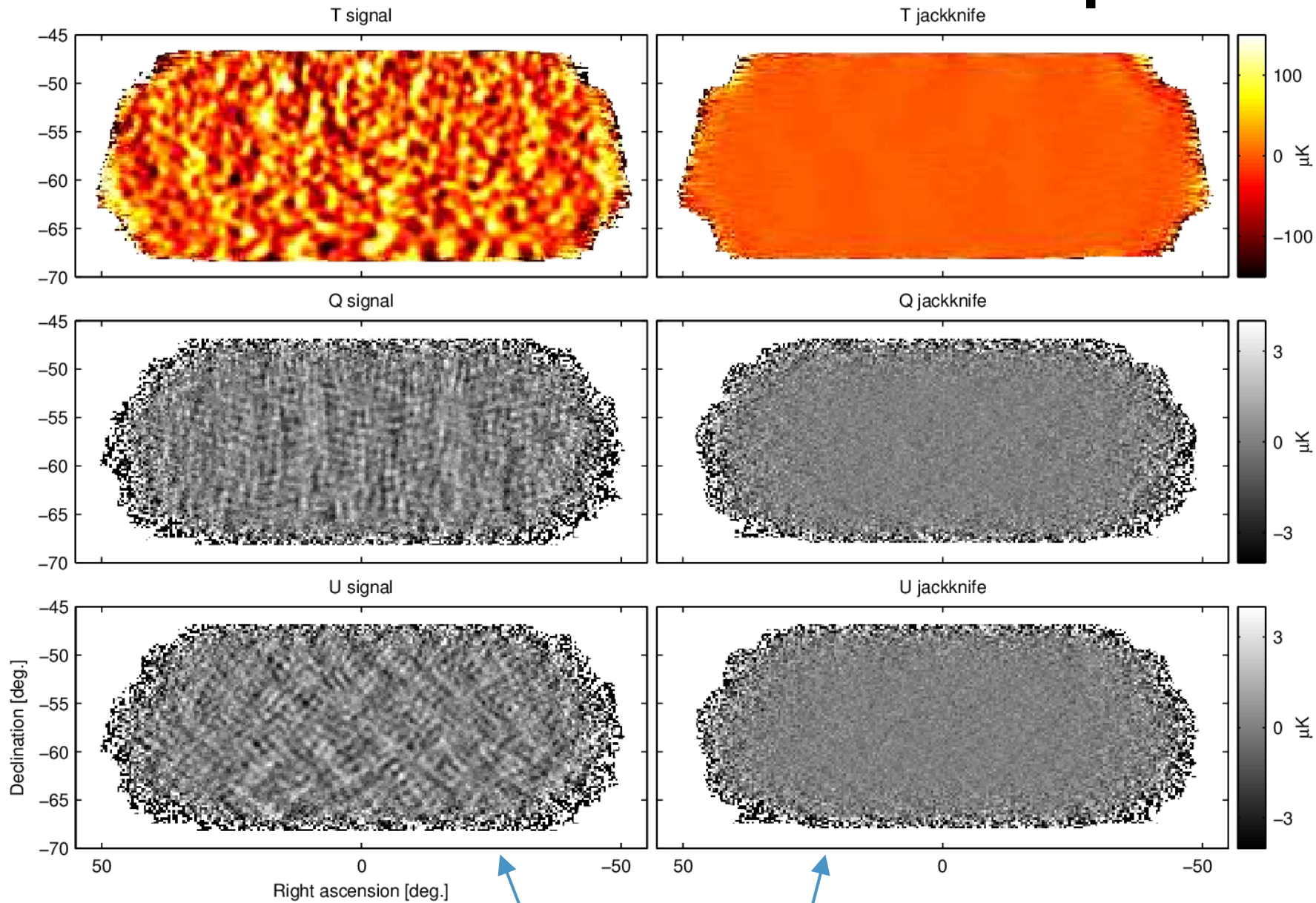
Focal Plane



Beams on Sky



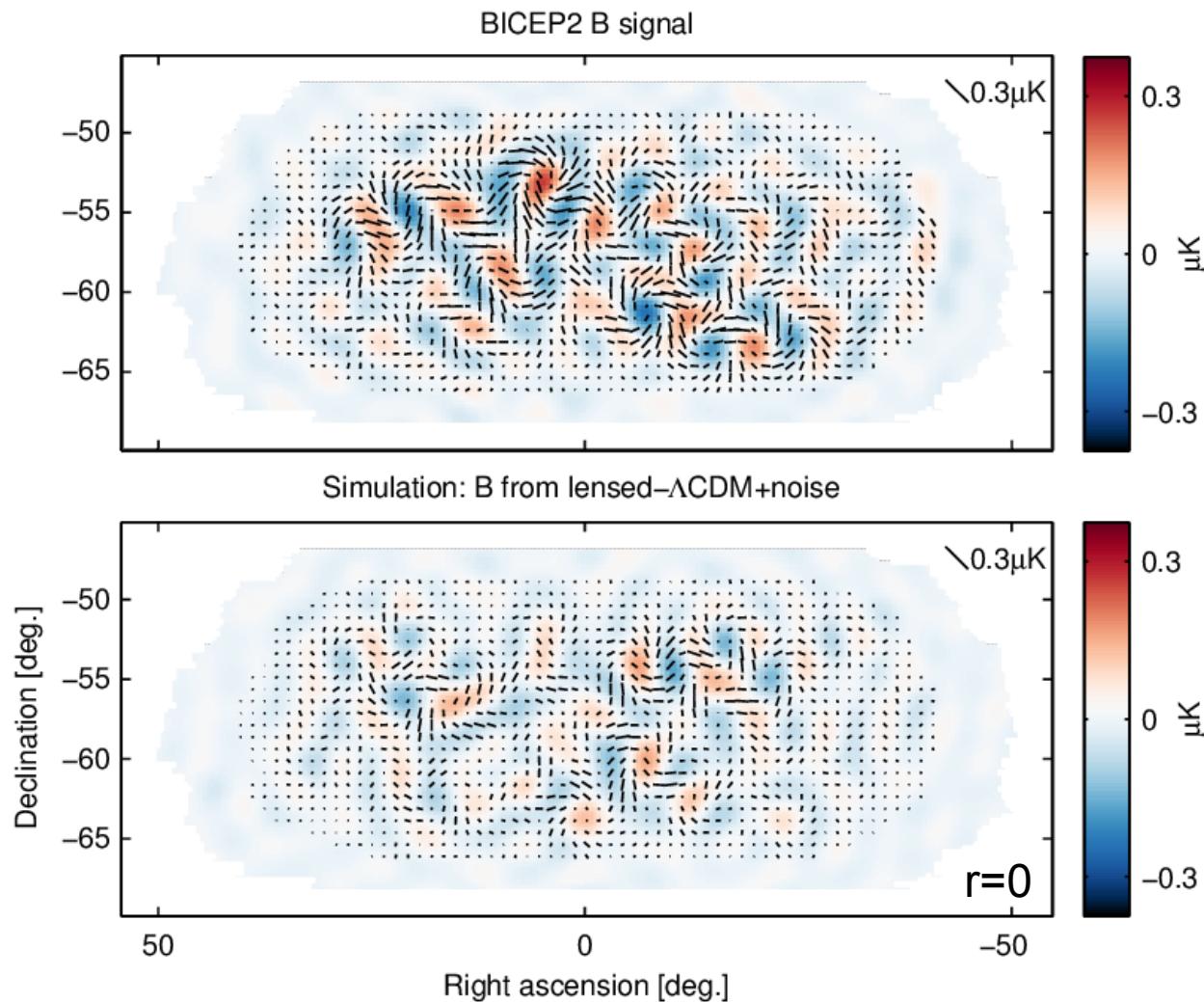
BICEP2 T and Stokes Q/U Maps



Sum Maps

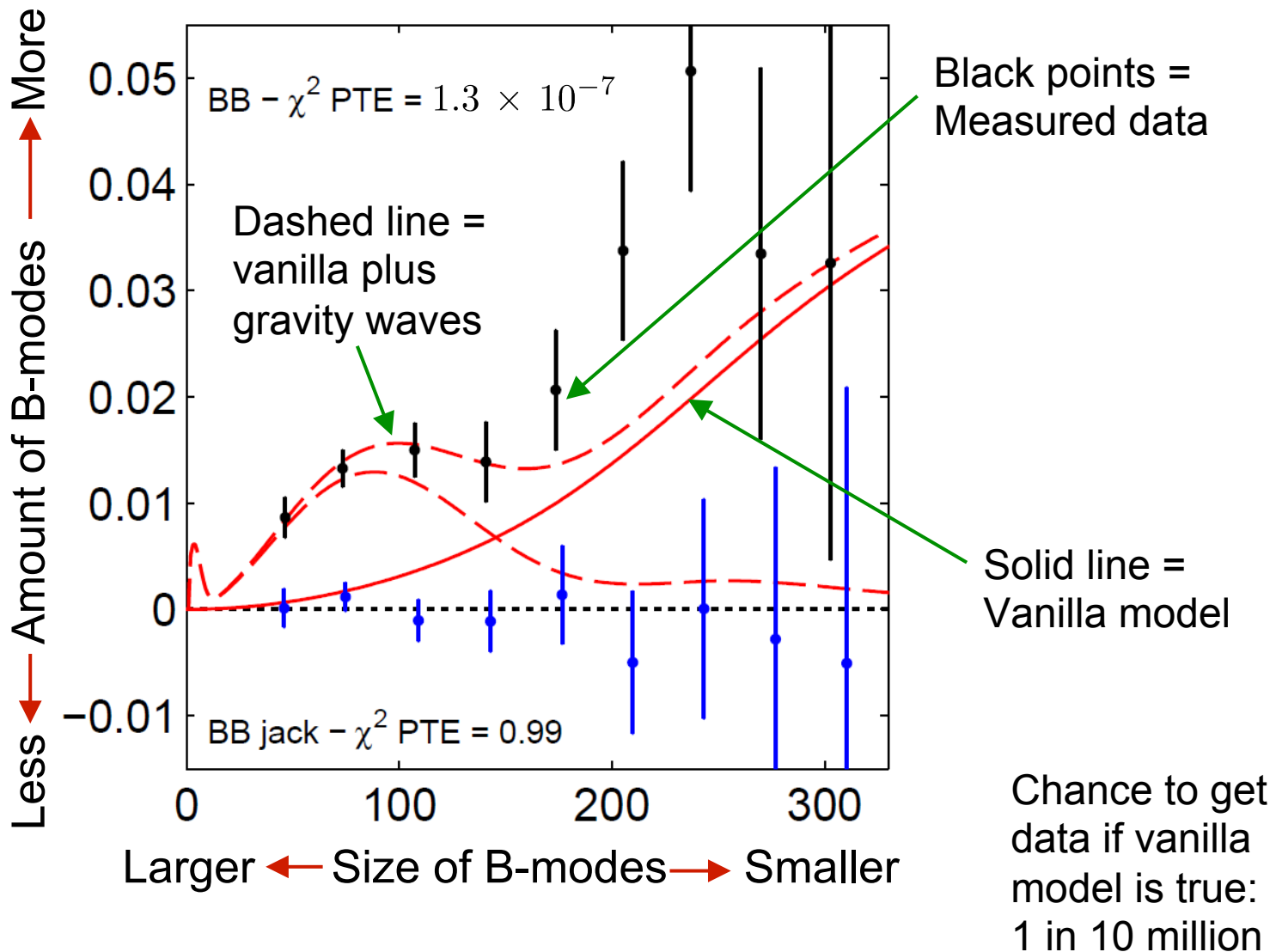
Difference Maps

Real B-mode Map vs. Simulation



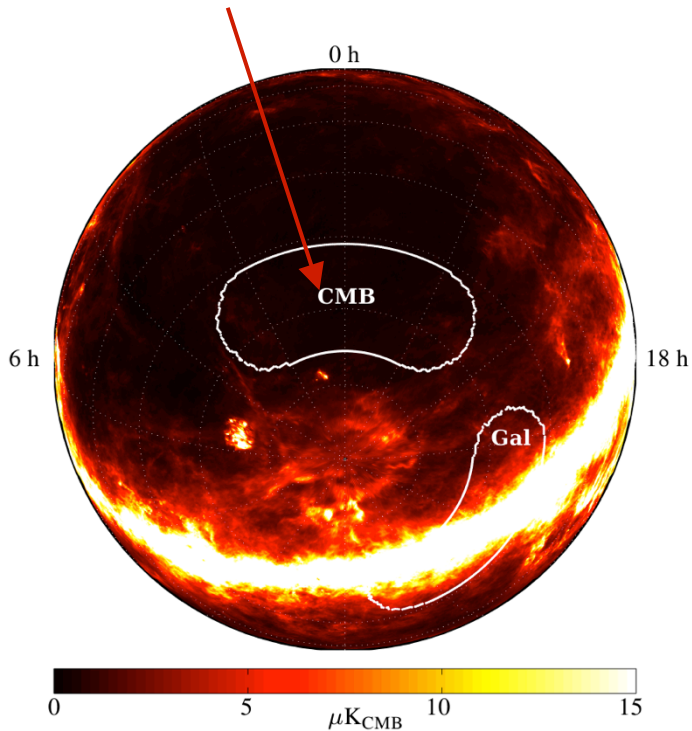
Way more B-modes in the real map (upper) than in simulations containing vanilla model plus experimental noise (lower)

BICEP2 B-mode Power Spectrum



Foreground Contamination from Our Galaxy

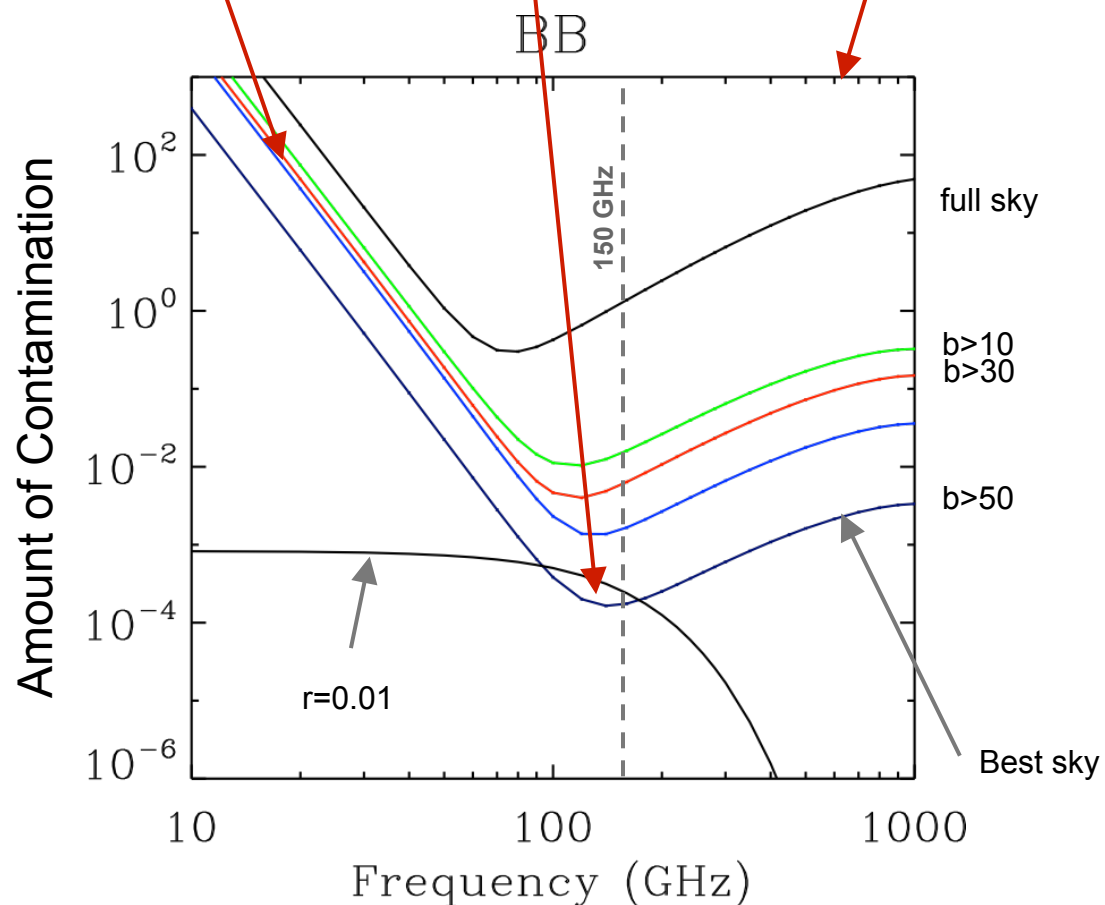
Pick a clean patch of sky



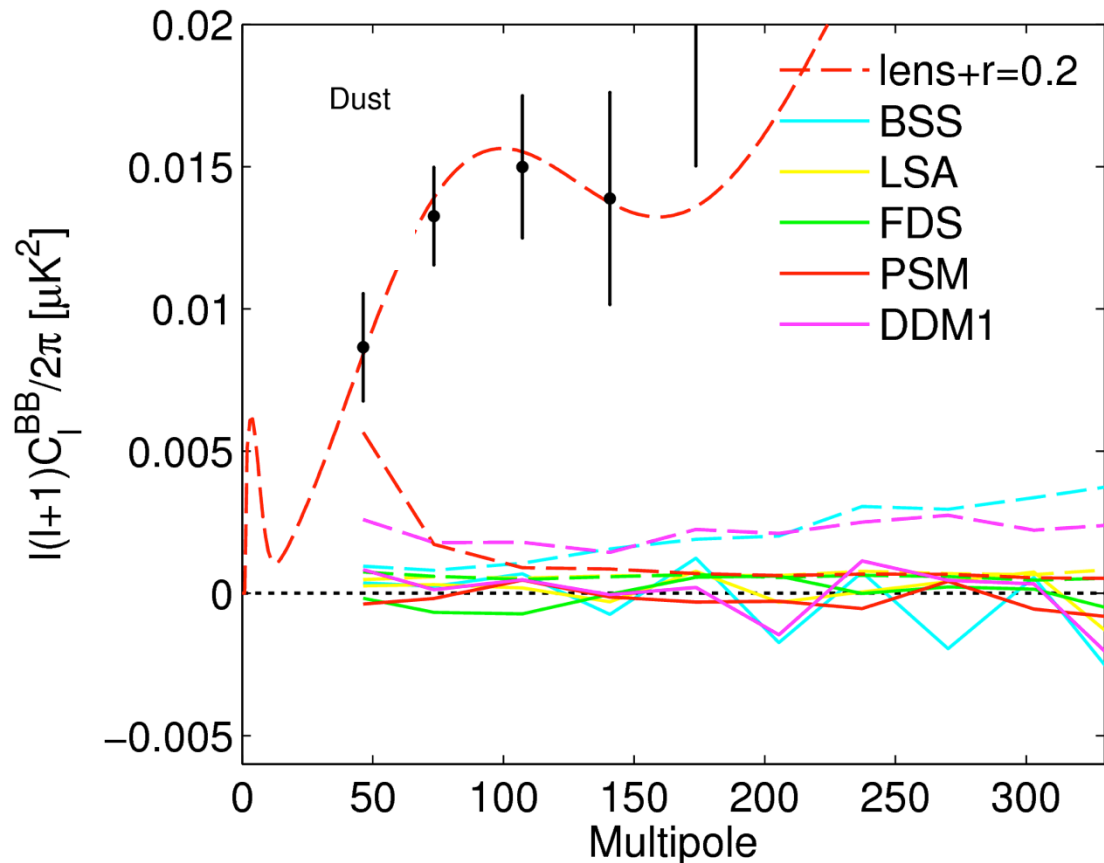
At low frequency
synchrotron
contamination

Sweetest spot

At high frequency **dust**
contamination



Pre-Planck Polarized Dust Foreground Projections



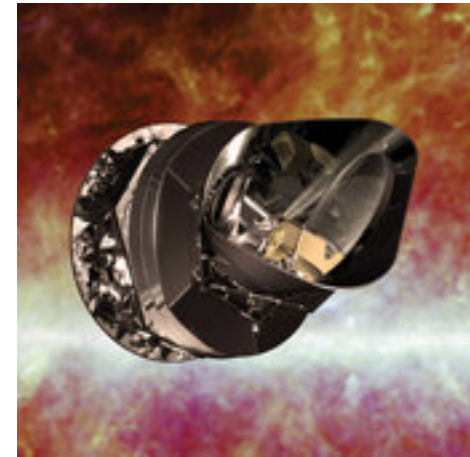
The BICEP2 observation region was chosen on the basis of extremely low unpolarized dust contamination

Used various models of polarized dust emission to estimate dust contamination

Result: All well below observed signal level

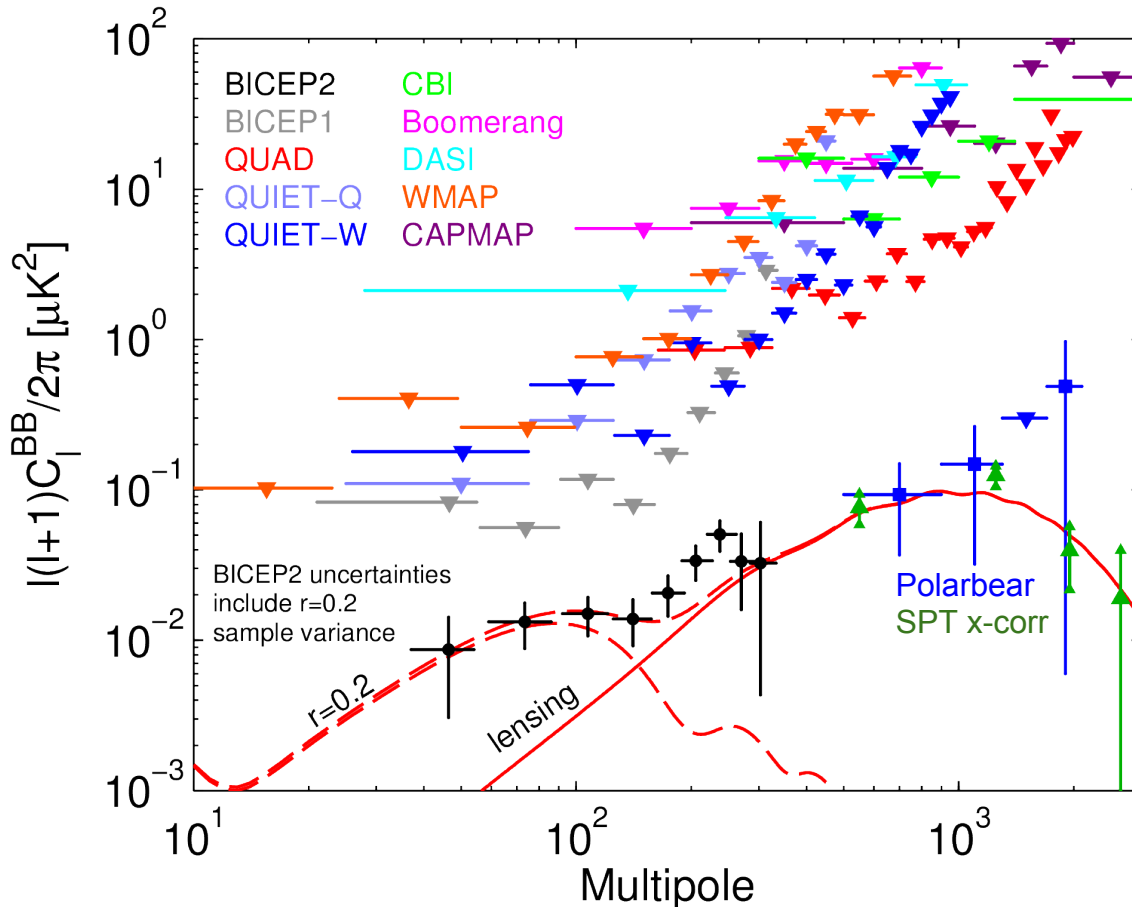
But considerable uncertainty in these models...

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:



Really looked like we'd found gravitational waves from inflation

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

<http://bicepkeck.org>