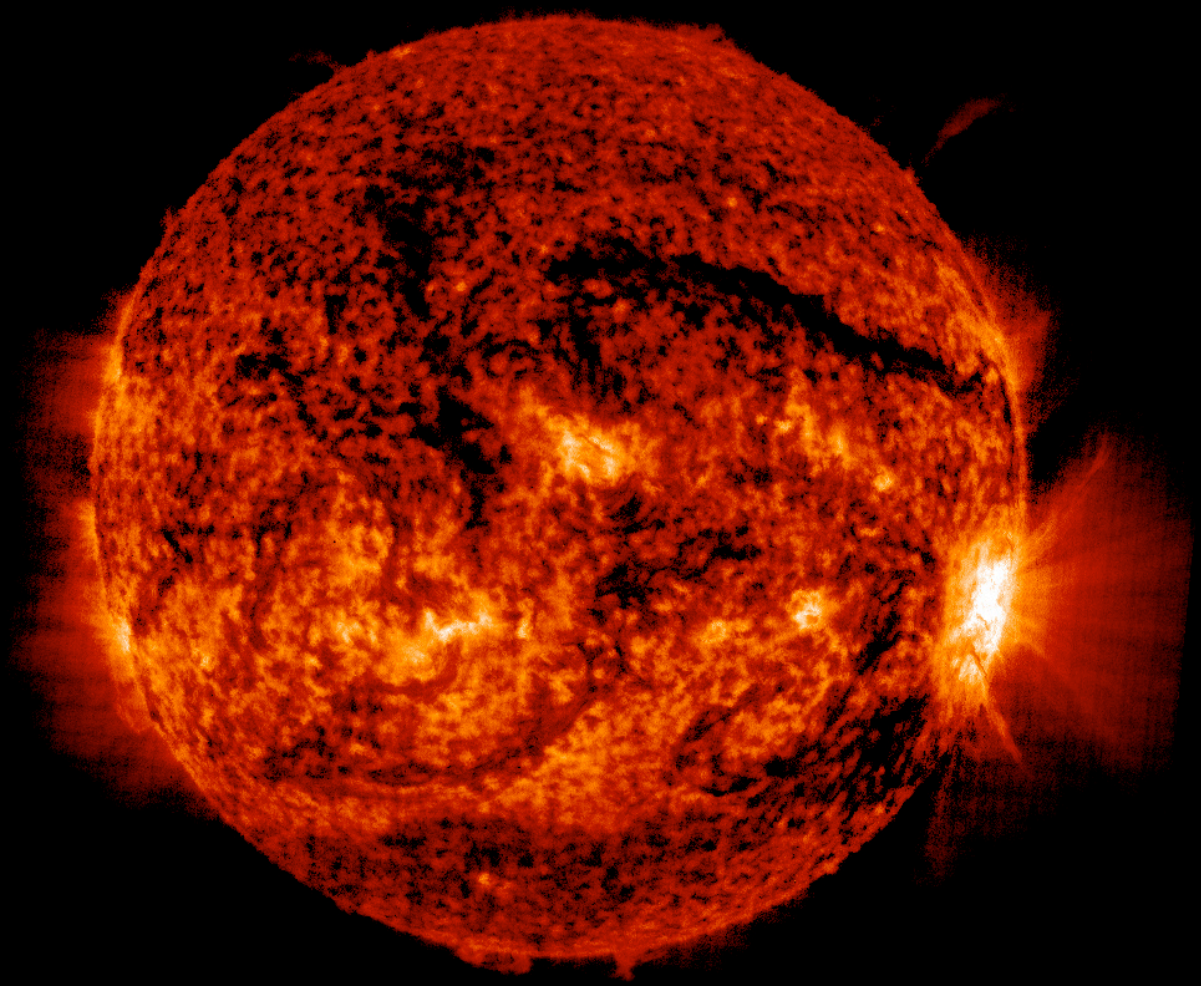
Viewing the Beginning of the Universe from the Bottom of the World

Clem Pryke – Physics Dept. Open House – Nov 3 2016

Our Sun is a Star

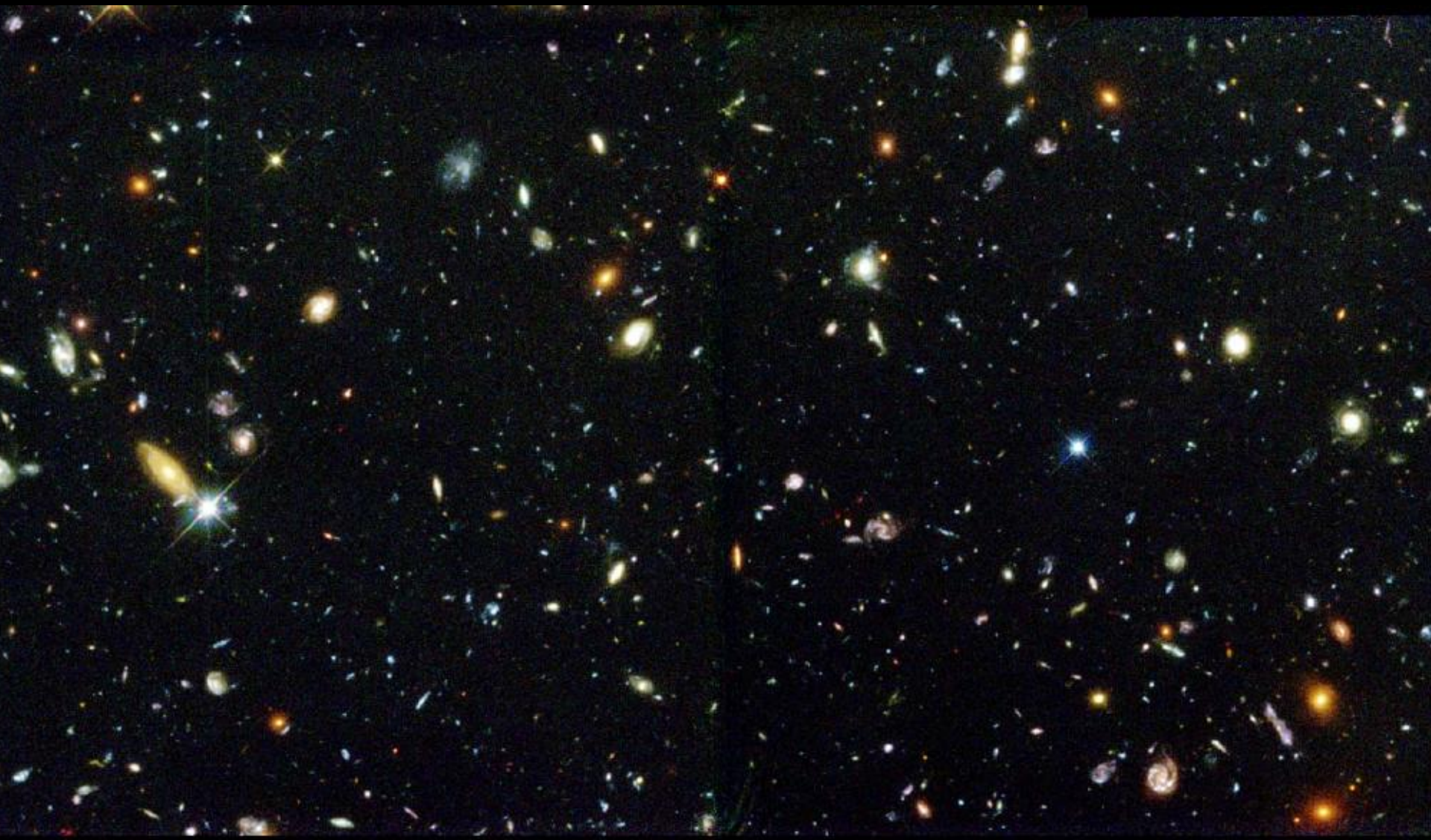


(Just an ordinary star)

…Many stars make a galaxy…

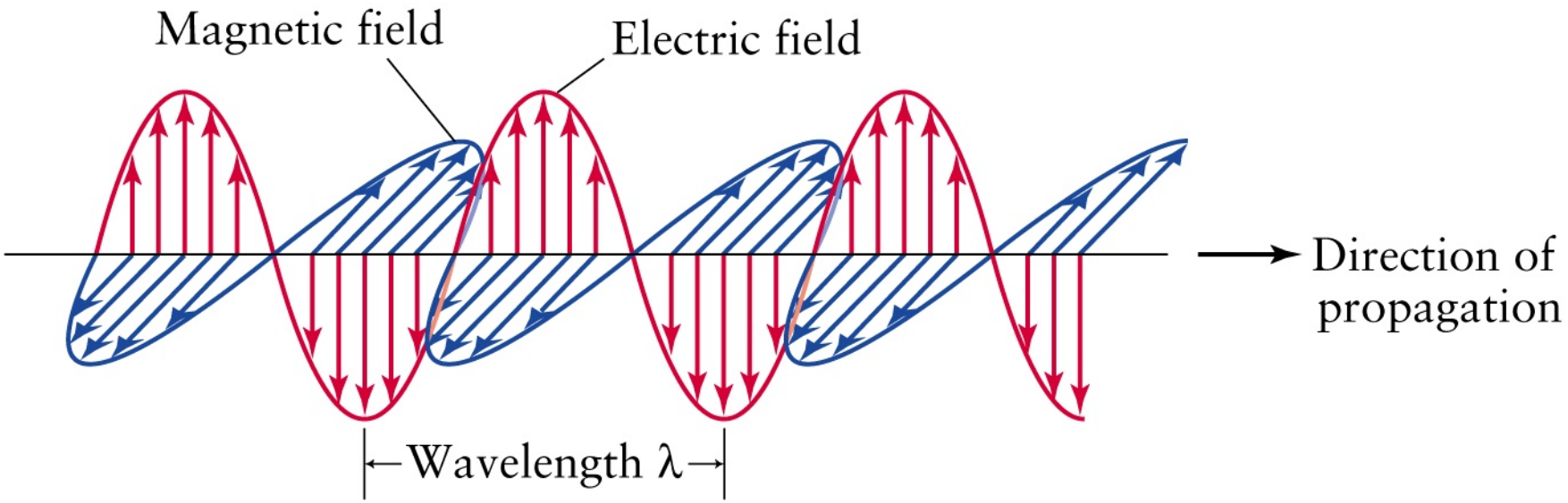
(A nearby galaxy similar to ours)

…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

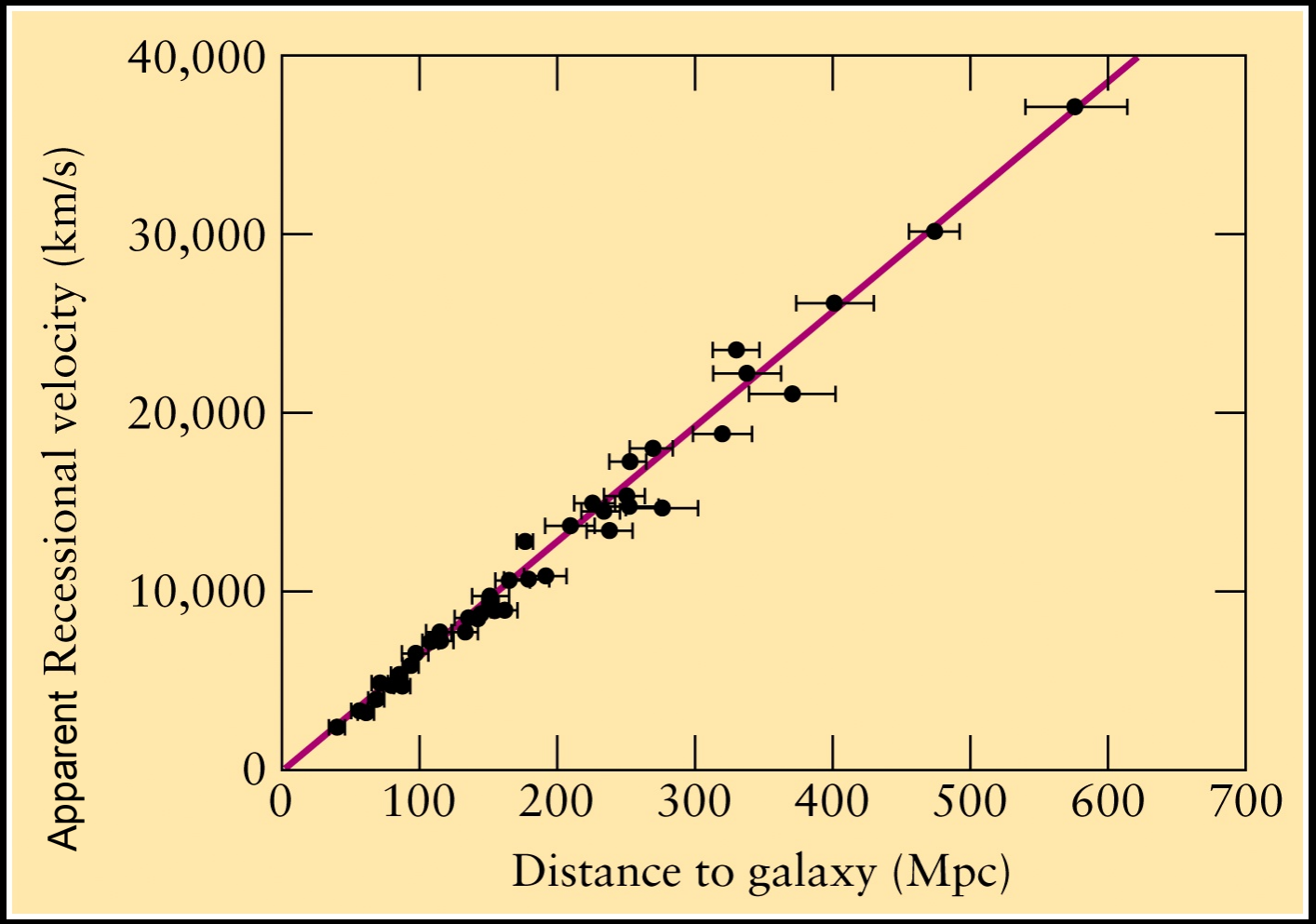
“Classic” Doppler Effect

- 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

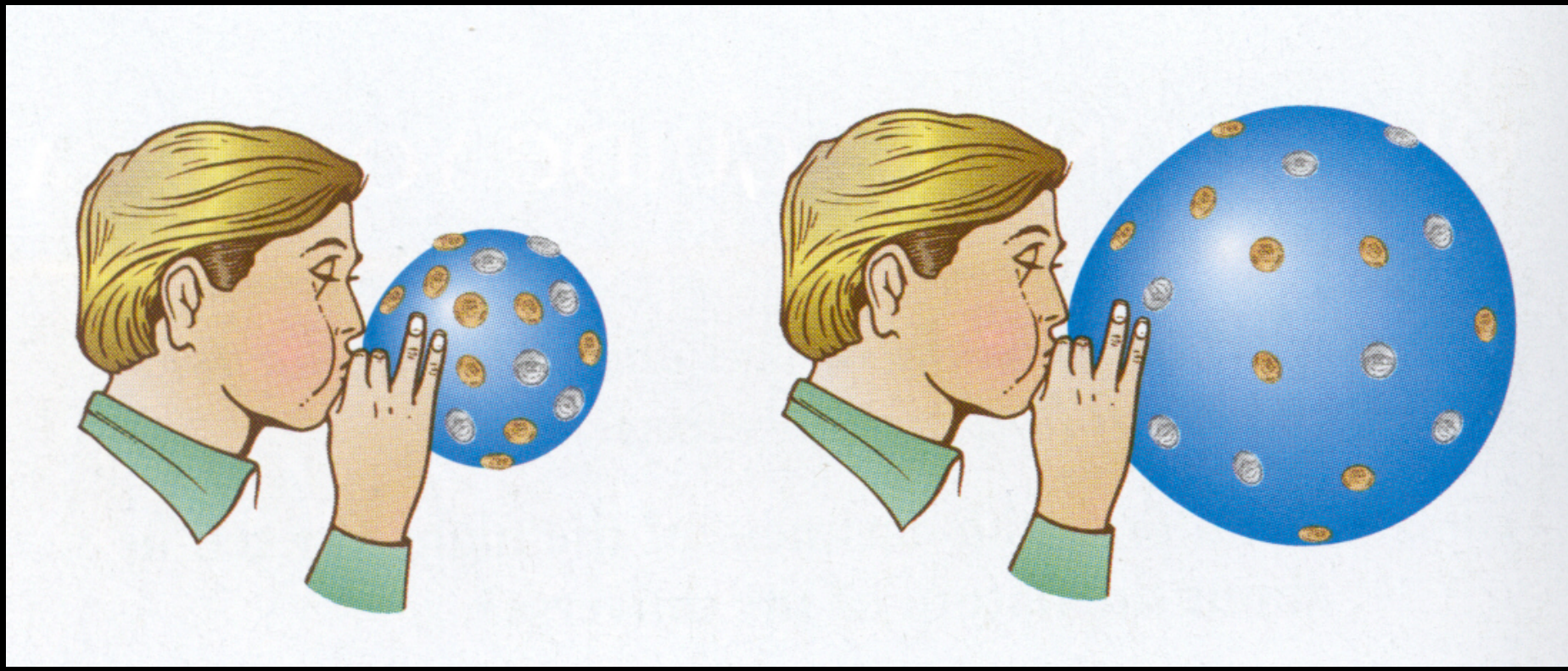
Hubble Diagram



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

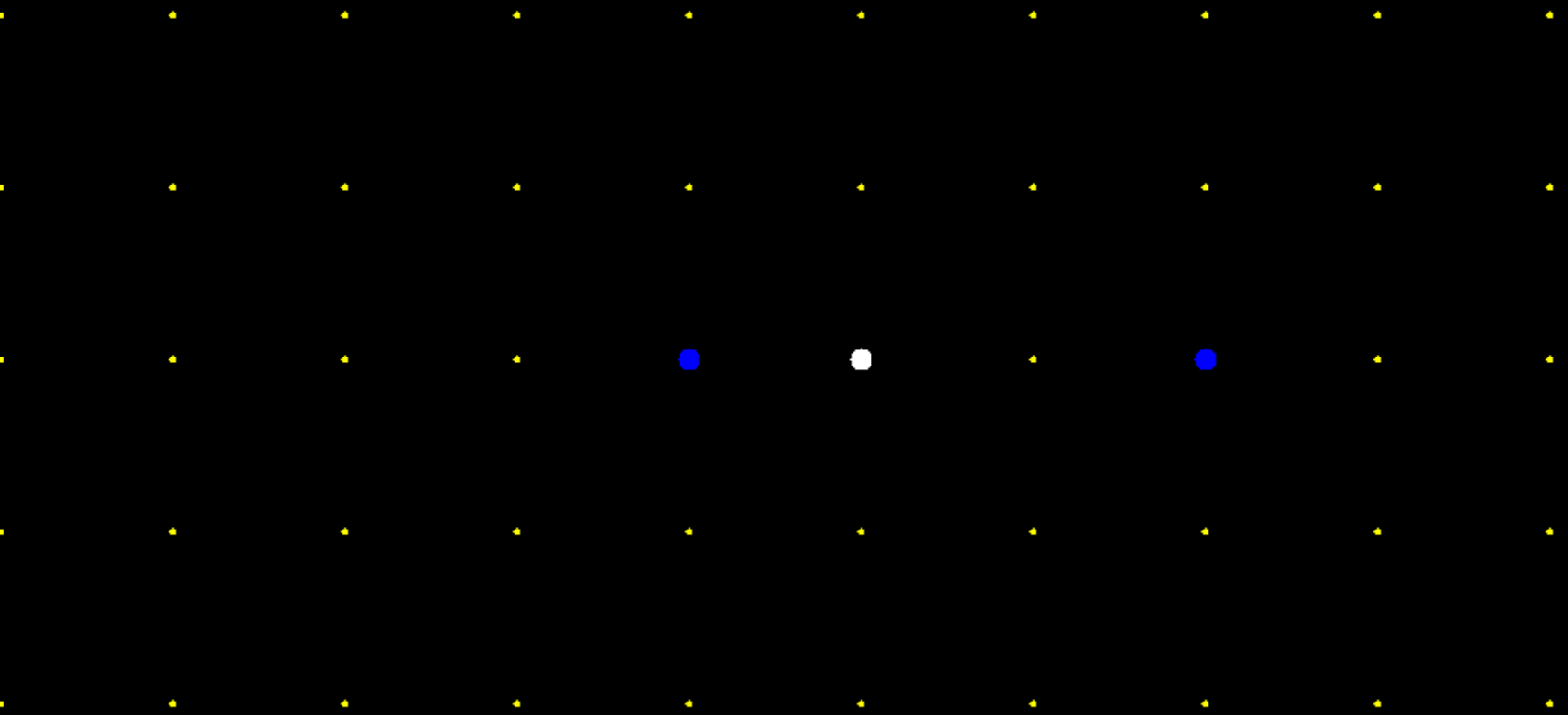
Are we the most unpopular place in the entire Universe?!

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

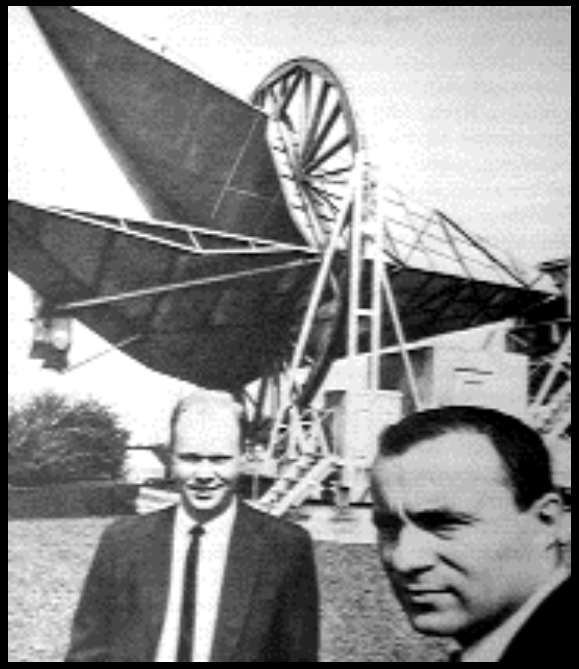
Modern cosmology in a nutshell:

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)

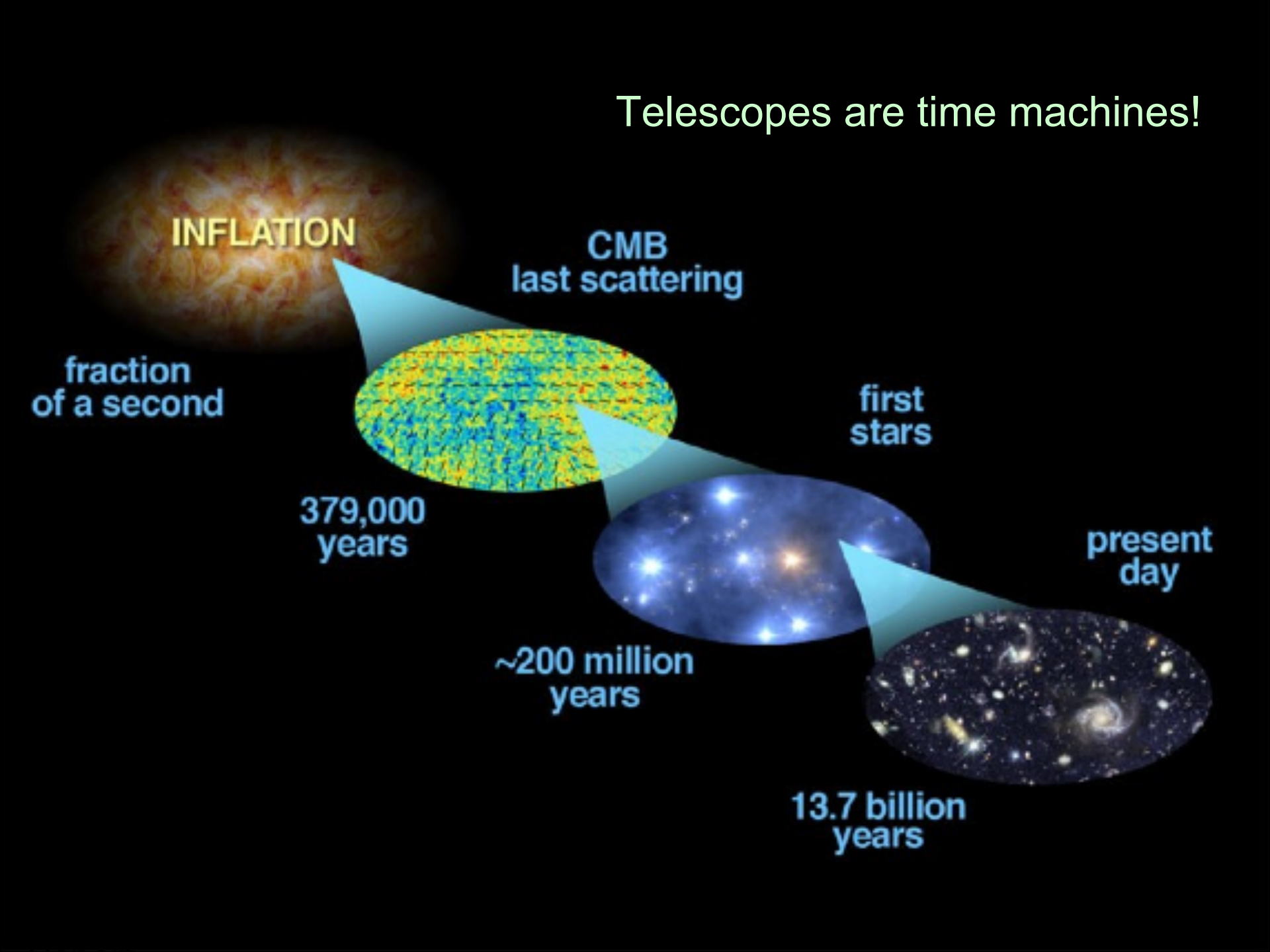


Bob Wilson & Arno Penzias
1978 Nobel Prize

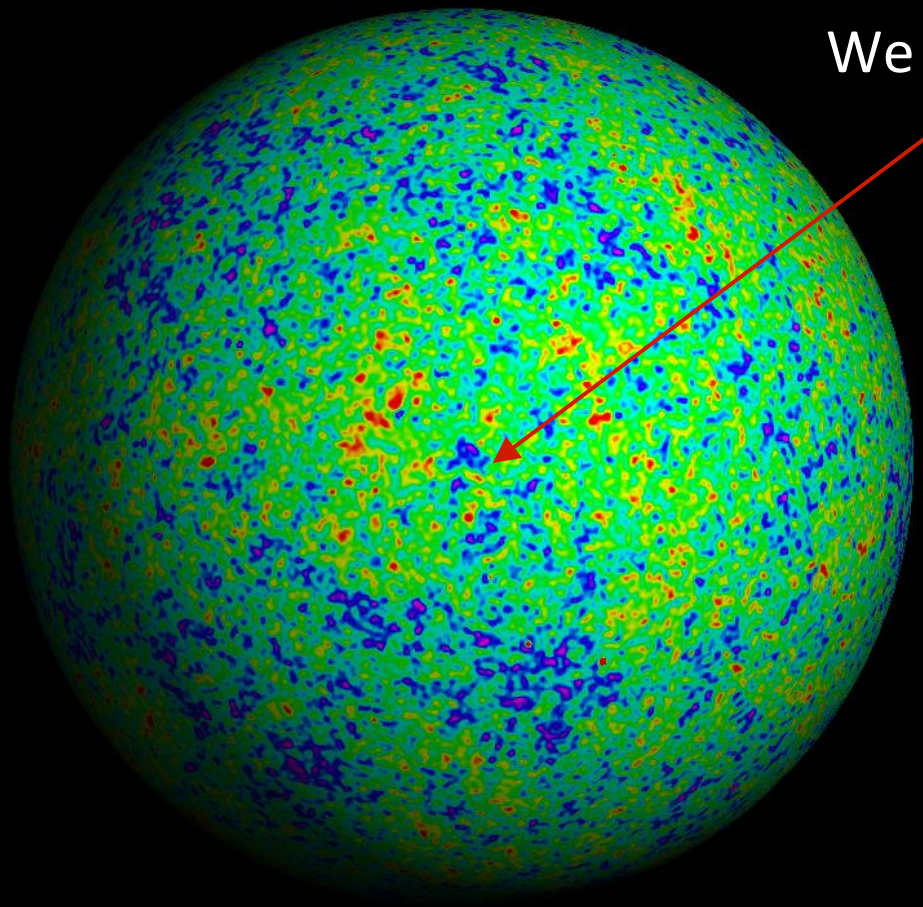
3) You can still see the glow!
The *Cosmic Microwave Background*
(Penzias & Wilson, 1964)

⇒ acceptance of the "HOT BIG BANG"

Telescopes are time machines!

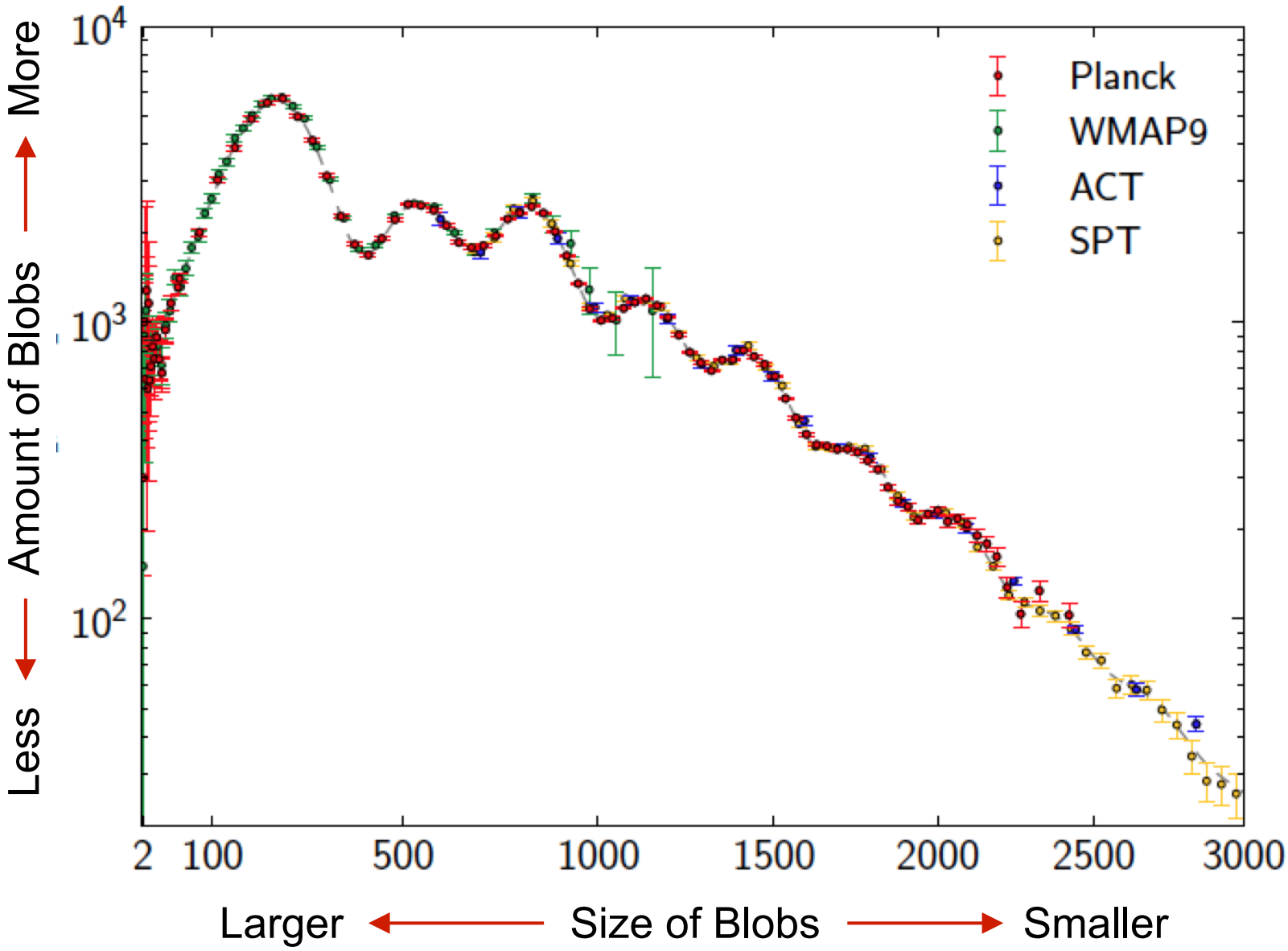


All Sky MAP of the Cosmic Microwave Background



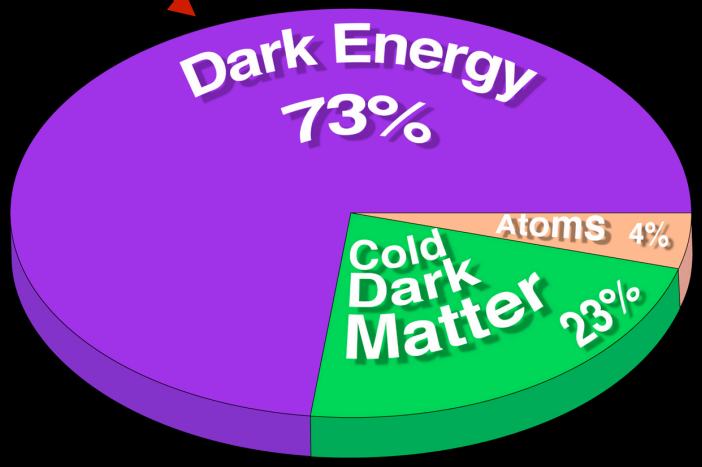
CMB is sample of the density structure on a shell cut through the 380,000 year old Universe

“Lump Sorter” Plot

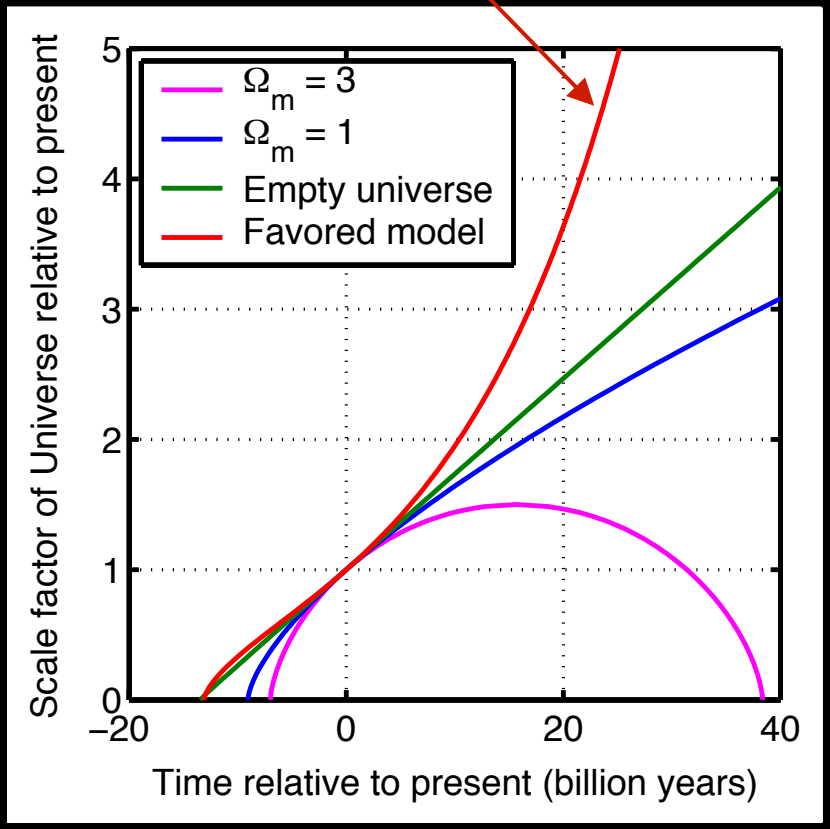


Triumphant/Embarrassing Cosmology

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…



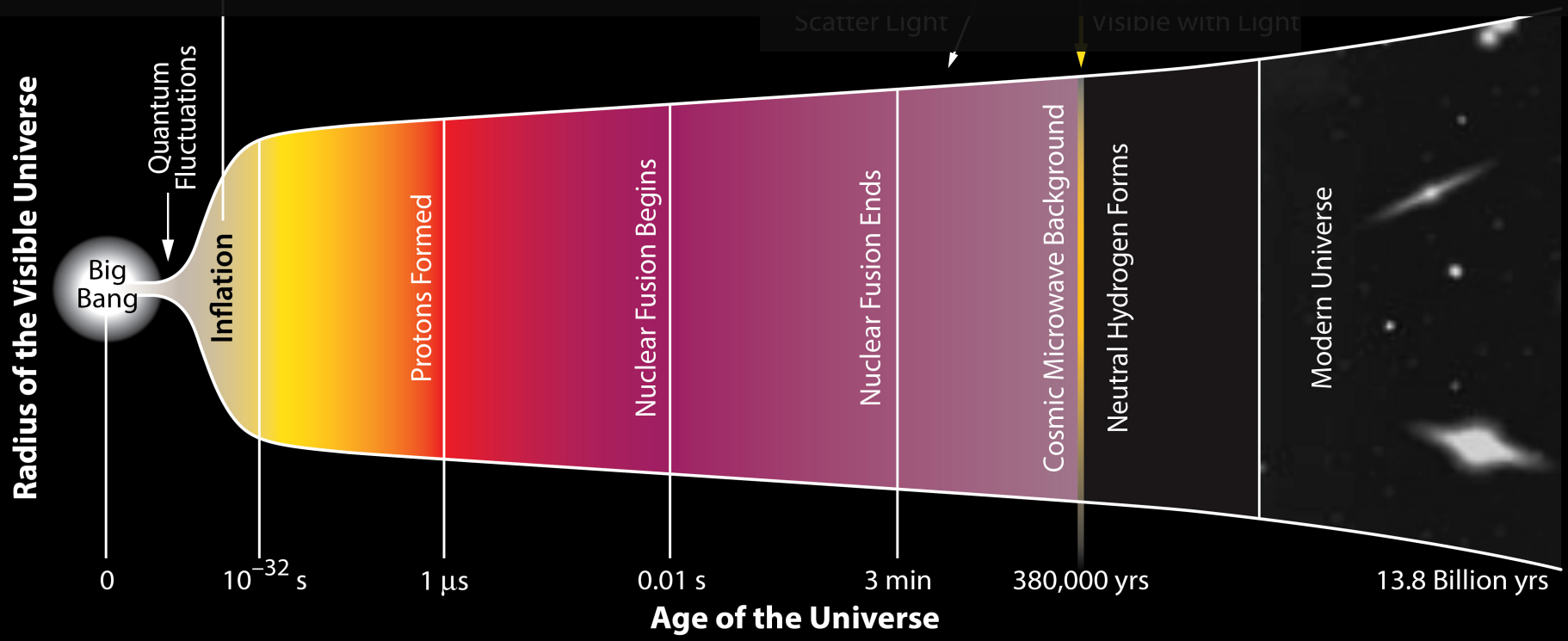
Also it doesn't explain the initial conditions…

History of the Universe

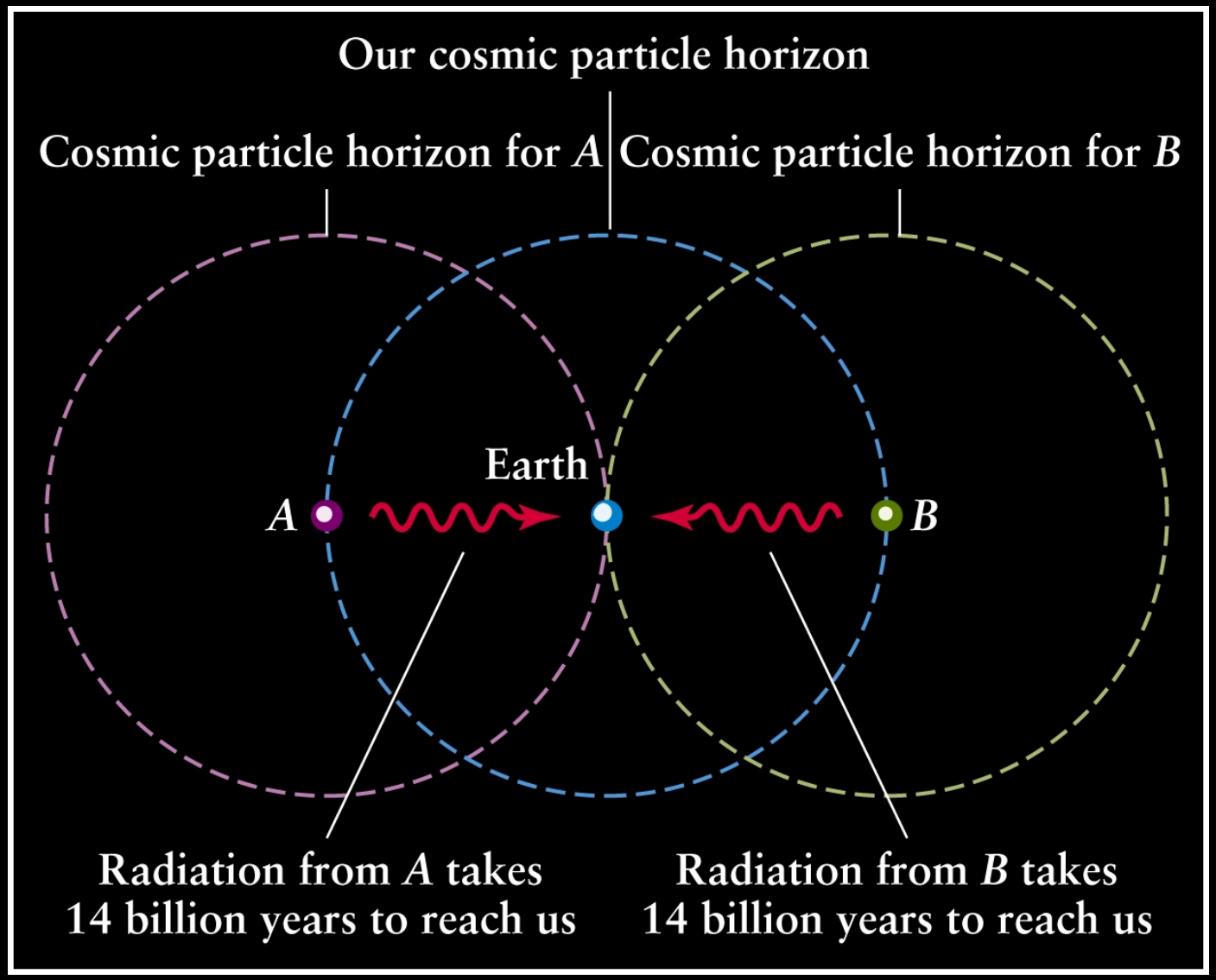
Inflation proposed to explain
Horizon and Flatness problems

Alan Guth

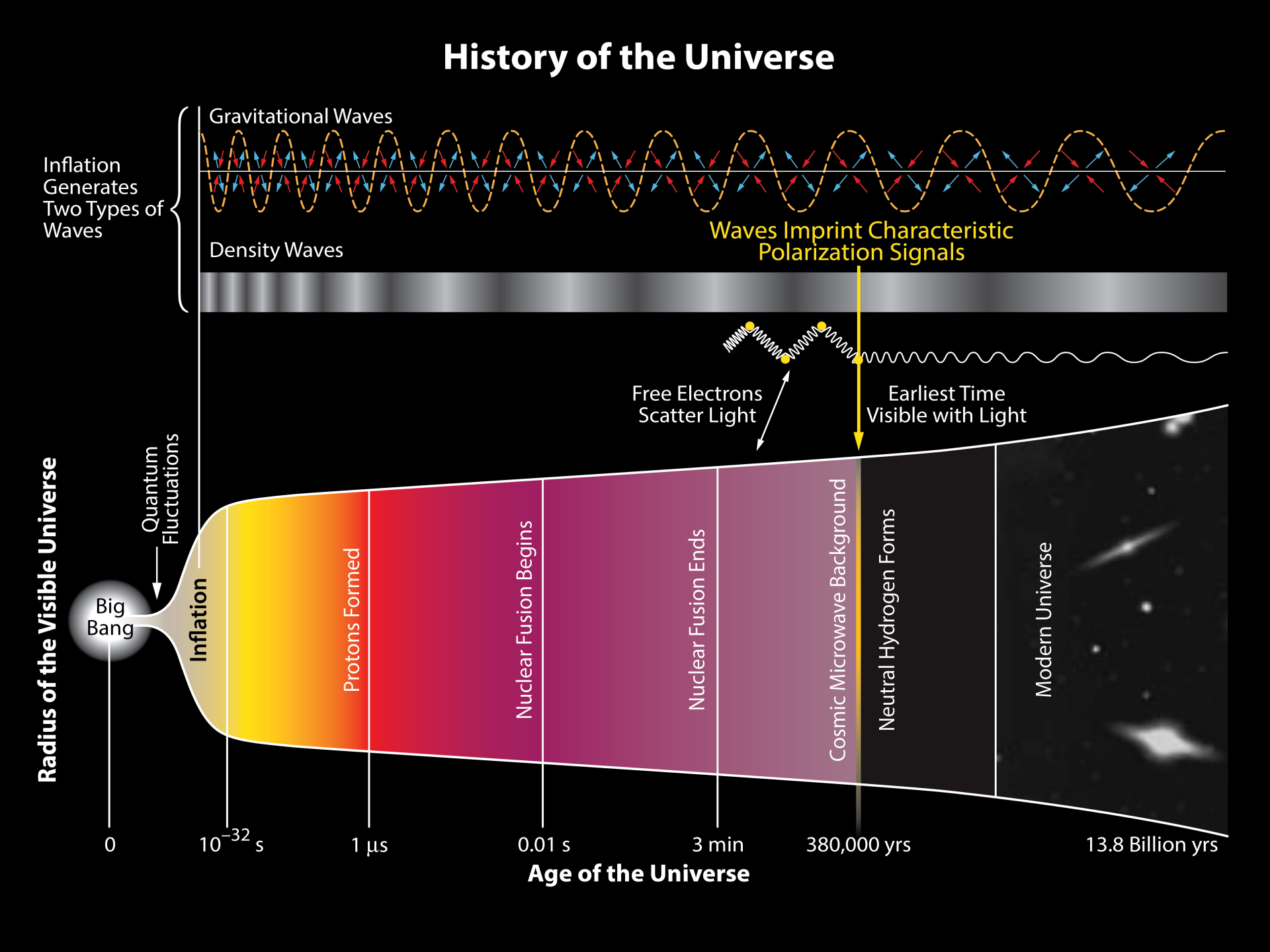
Andrei Linde



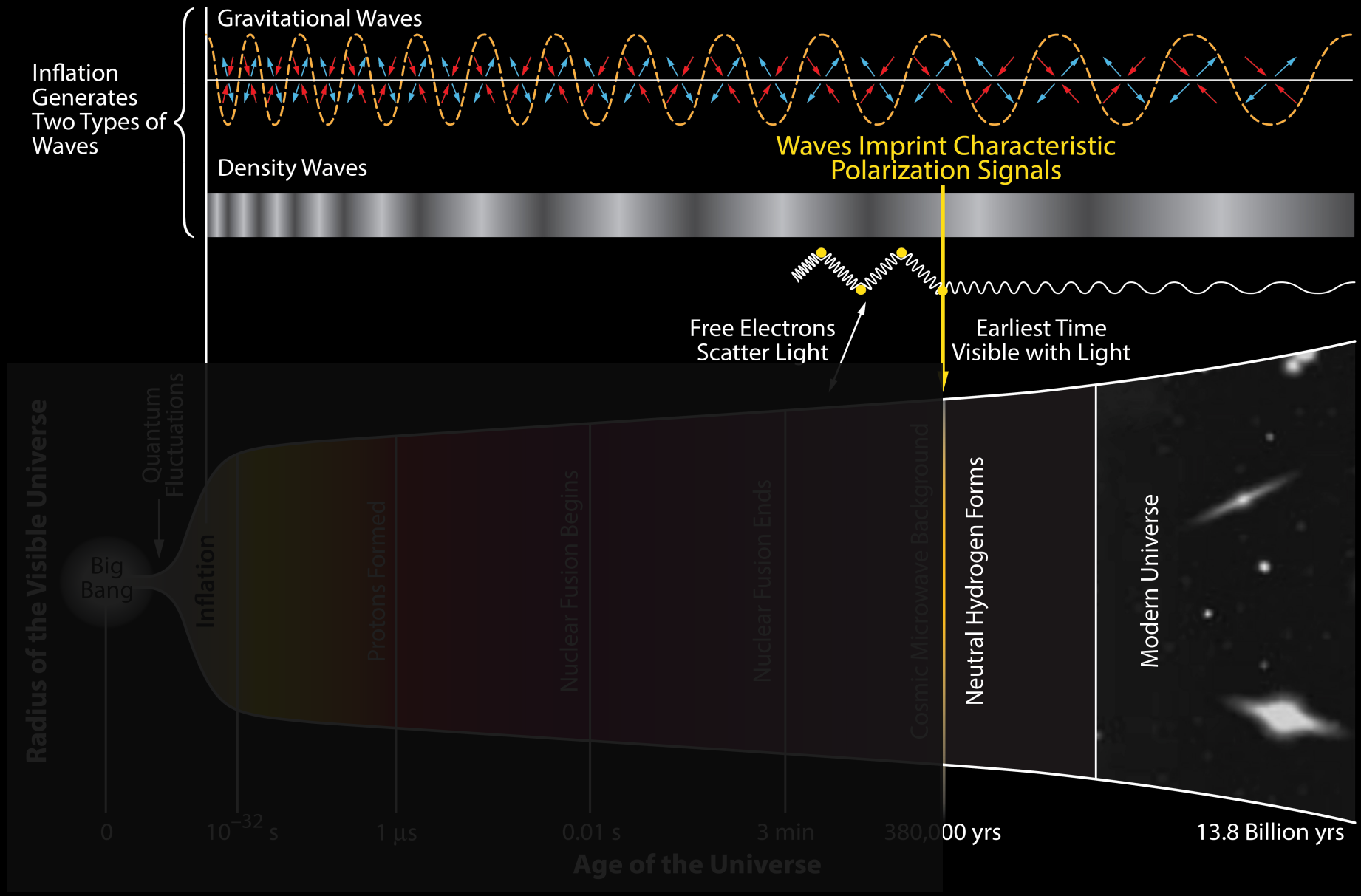
The Horizon Problem



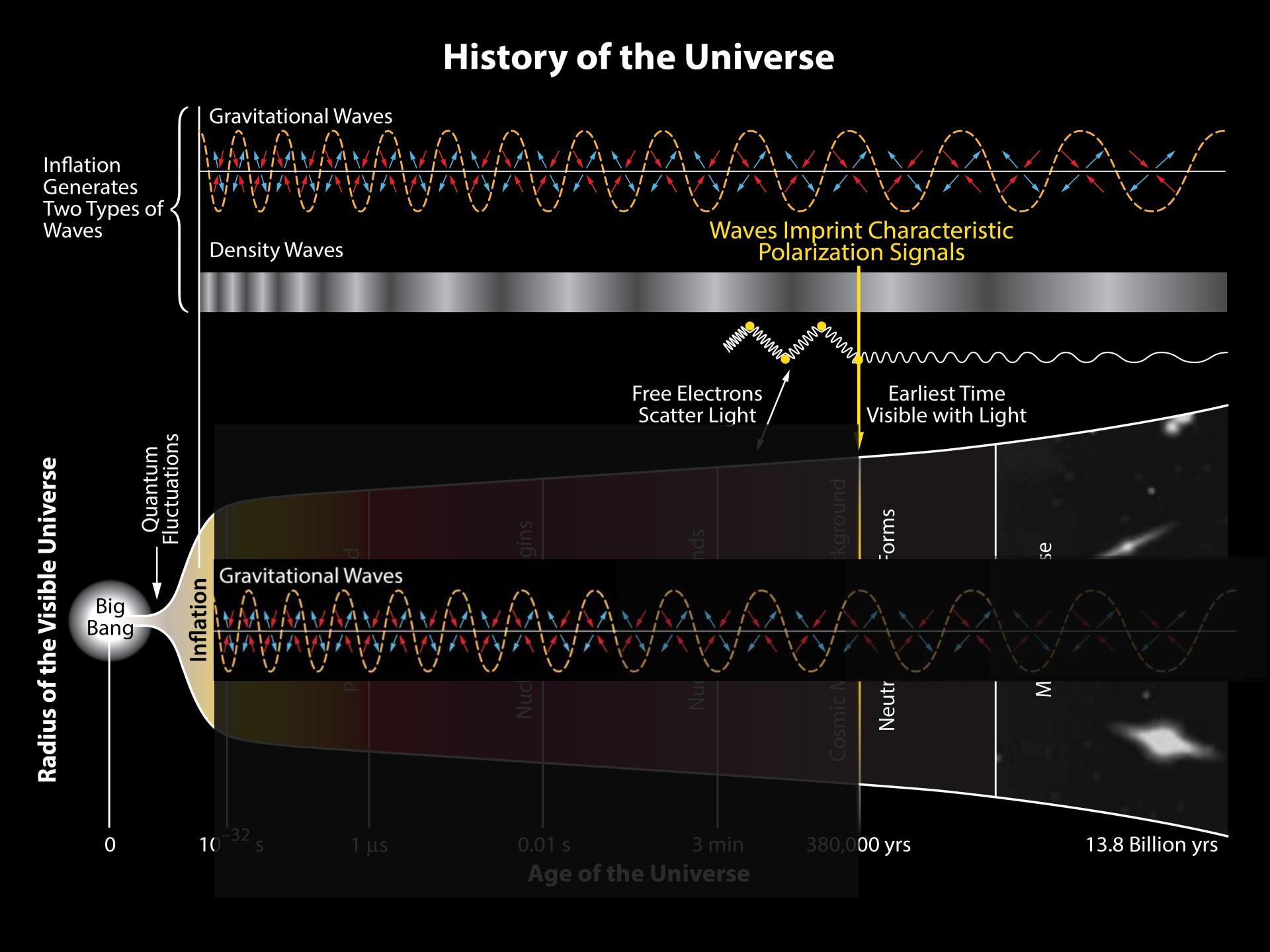
How did points A and B "know" to be at the same temperature at 380,000 years?


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

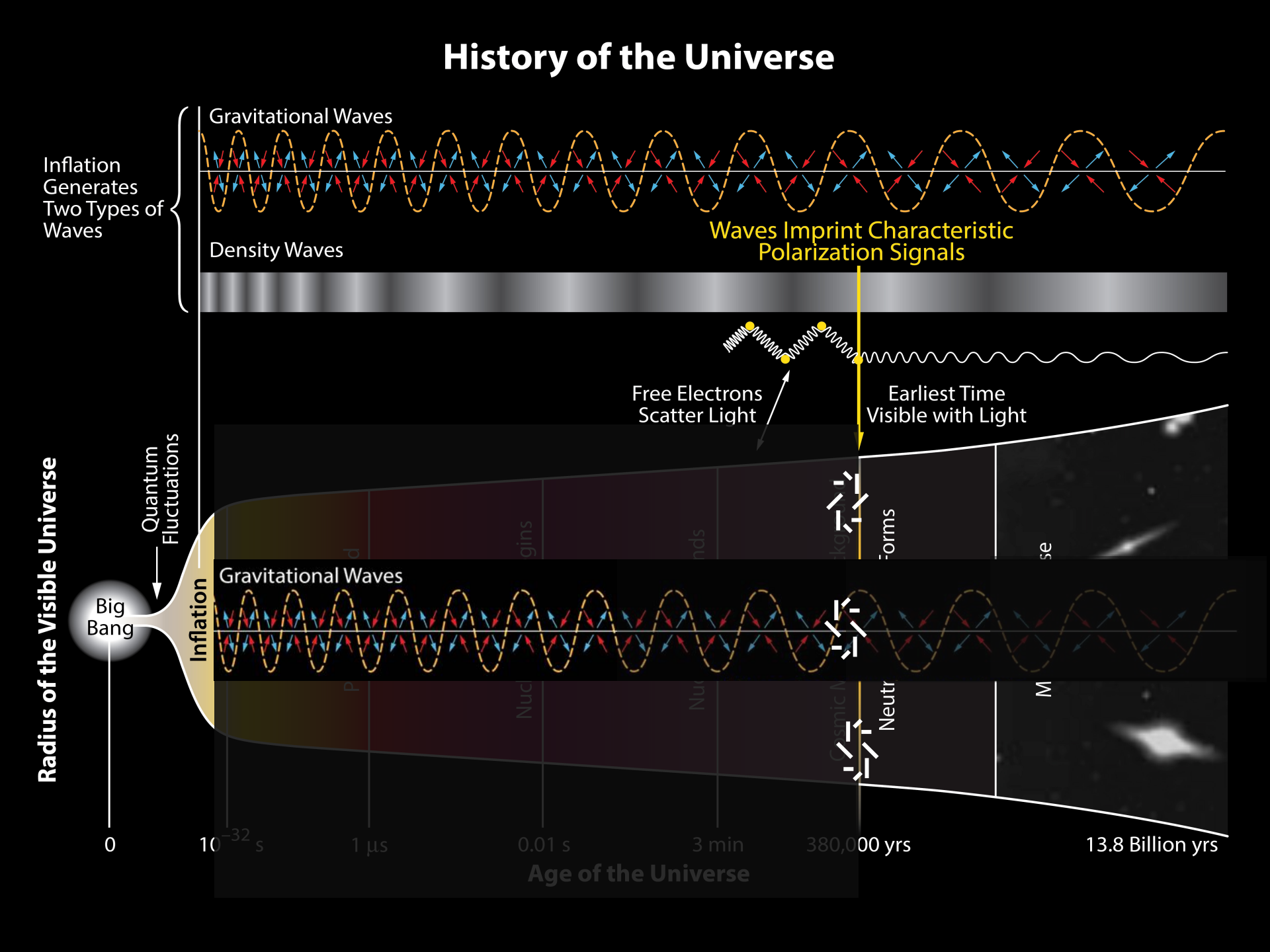
History of the Universe



History of the Universe

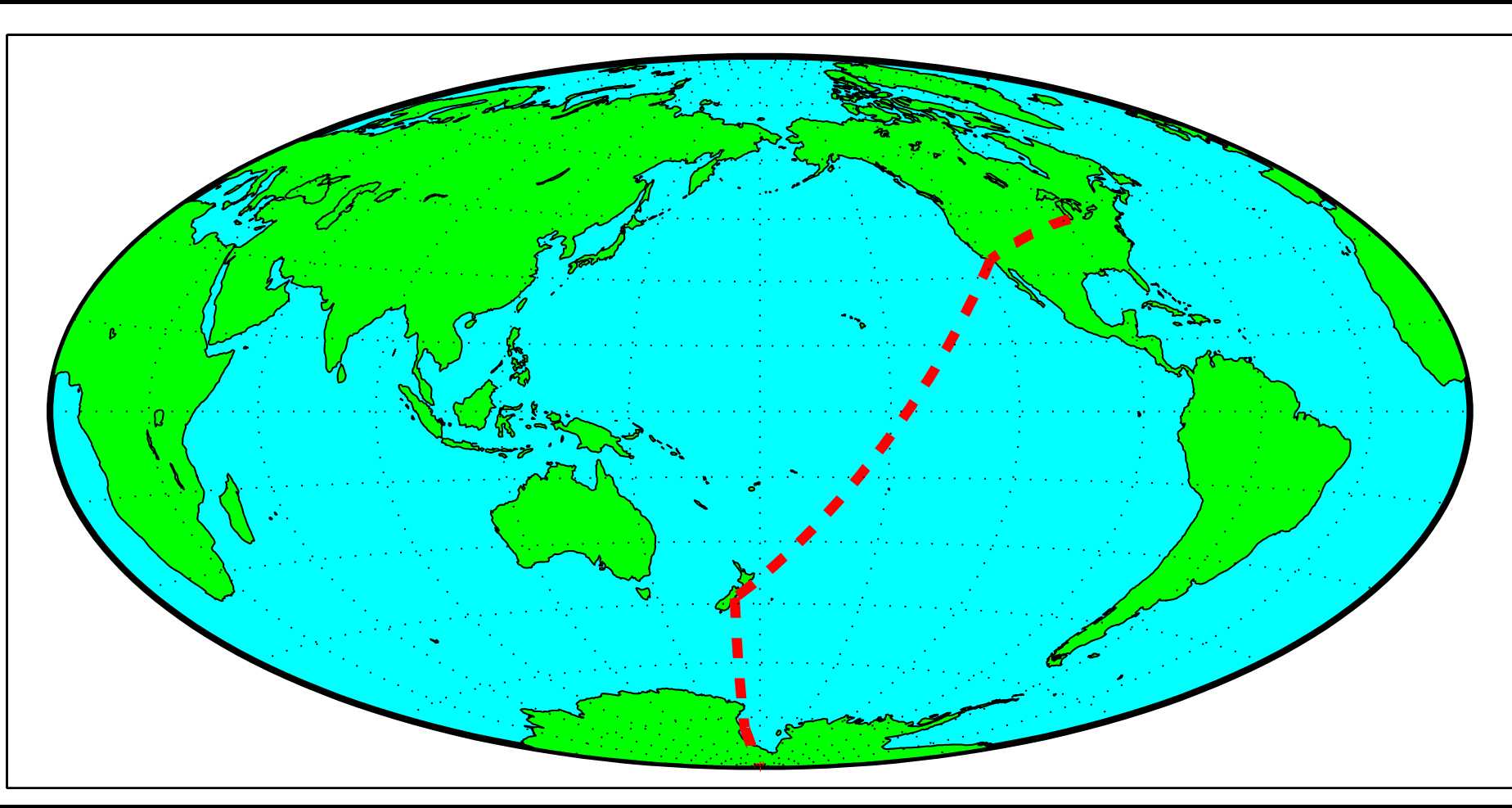


History of the Universe



This is our collaboration – about half these people are graduate students, and undergrads also work with us.

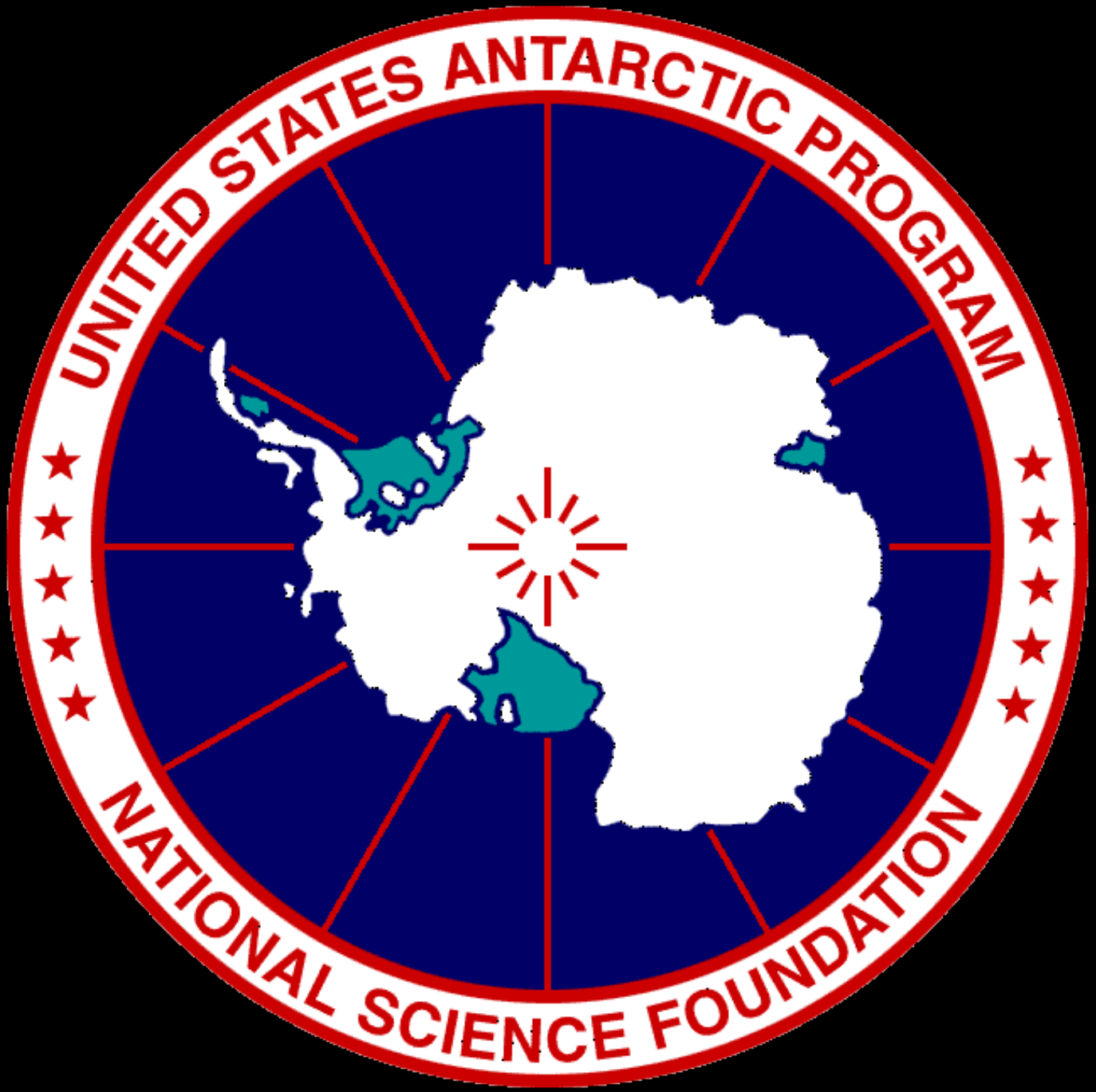
Journey to the South Pole



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

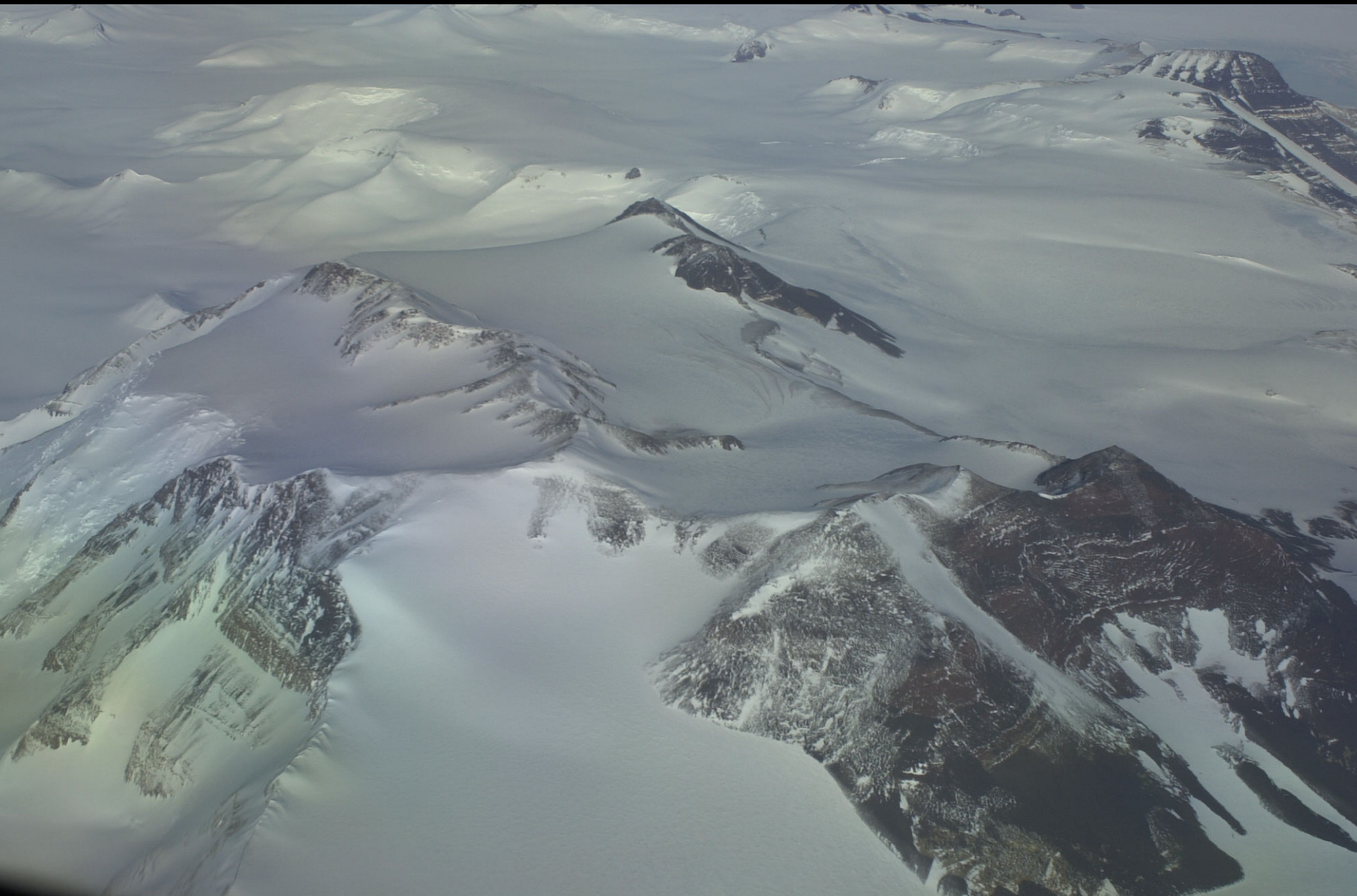
Christchurch New Zealand – Clothing Warehouse

Big Program!

Arrival in Antarctica

McMurdo – base on the coast

On to the Pole – over the Transantarctic Mountains

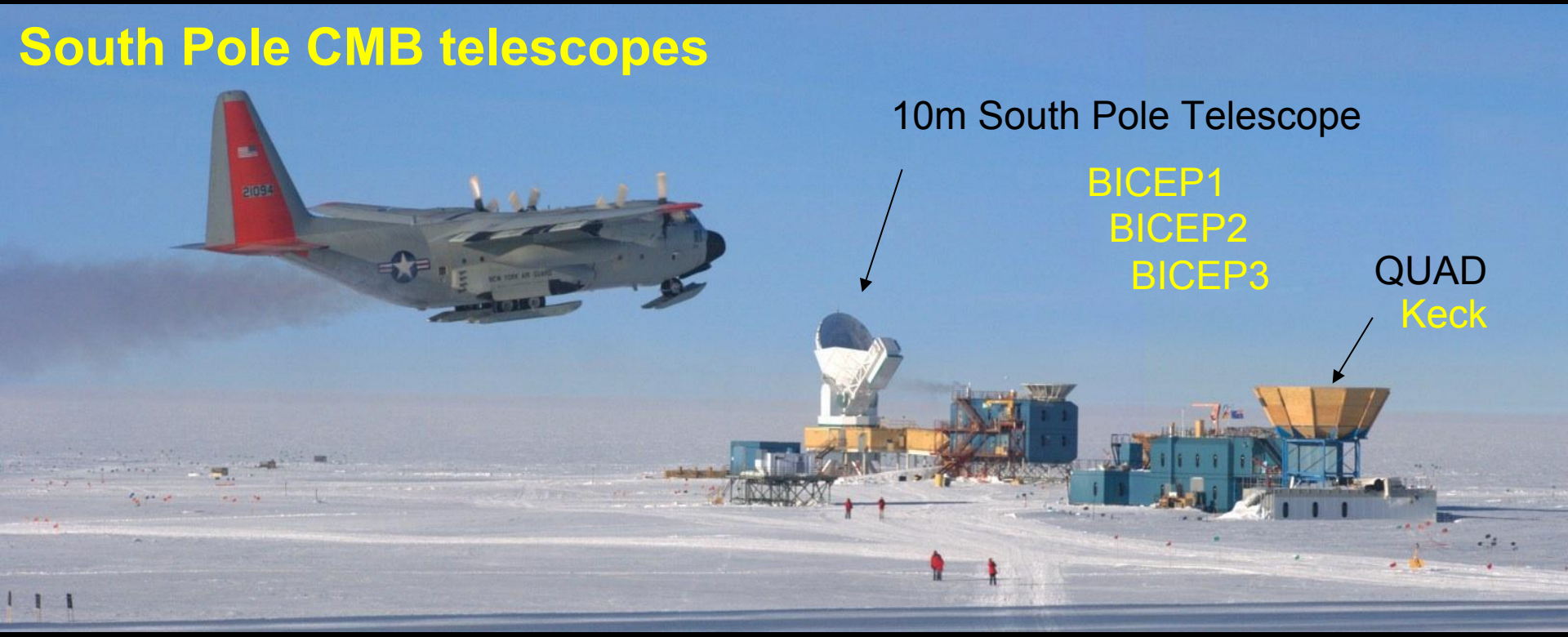


Unloading at Pole

The Actual South Pole

Nothing Out There!

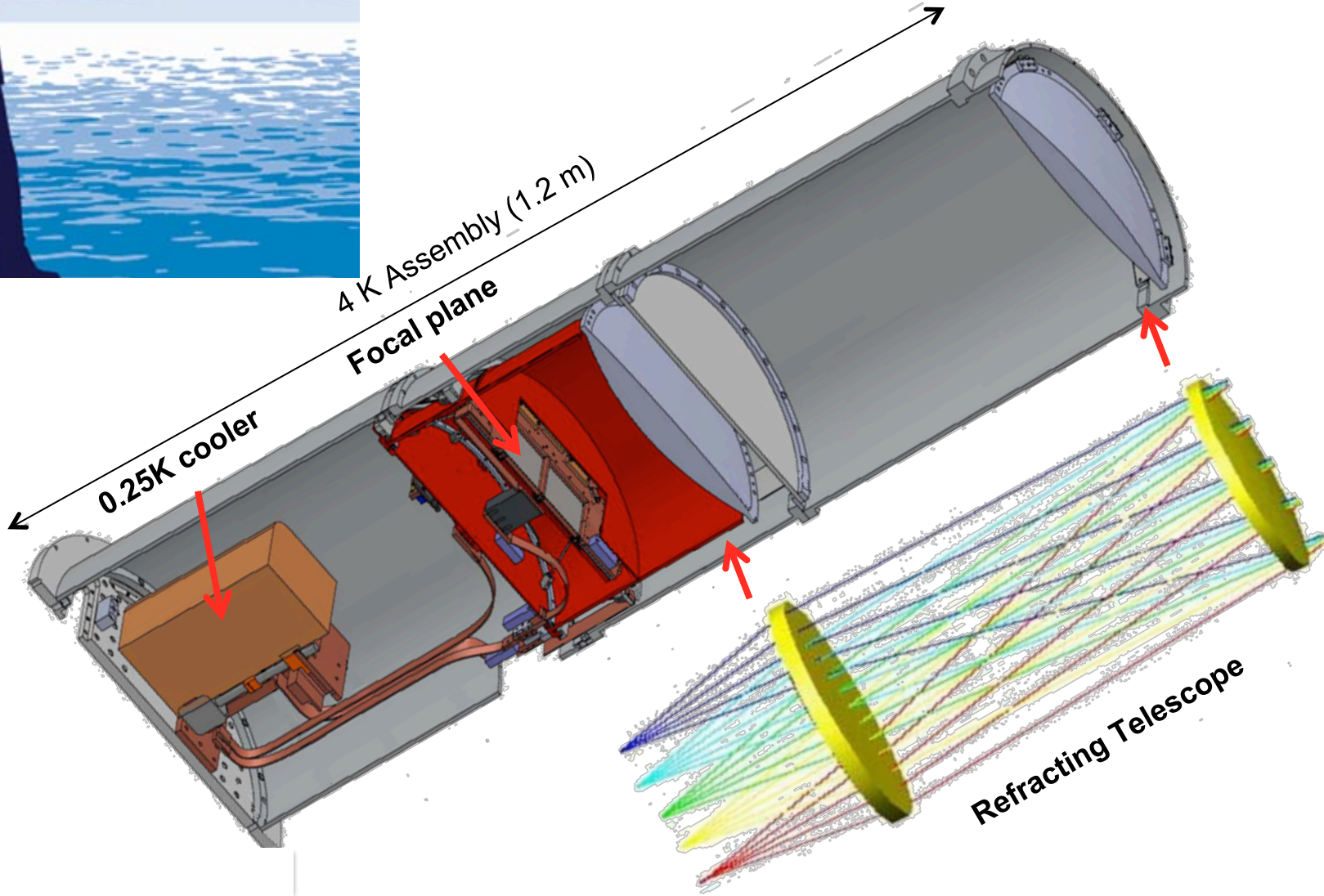
Why do this at the Pole?

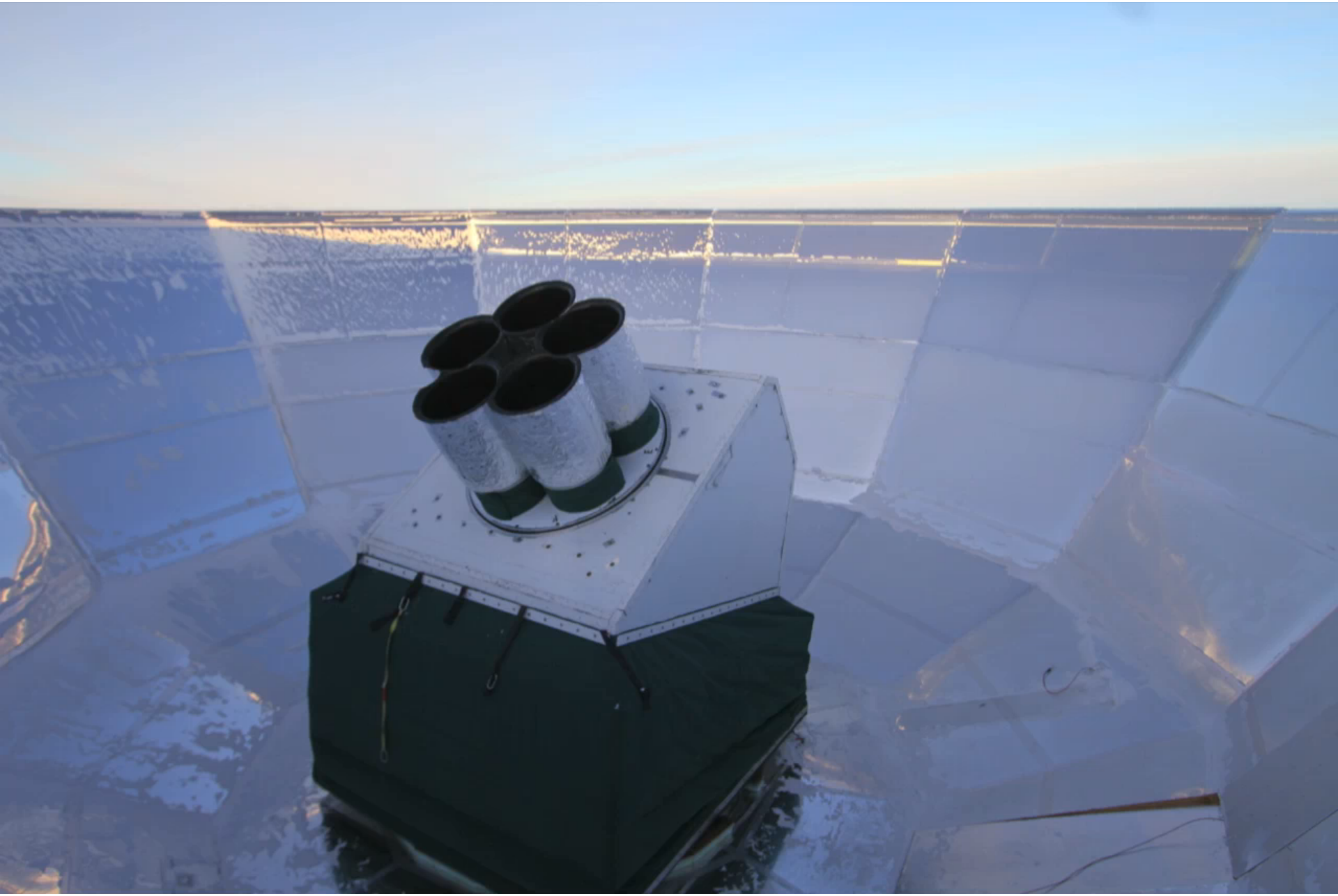


- High and *dry* – see out into space
- On Earth's rotational axis - One day/night cycle per year
  - Long night makes for great quality data
- Good support infrastructure – power, cargo, data comm
- Food and accommodation provided
- Even Tuesday night bingo…

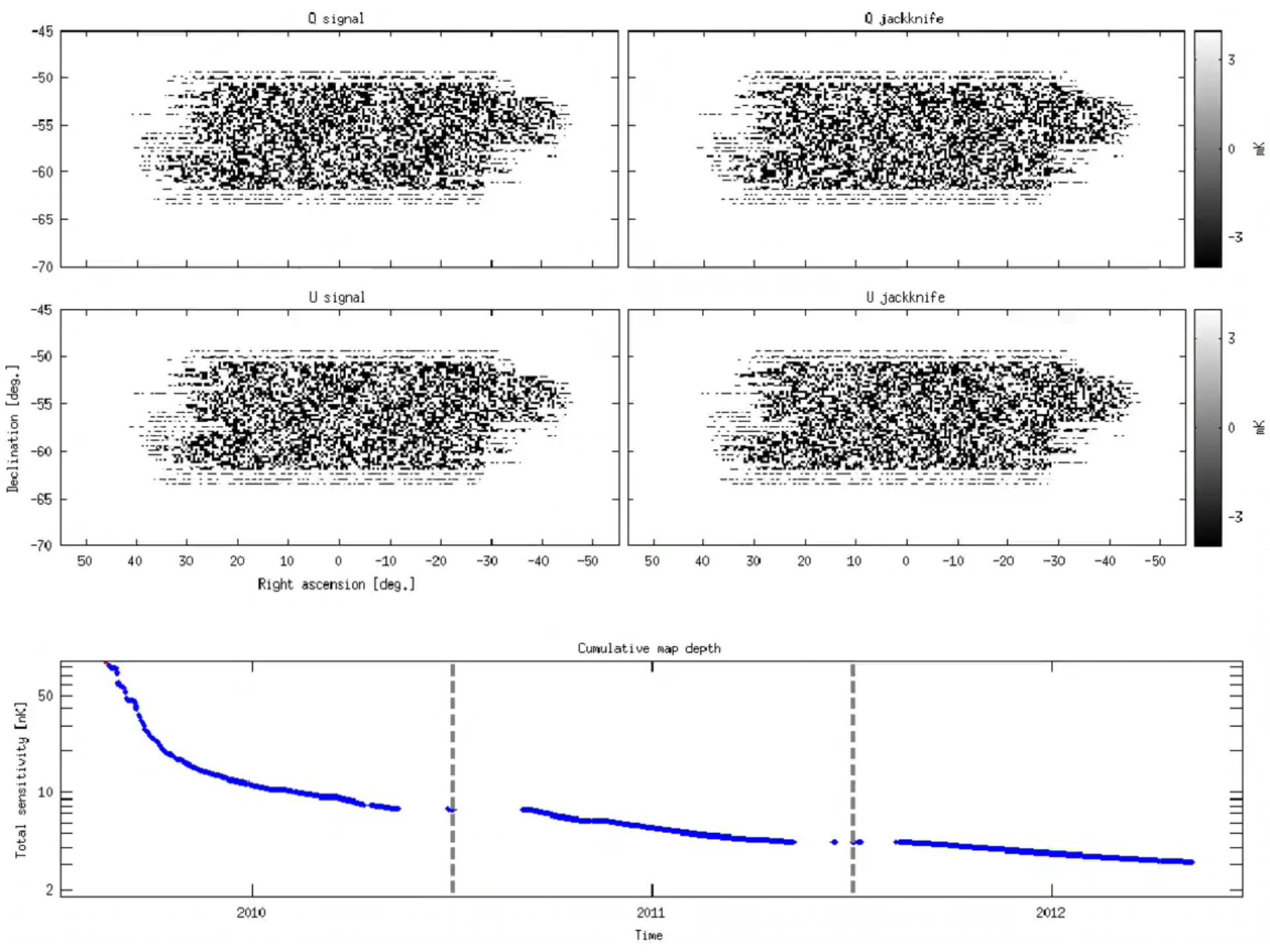
Basic Experiment Design

- Small aperture
- Wide field of view
- Cold refractor



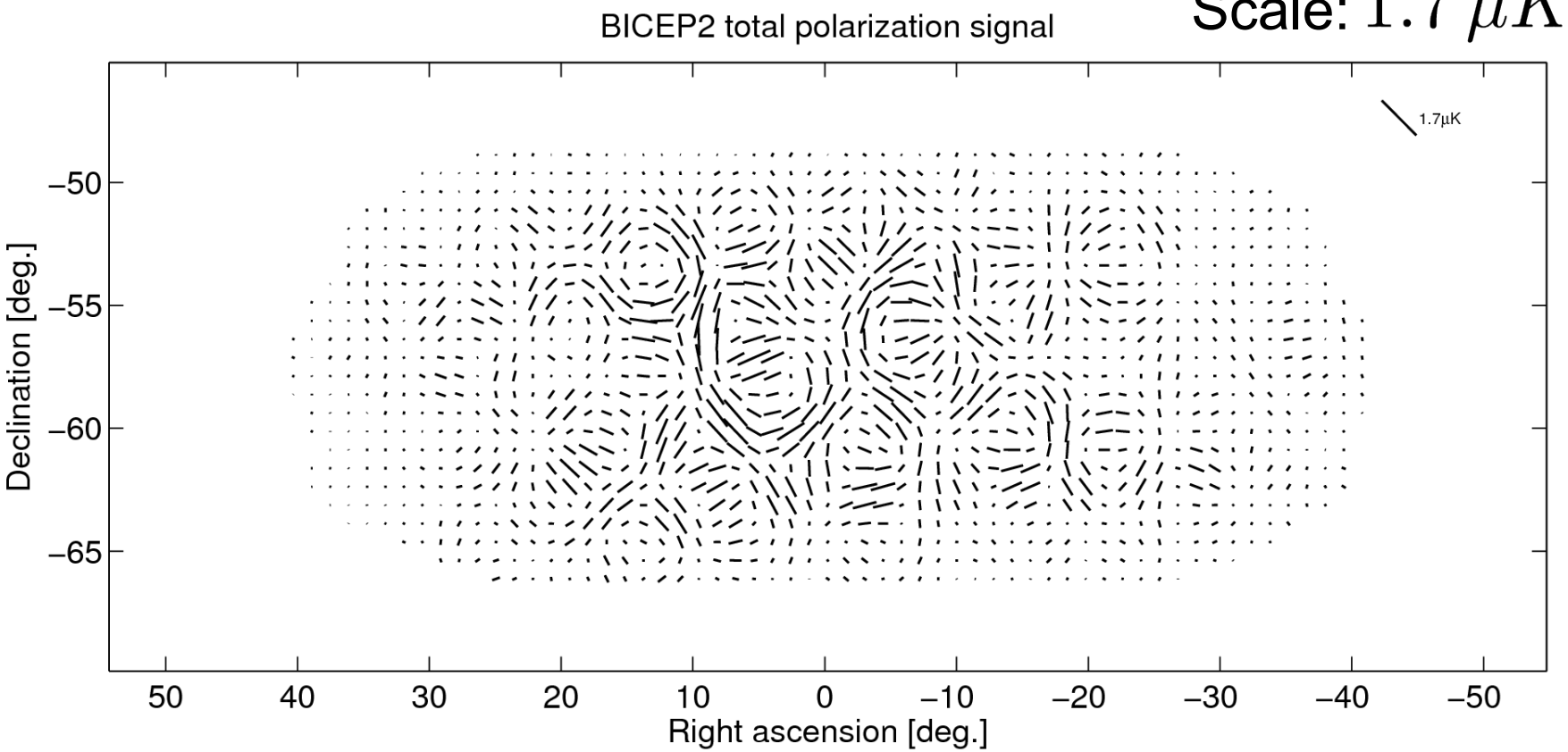


Clem Pryke for The Bicep2 Collaboration


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 [nK]
50
10
2
2010
2011
2012
Time

Total Polarization

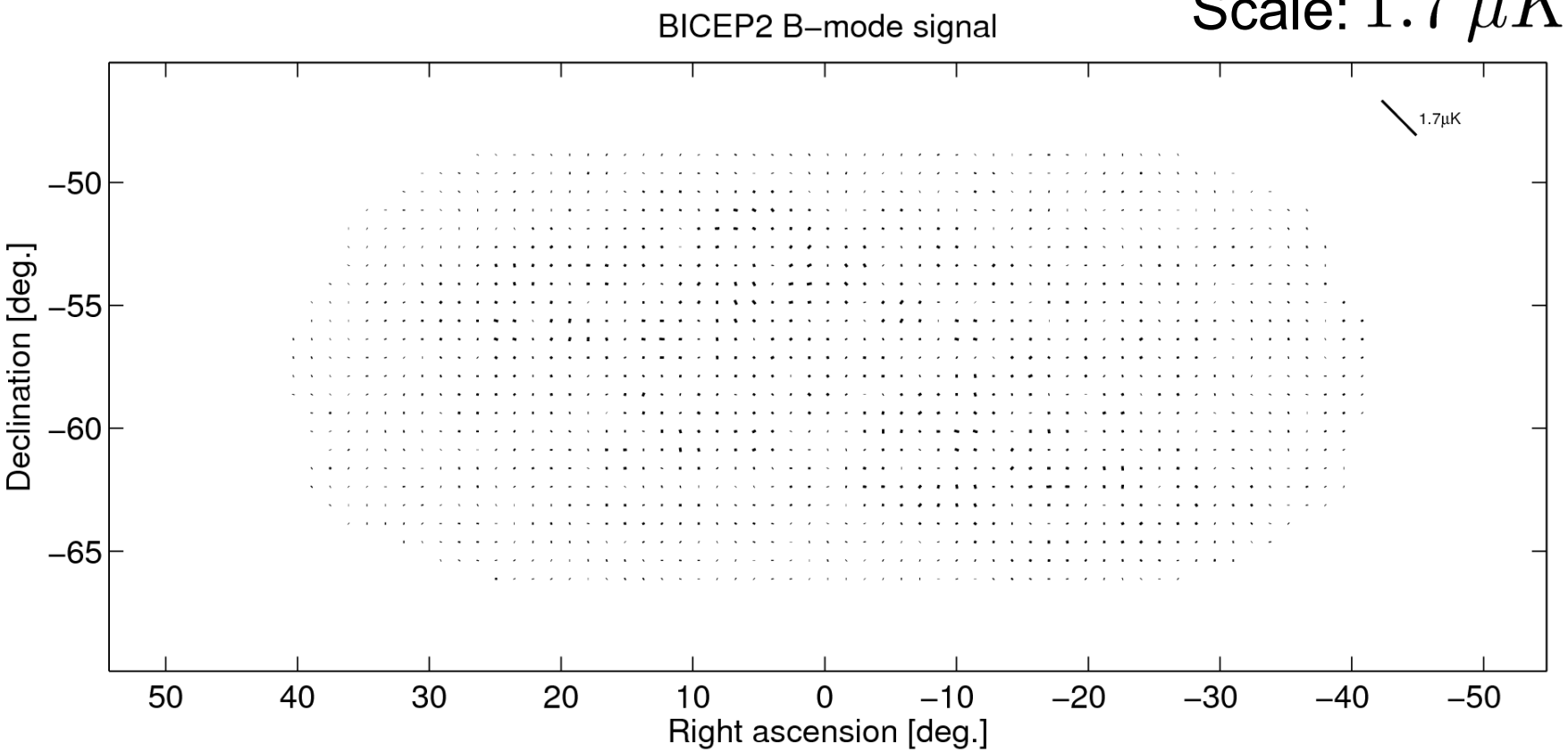
Scale: $1.7\ \mu K$



E-mode dominated pattern – no obvious curl component

B-mode Contribution

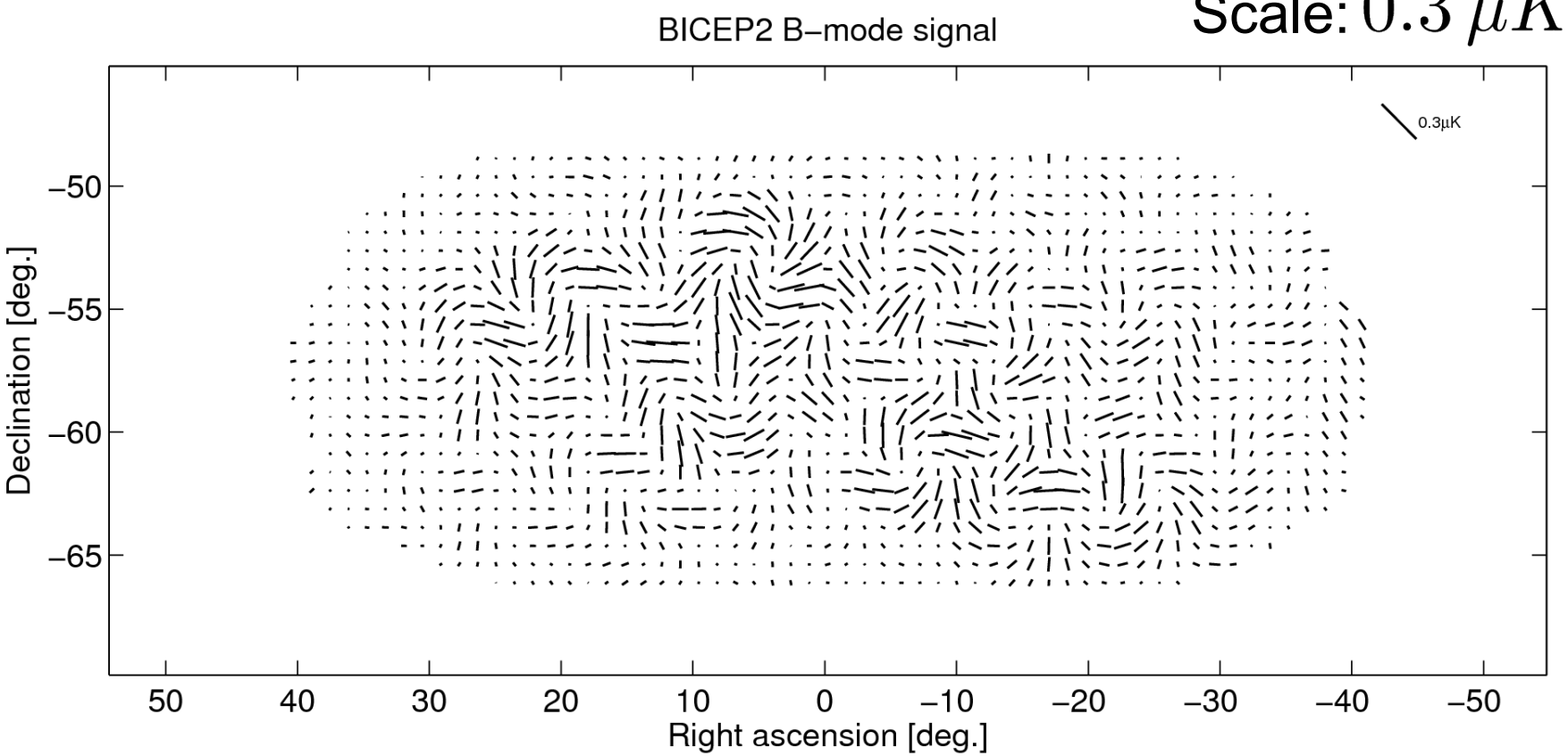
Scale: $1.7\ \mu K$



Apply purification operation which leaves only pure B-modes

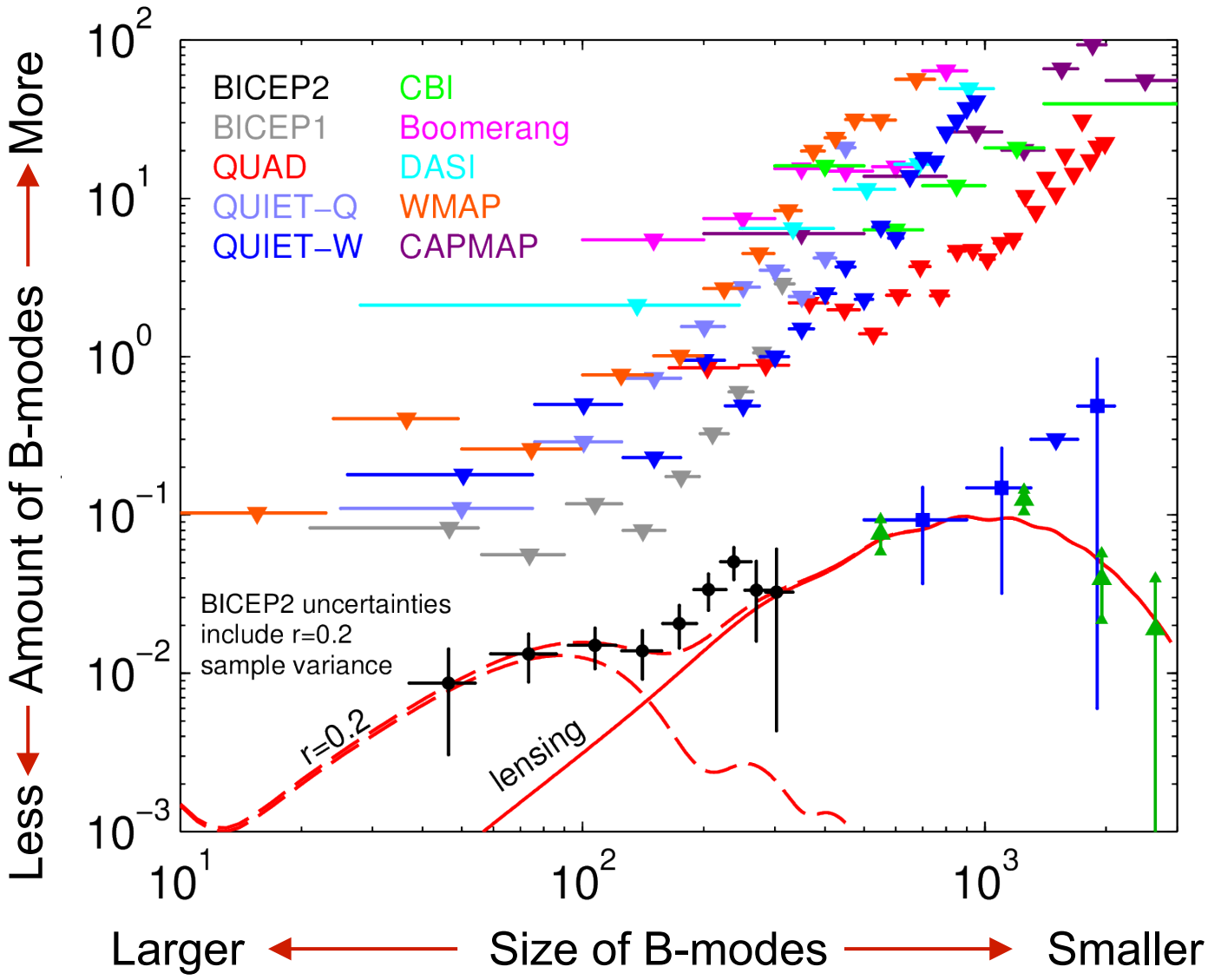
B-mode Contribution

Scale: $0.3\,\mu K$



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

In 2014 we thought we had found what we were looking for!

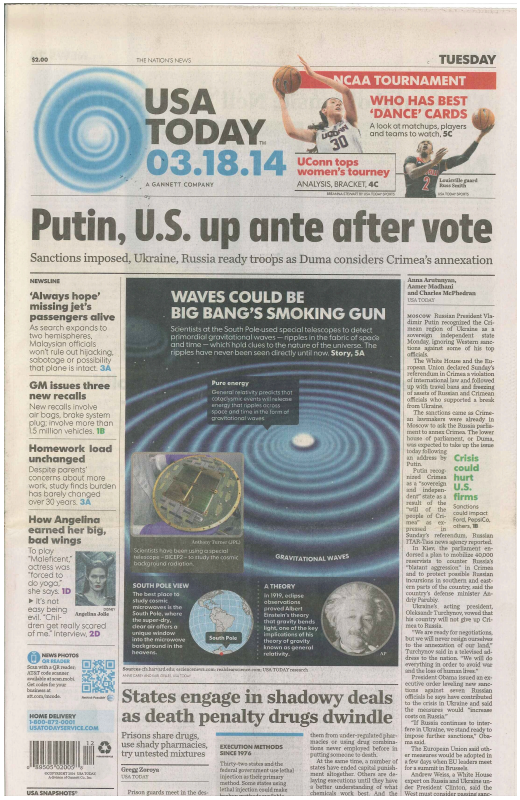


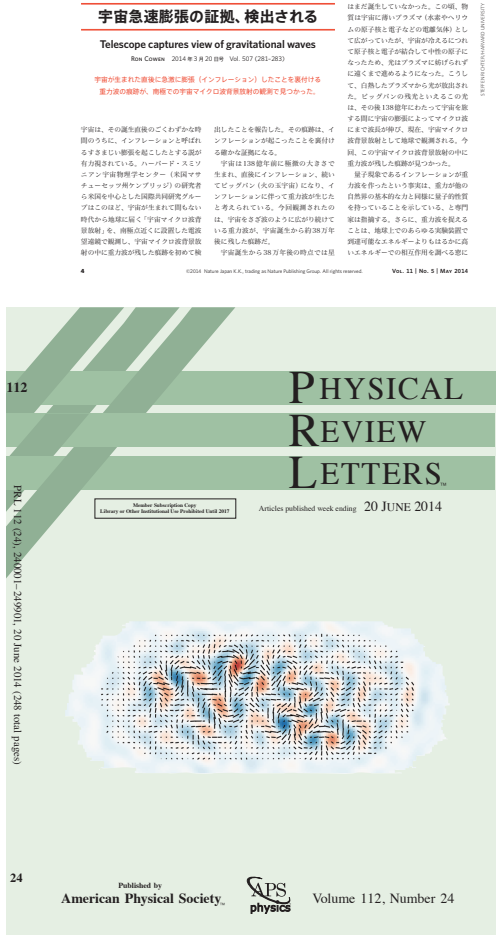
(r is a measure of amount of gravitational waves)

In 2014 we thought we had found the signature of inflationary gravitational waves but…

Clem Pryke for The Bicep2 Collaboration

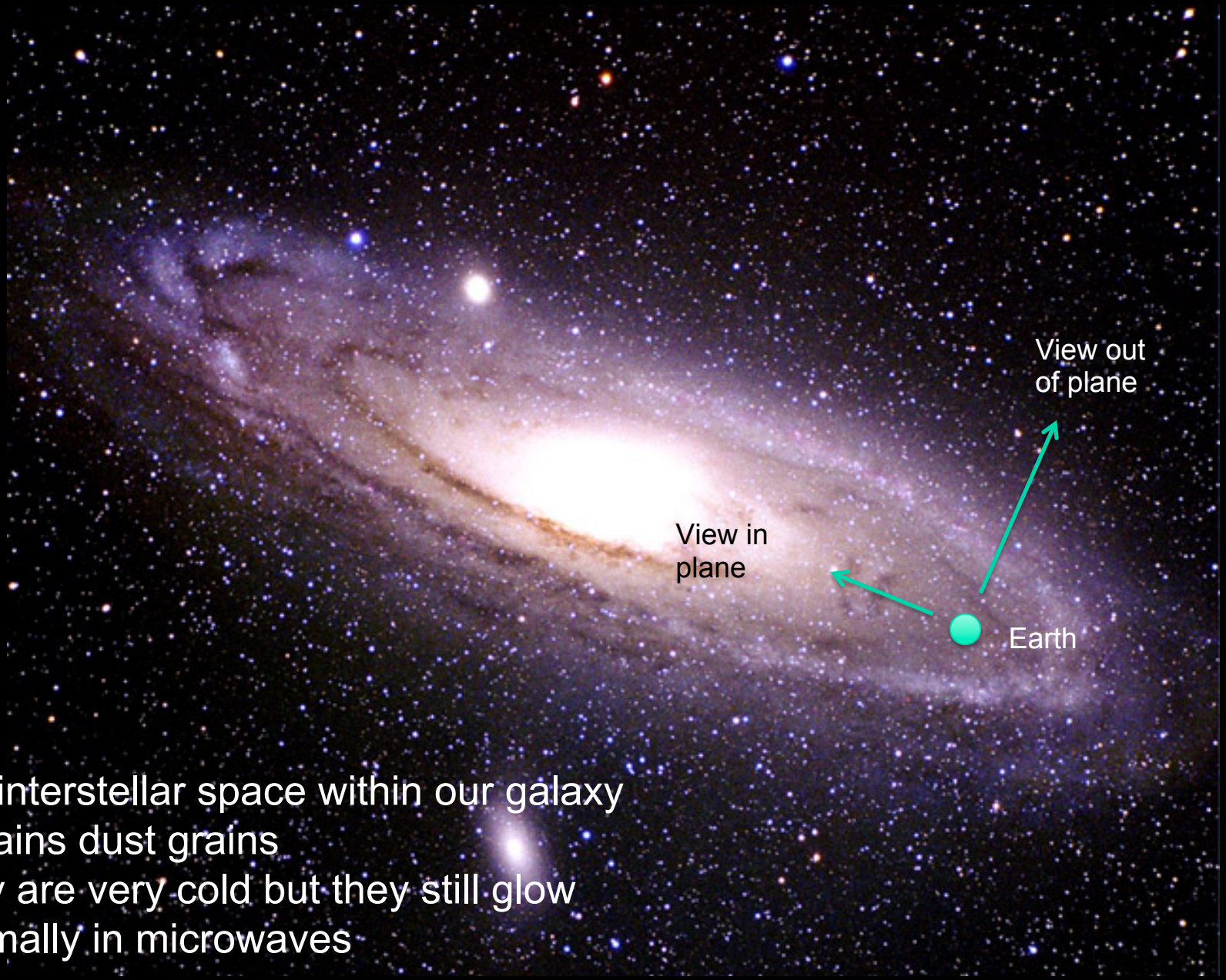
2014 Storm of Media Attention





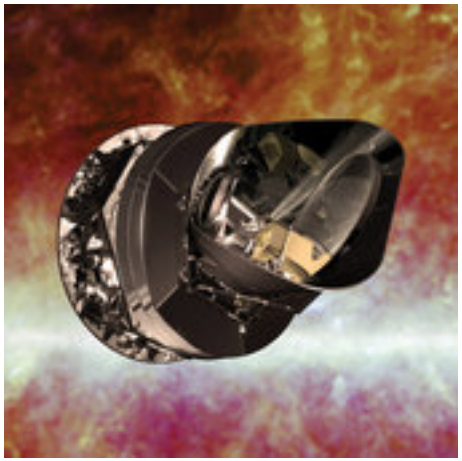
Actually not a lot of fun…

Unfortunately we are in a galaxy!

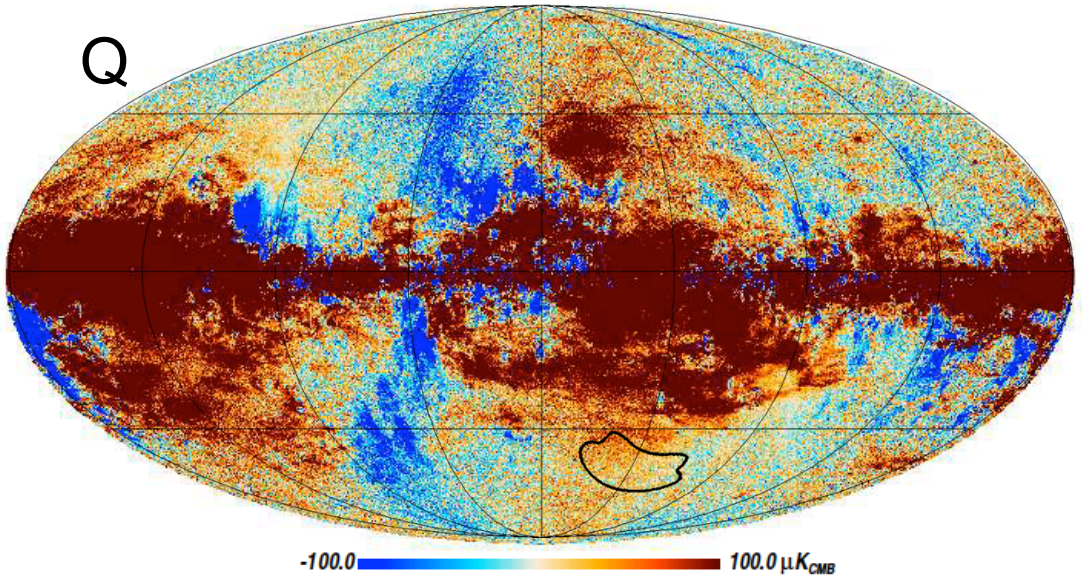


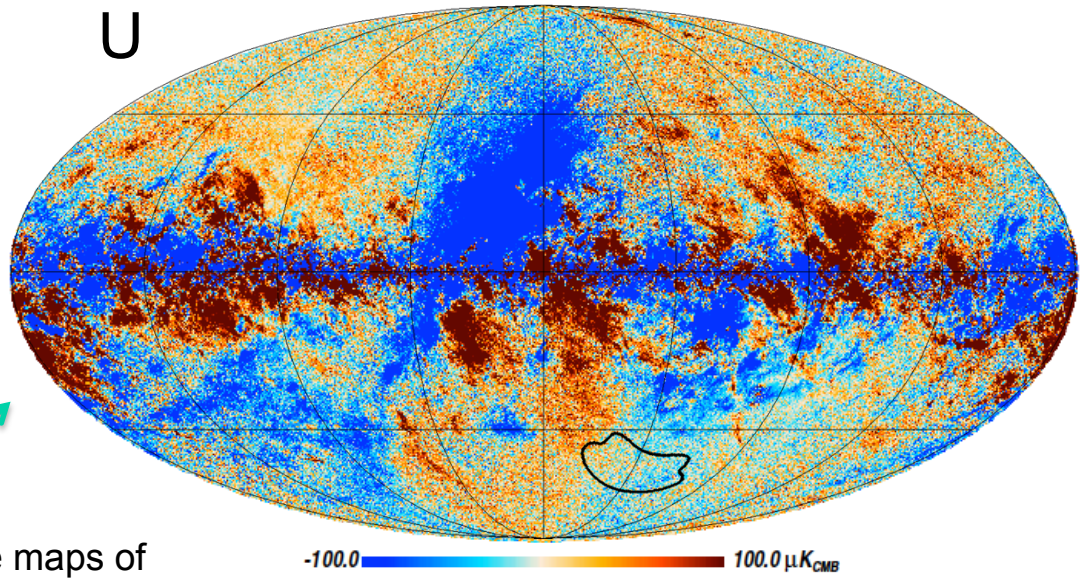
The interstellar space within our galaxy contains dust grains
They are very cold but they still glow thermally in microwaves

Dust emission from our galaxy turns out to be brighter than expected…



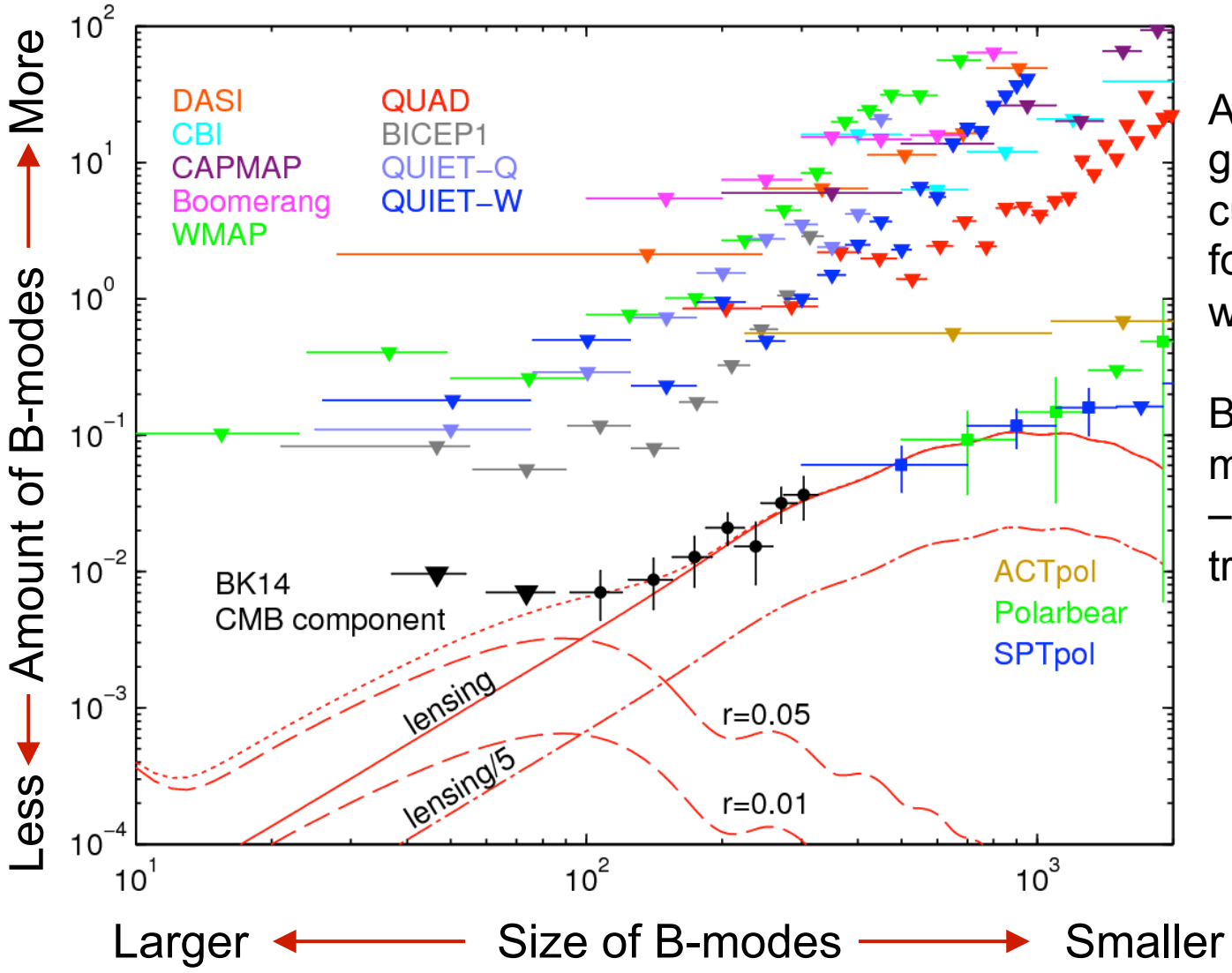
Planck was a billion dollar Euro/NASA space mission





All sky maps like maps of the Earth

So the Search Goes On…



After accounting for galactic dust there is currently no evidence for gravitational waves

But that doesn't mean they don't exist – just that we need to try harder!

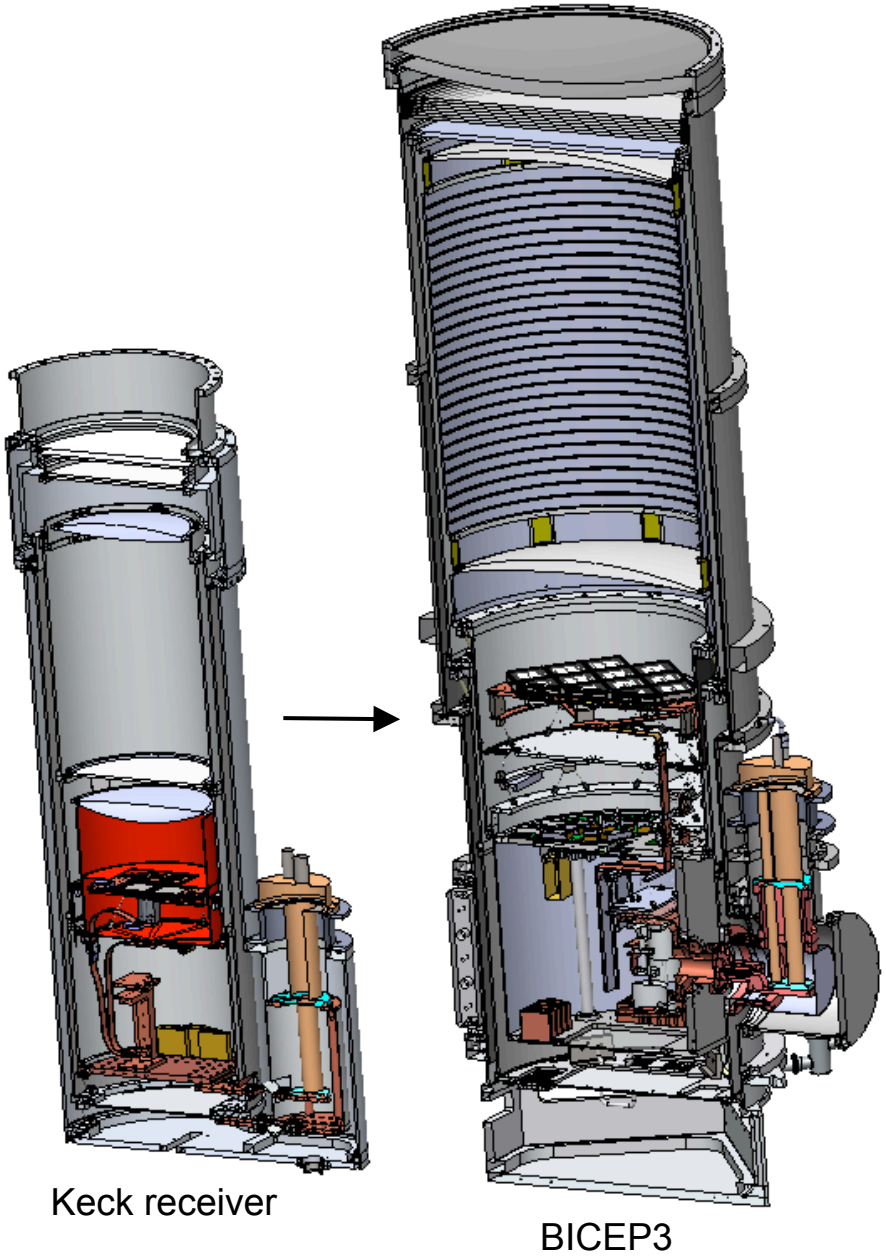
Clem Pryke for The Bicep2 Collaboration

BICEP3: Next Gen. Super receiver

2560 detectors in modular focal plane

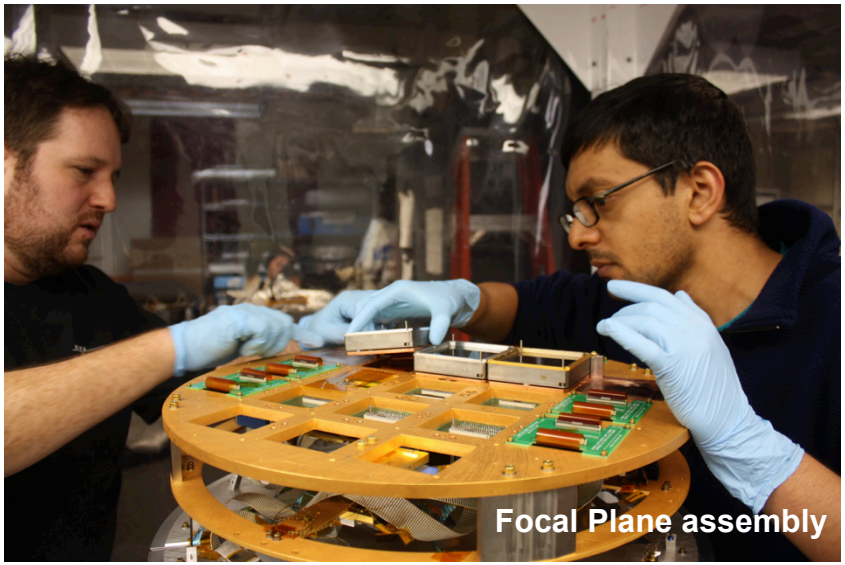
Large-aperture optics and infrared filtering

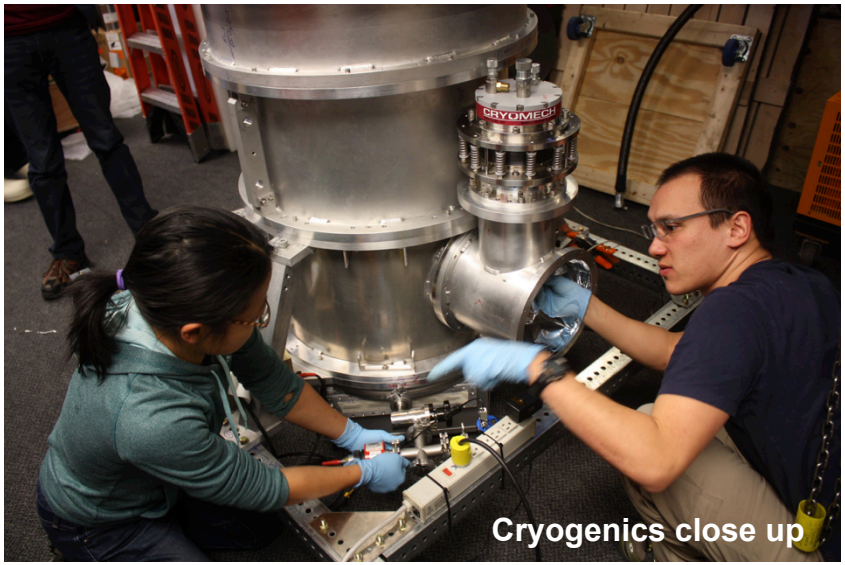
> 10x optical throughput of single BICEP2/Keck receiver



December 2015: BICEP3 assembly at South Pole


Optics tube installation

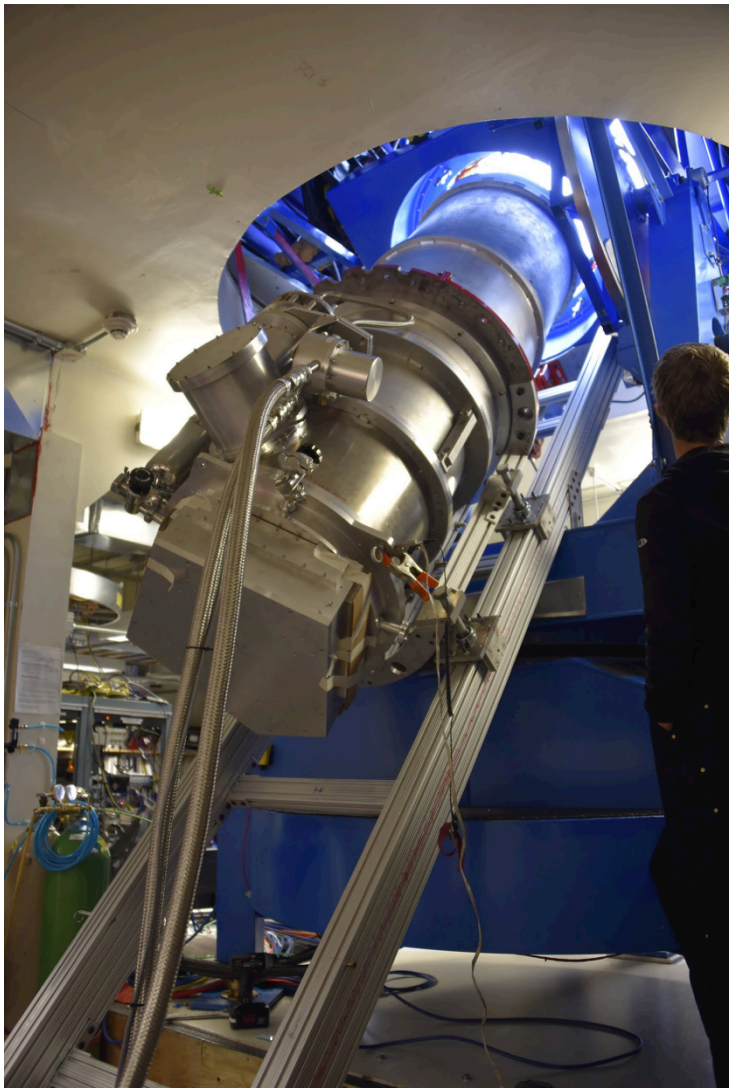

Focal Plane assembly



Cryogenics close up

Physics grad. Students designed and built this thing!

January 2016: BICEP3 installed in the telescope



Physics grad. Students at the South Pole in Antarctica!

Stage 2

Stage 3

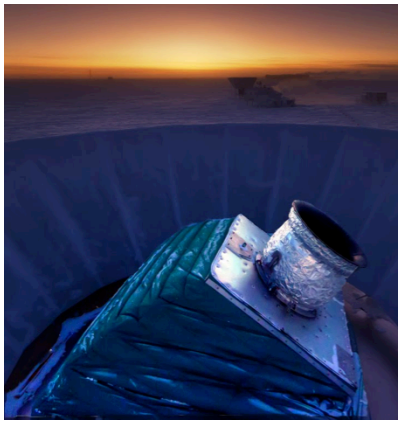
BICEP2
(2010-2012)

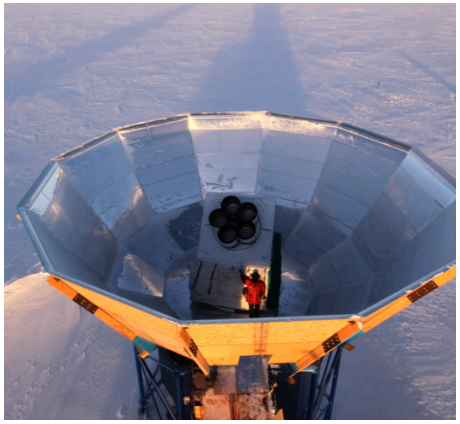
Keck Array
(2012-2017)

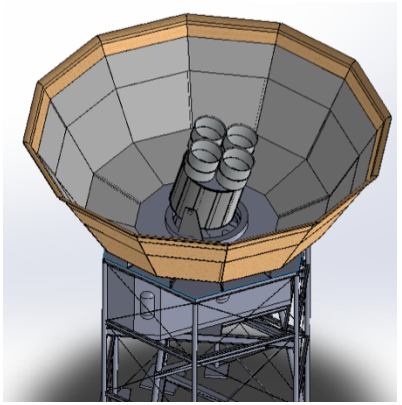
BICEP3
(2015-)

BICEP Array
(2018-)

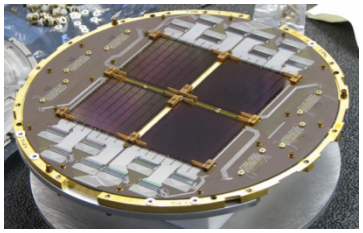
Telescope and Mount

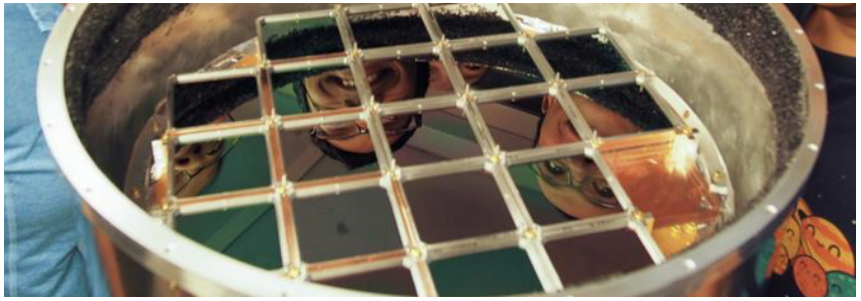




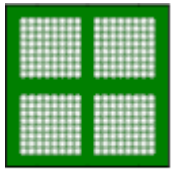


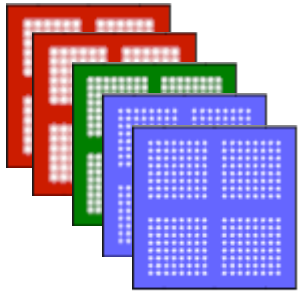
Focal Plane

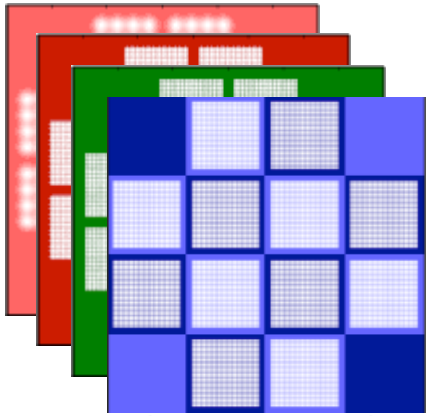




Beams on Sky







Summary

- The Universe is expanding – it was once a hot dense “fireball”.
- We understand its development all the way back to very close to the beginning. (For instance we know it is 14 billion years old.)
- The theory of Inflation says that our entire observable Universe today all came from a single sub-atomic spec in a hyper expansion lasting a tiny fraction of a second
  - If this Inflation really happened it will have made a background of gravitational waves
    - We may be able to detect the imprint of these as B-modes in the polarization pattern of the Cosmic Microwave Background
      - A few years ago we thought we had actually done this but unfortunately we were fooled by galactic dust emission.
        - However the search goes on with bigger and better experiments…
- Physics under grad. students work in our research labs!