

Studying the Beginning of the Universe from the End of the Earth

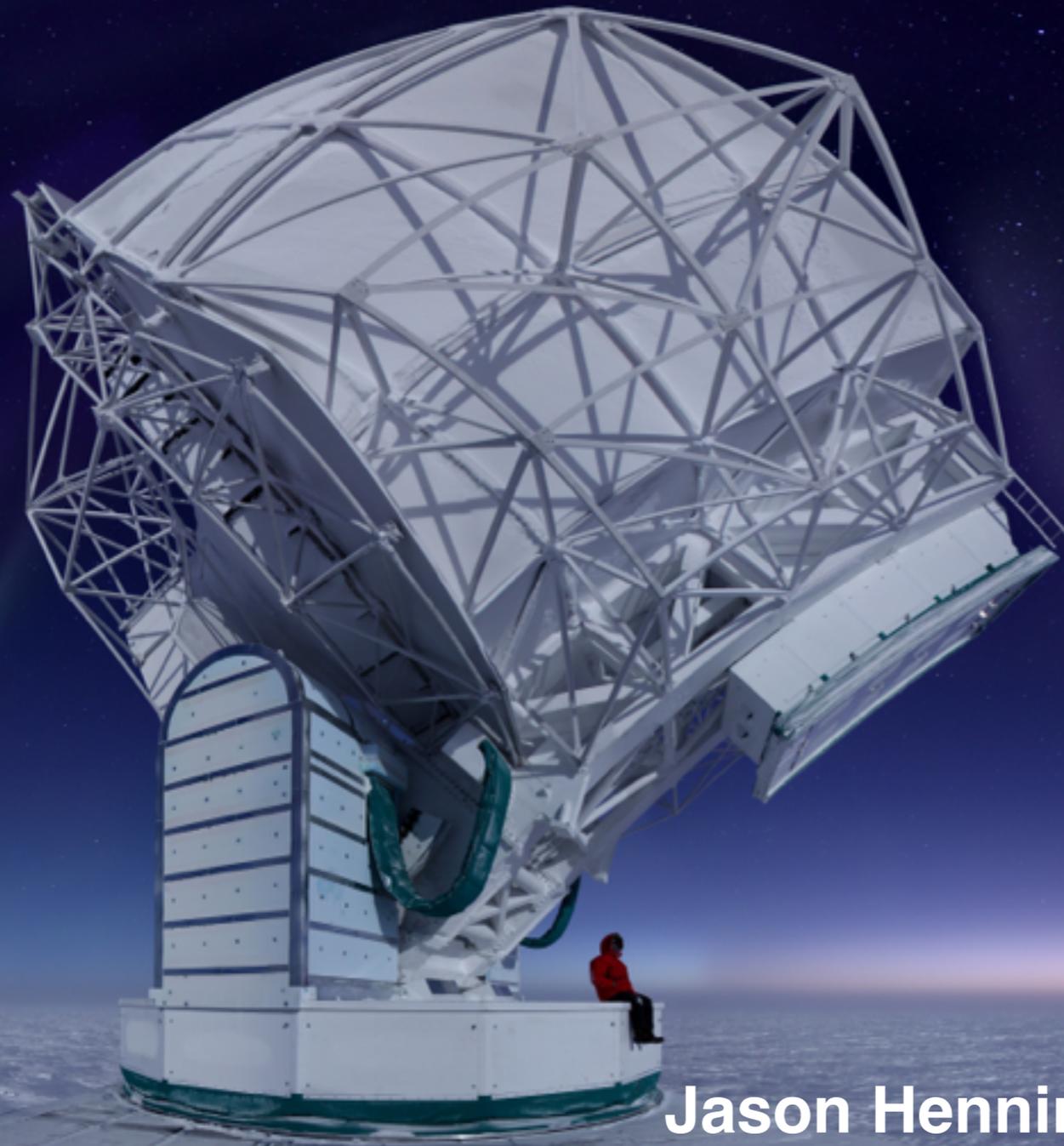


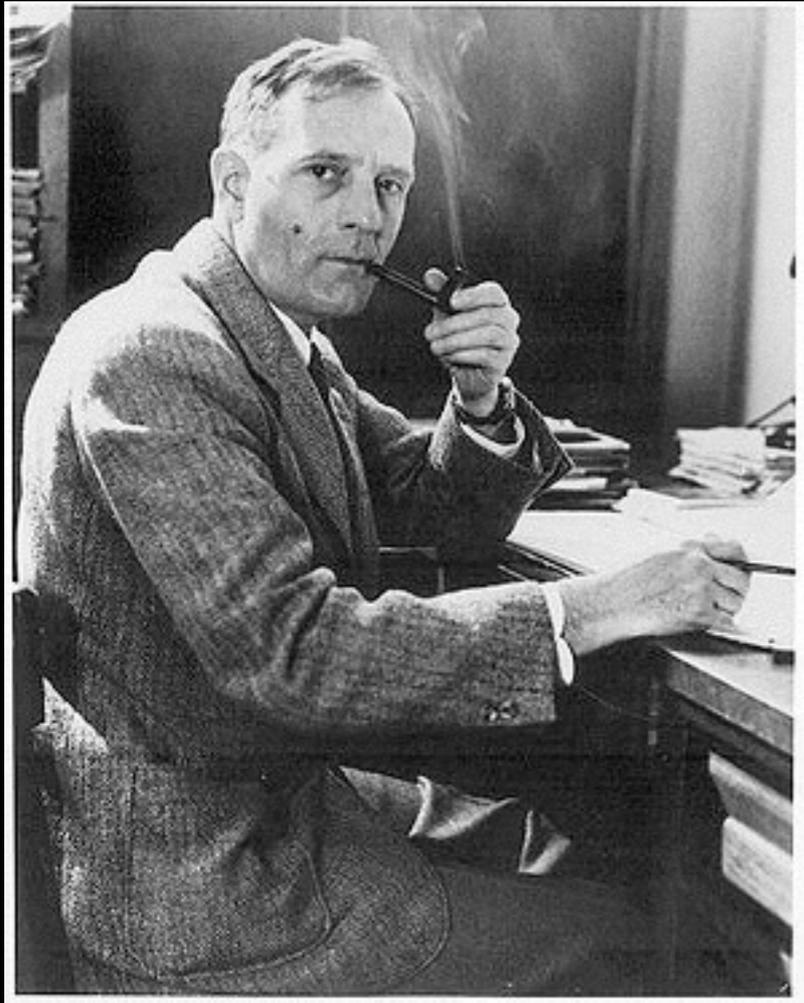
Photo credit: Jason Gallicchio

Jason Henning
5/7/2016

Woodson Regional Library

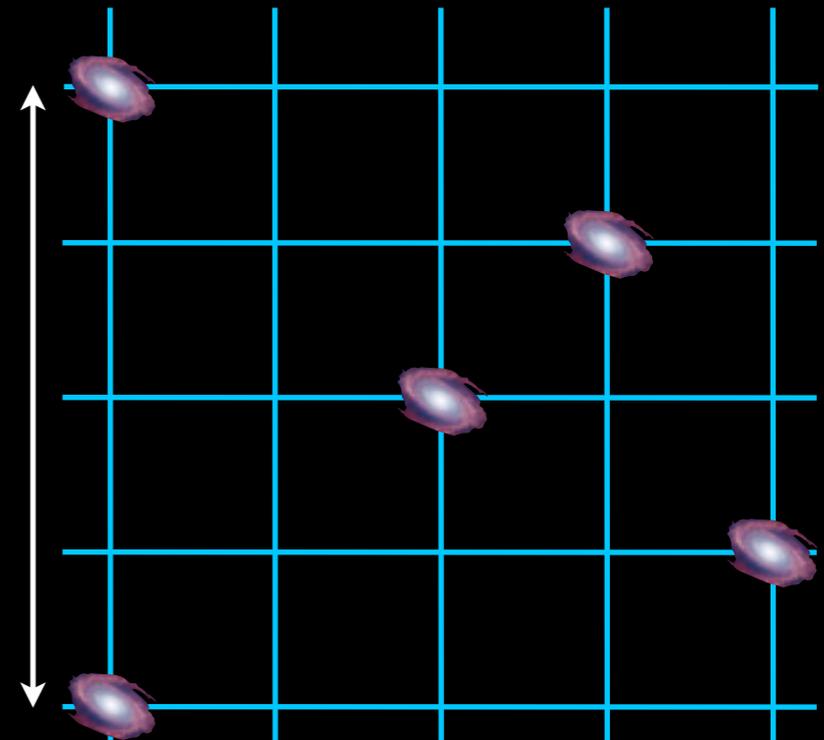
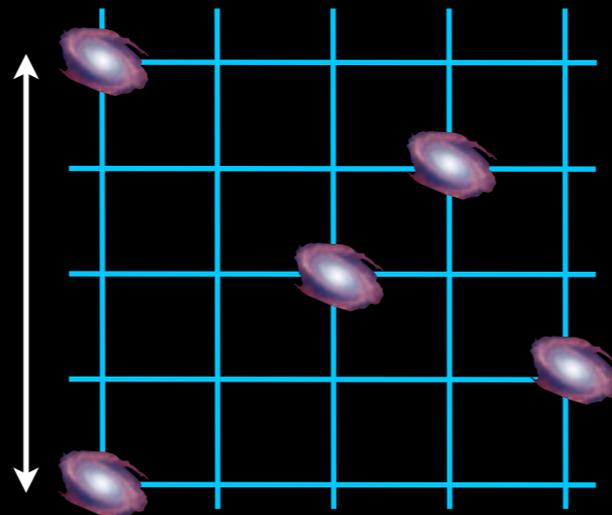
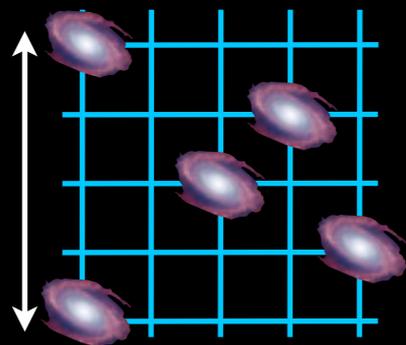
- A brief history of the universe (in reverse)
- The Cosmic Microwave Background
- South Pole Telescope
- Working at the South Pole

The Expanding Universe



Edwin Hubble - 1929

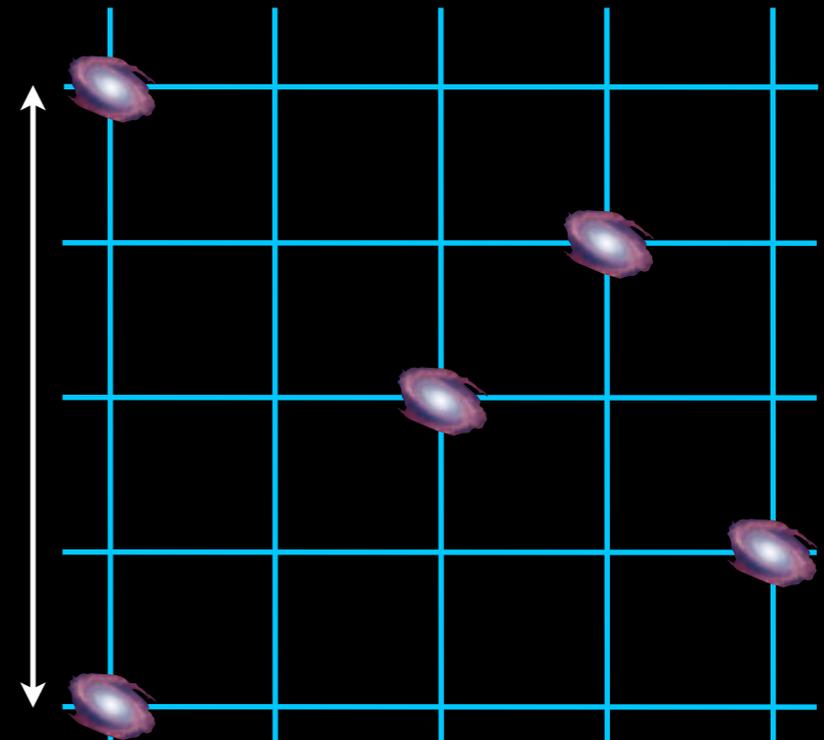
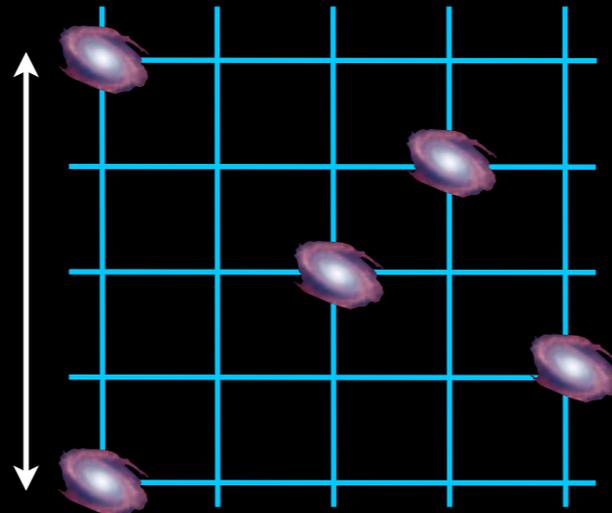
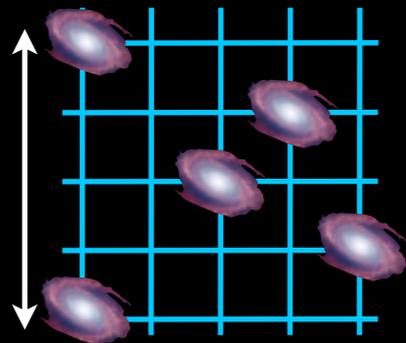
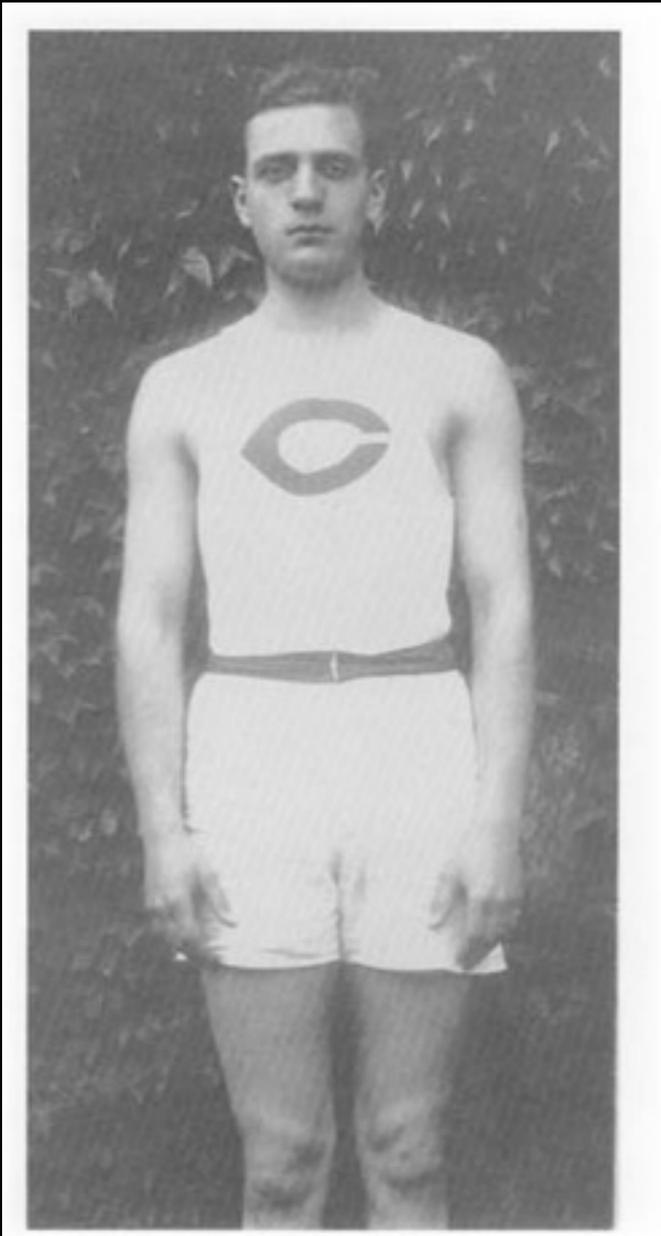
Galaxies are moving away from each other. The farther apart they are, the faster they recede!

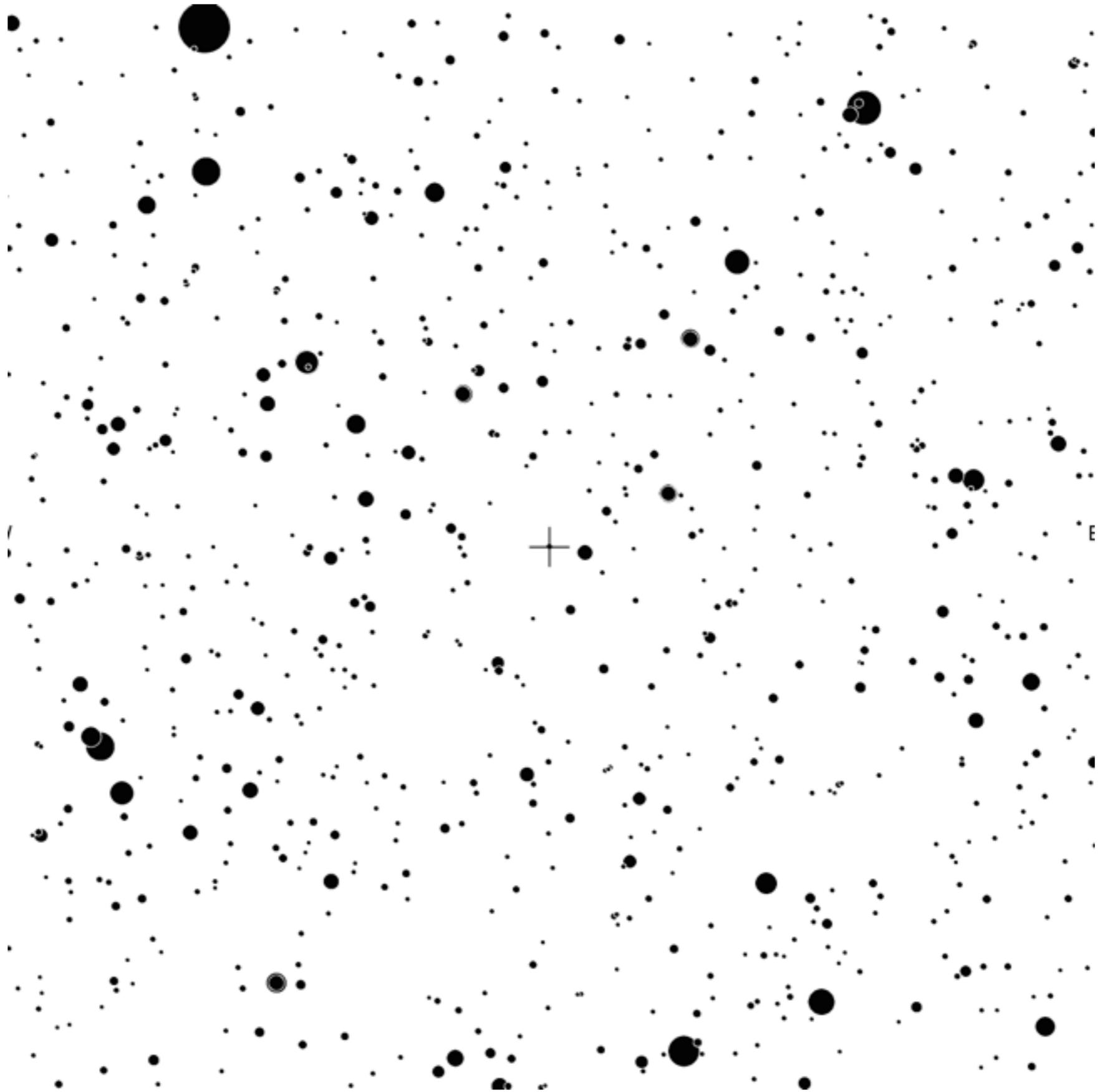


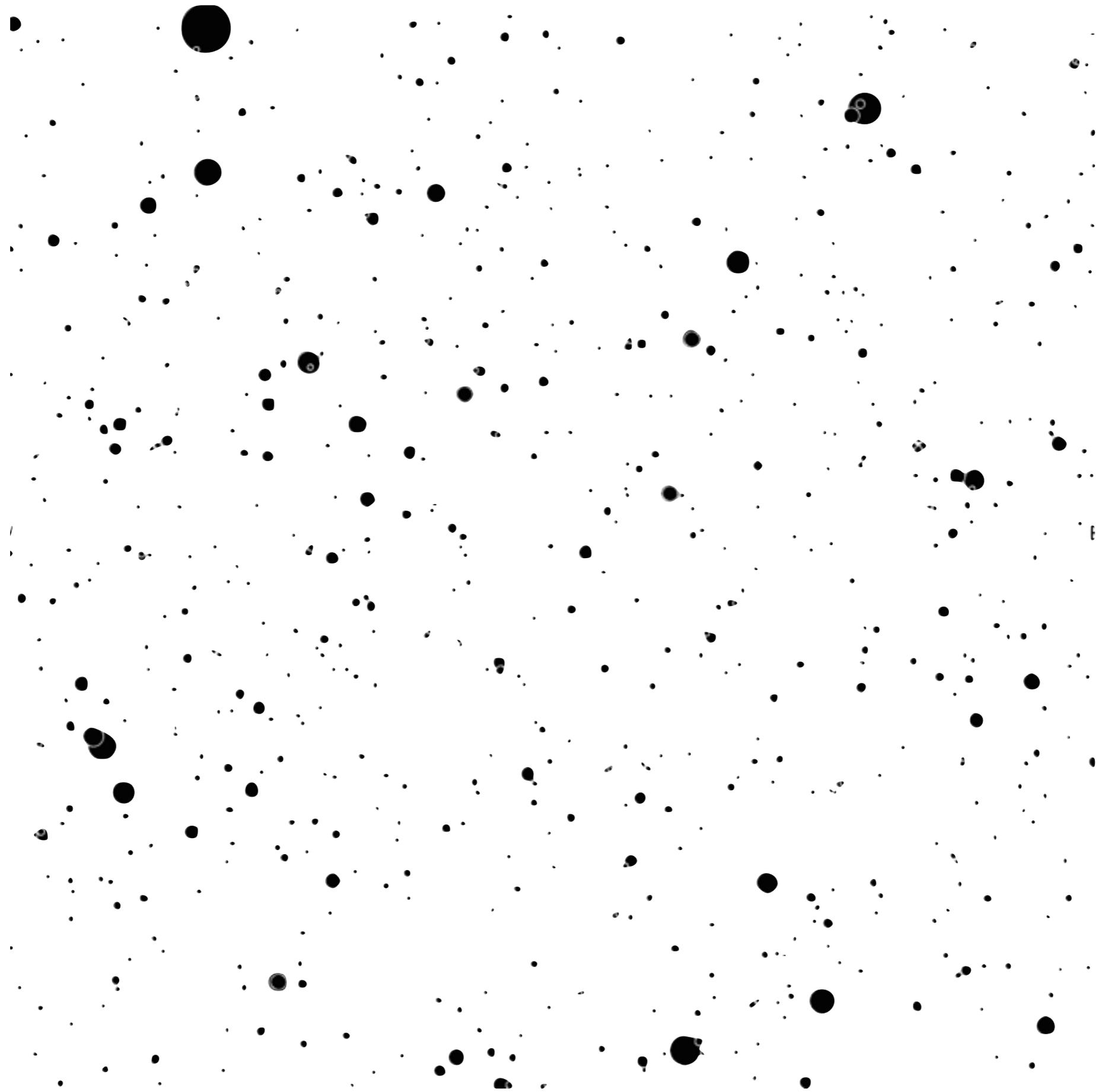
The Expanding Universe

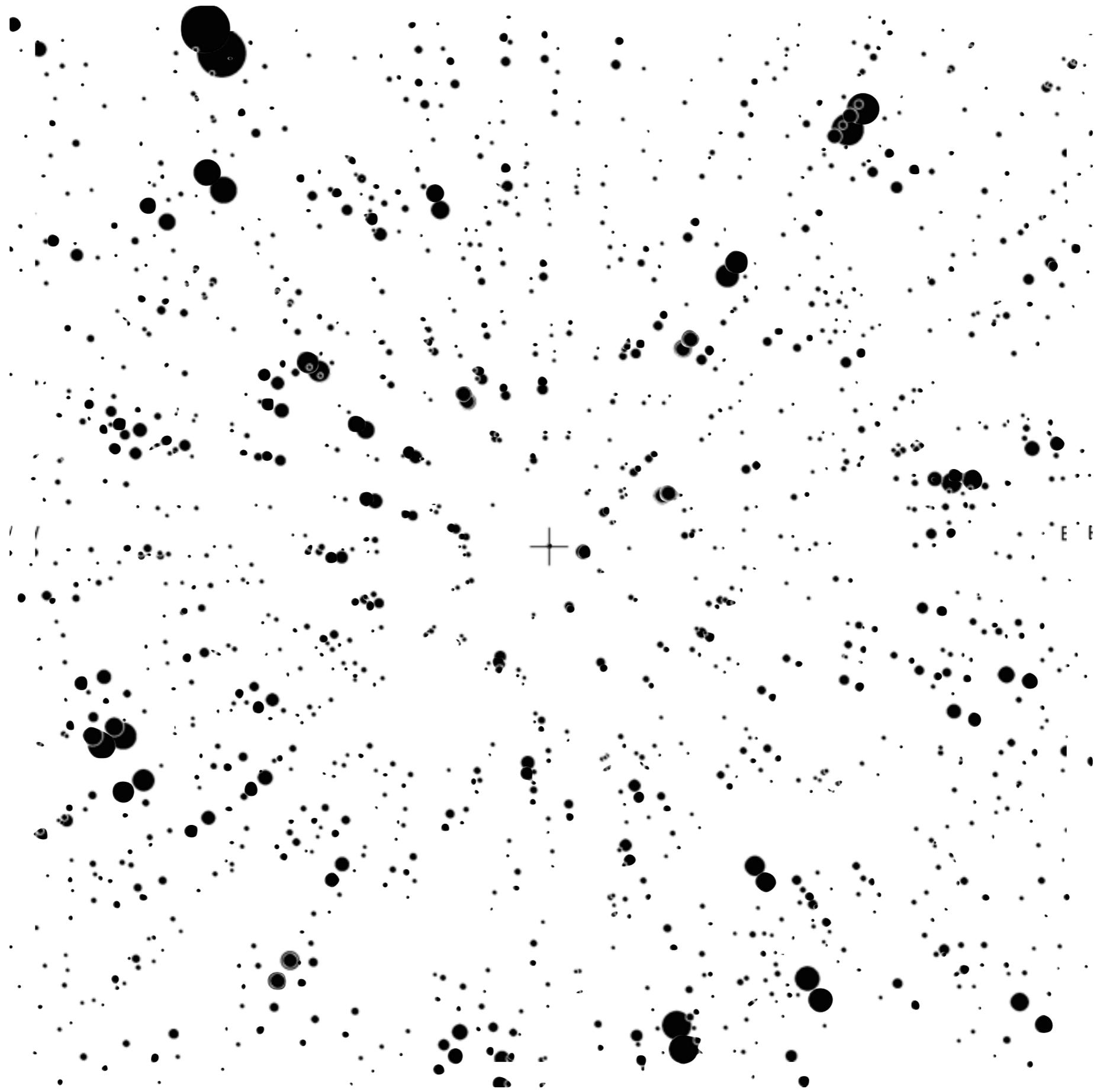
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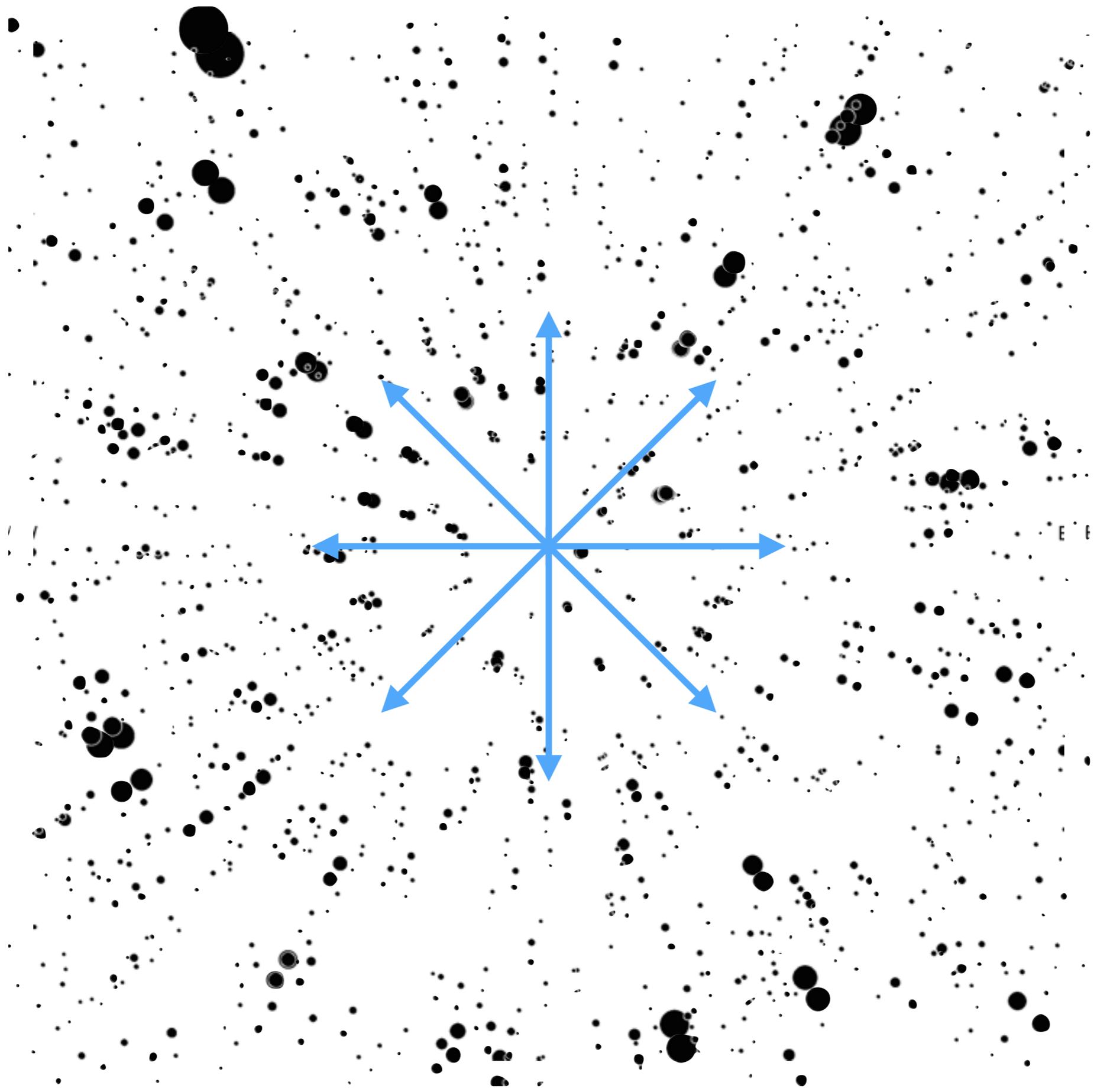
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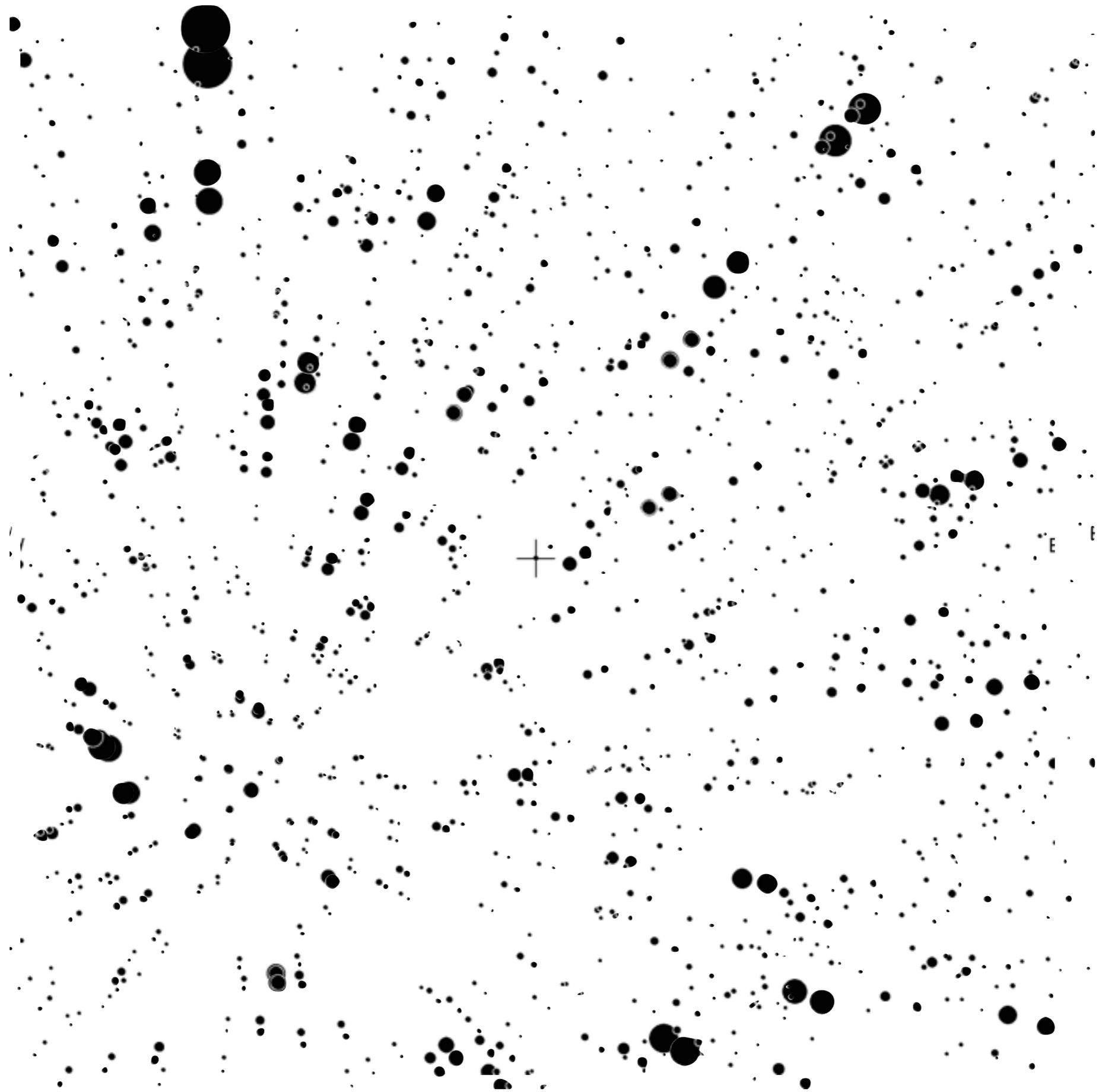


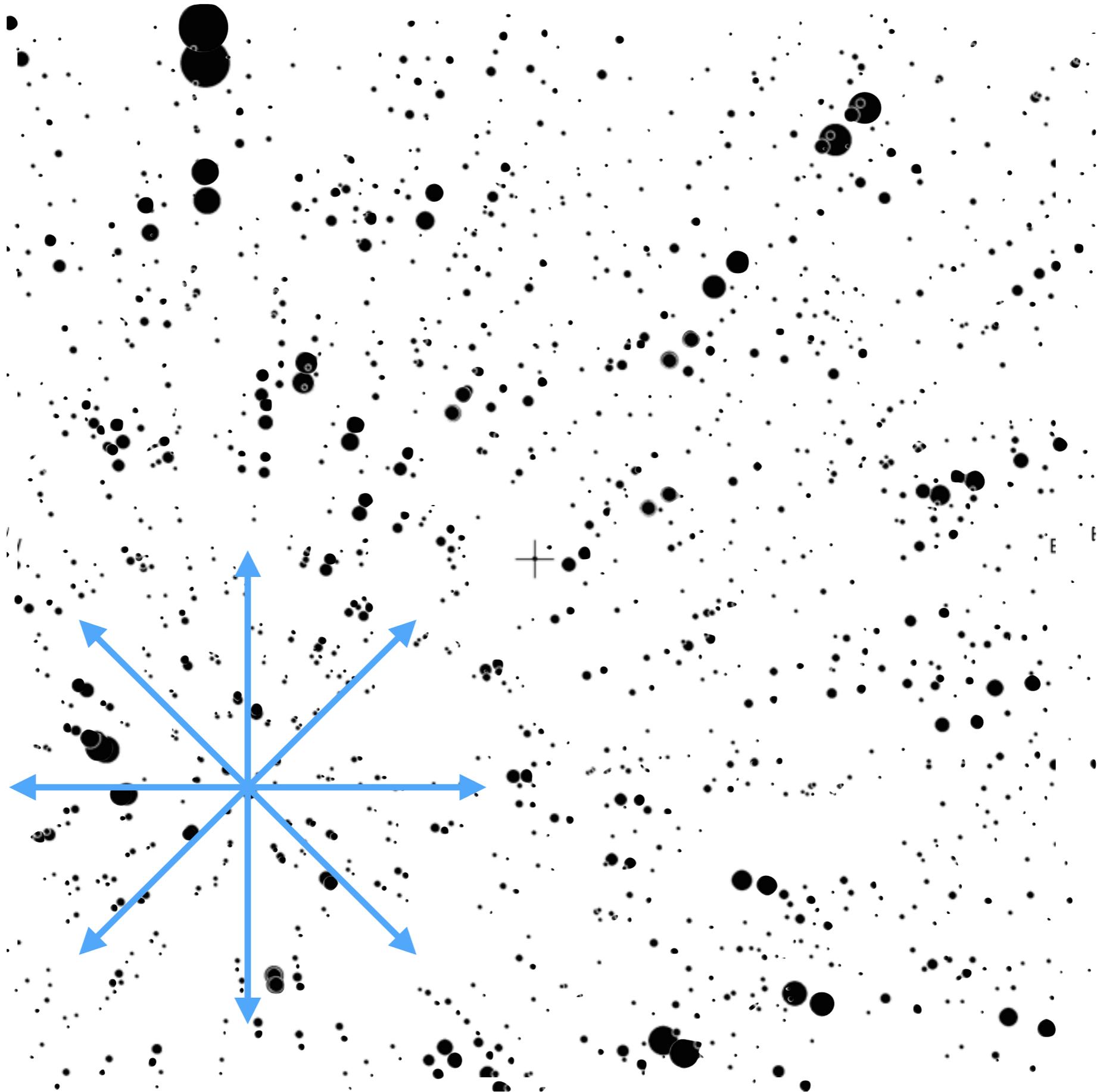


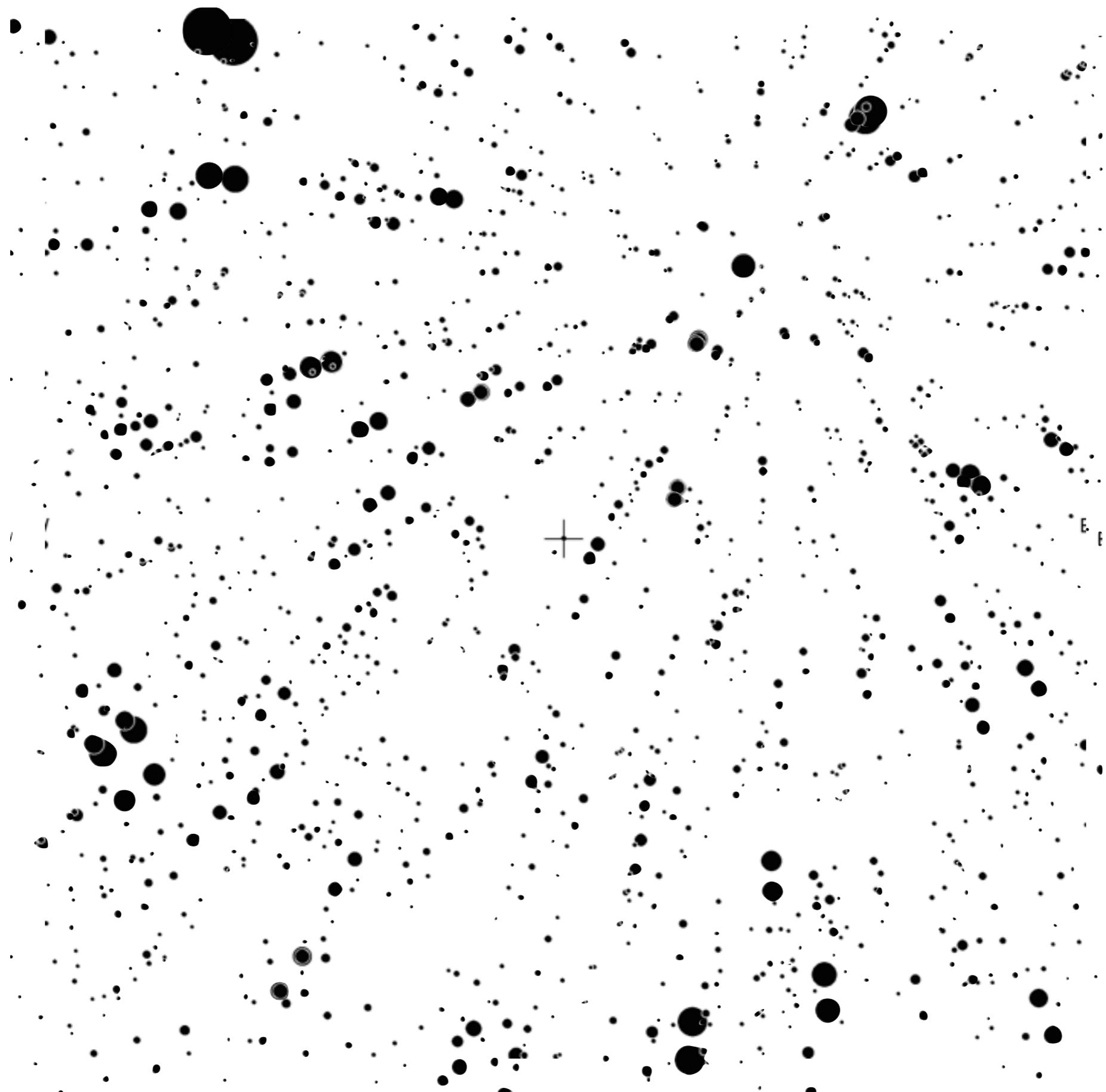


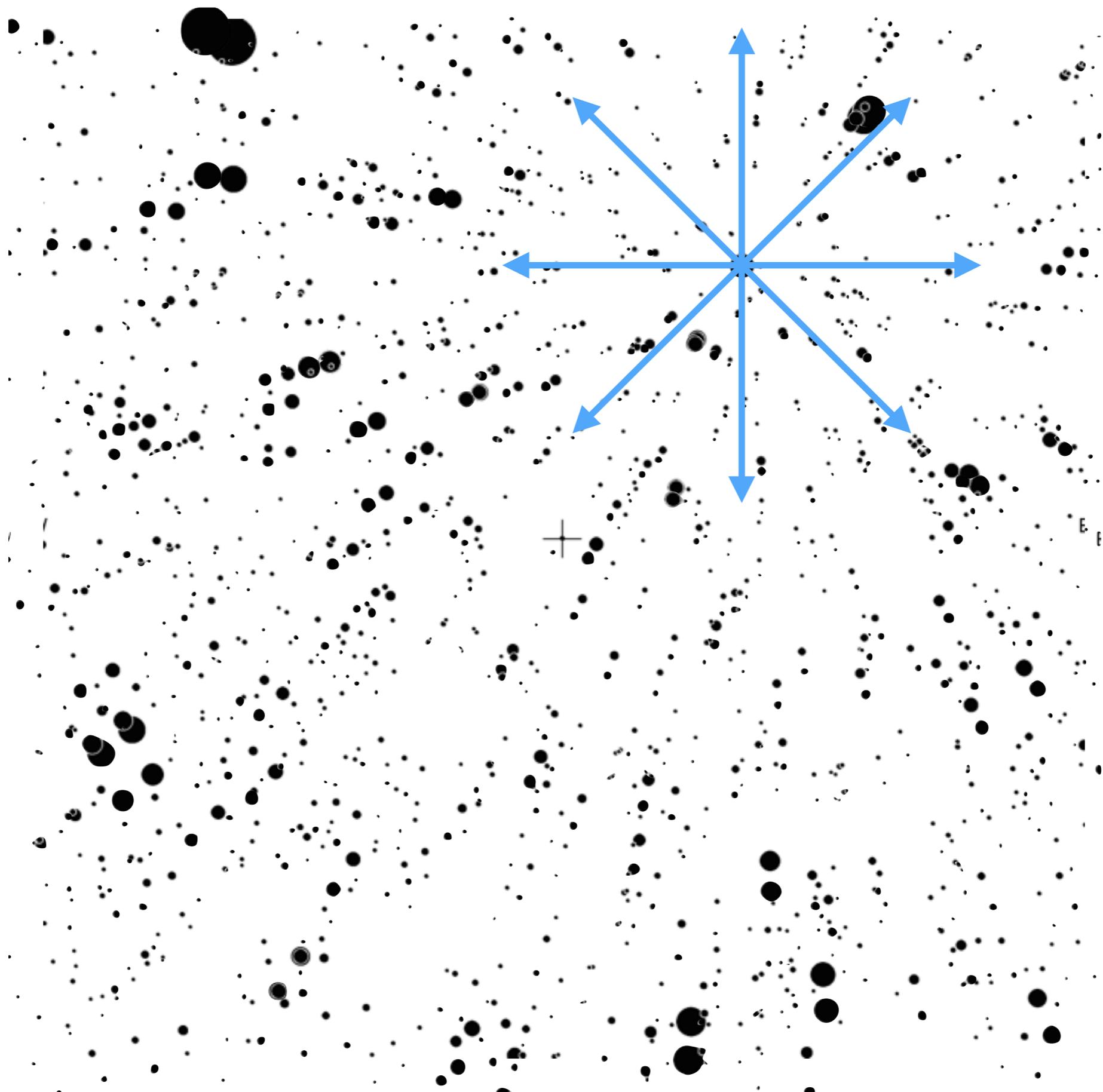




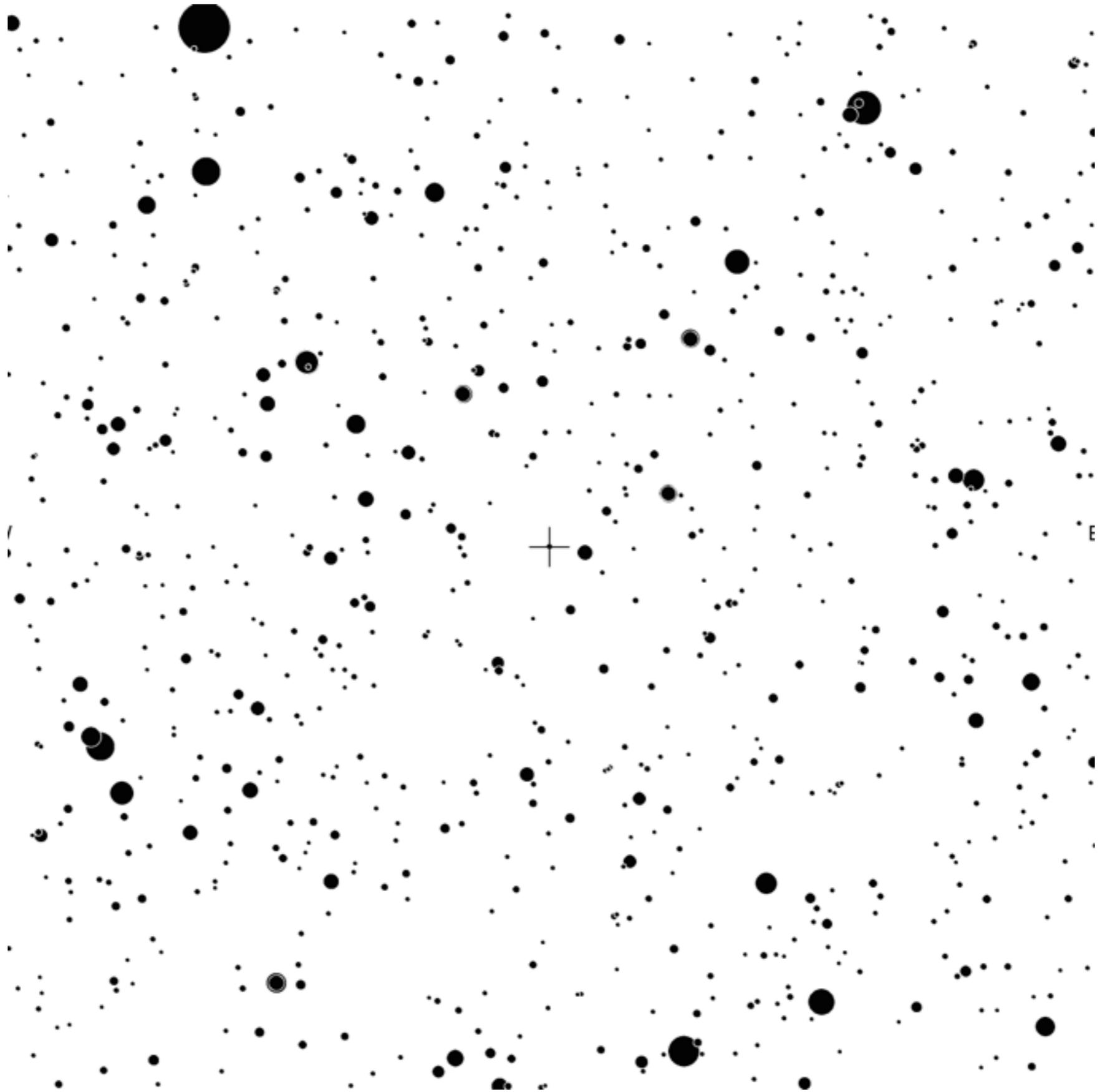


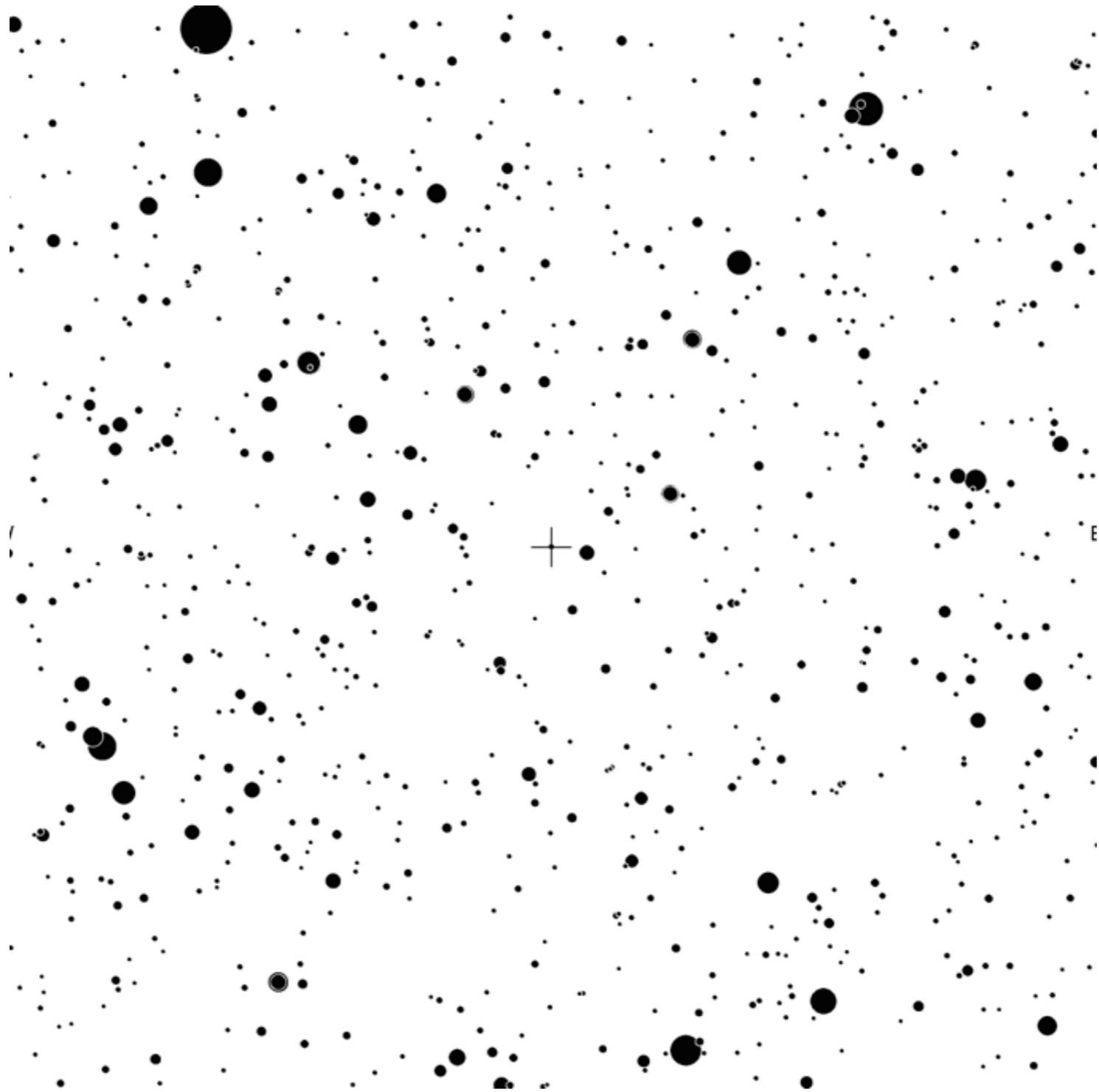




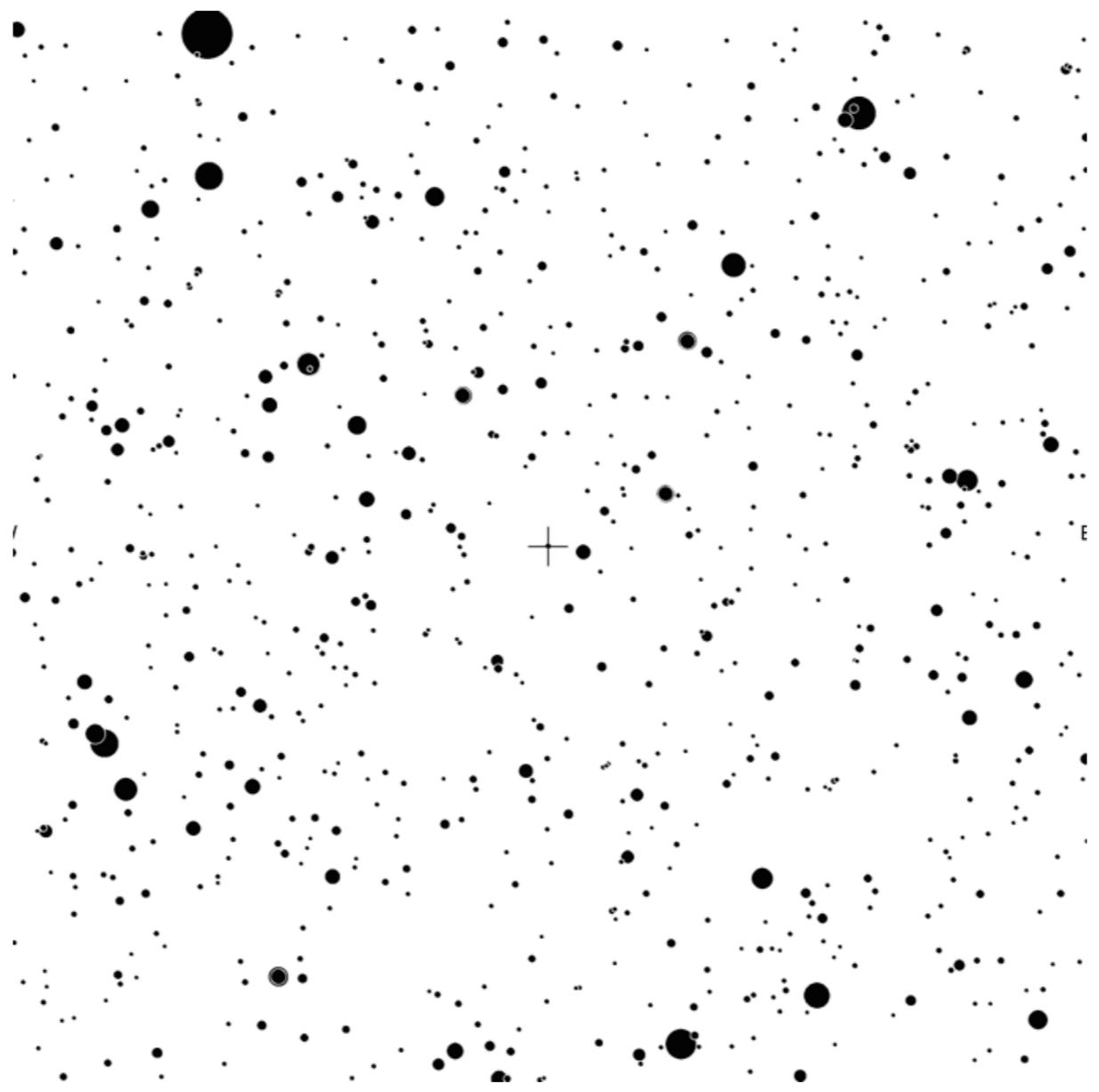


If the universe is
expanding, what if we
run time in reverse?





The universe gets denser and hotter...



...and denser and hotter...

...and denser and hotter...

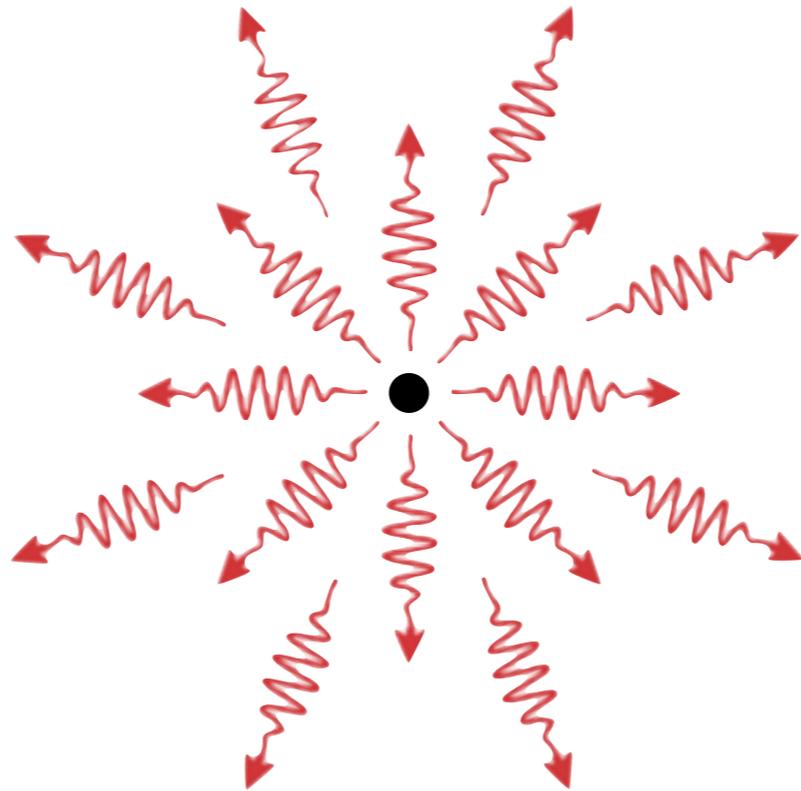


... until it's infinitely dense
and infinitely hot at the very
first moment.



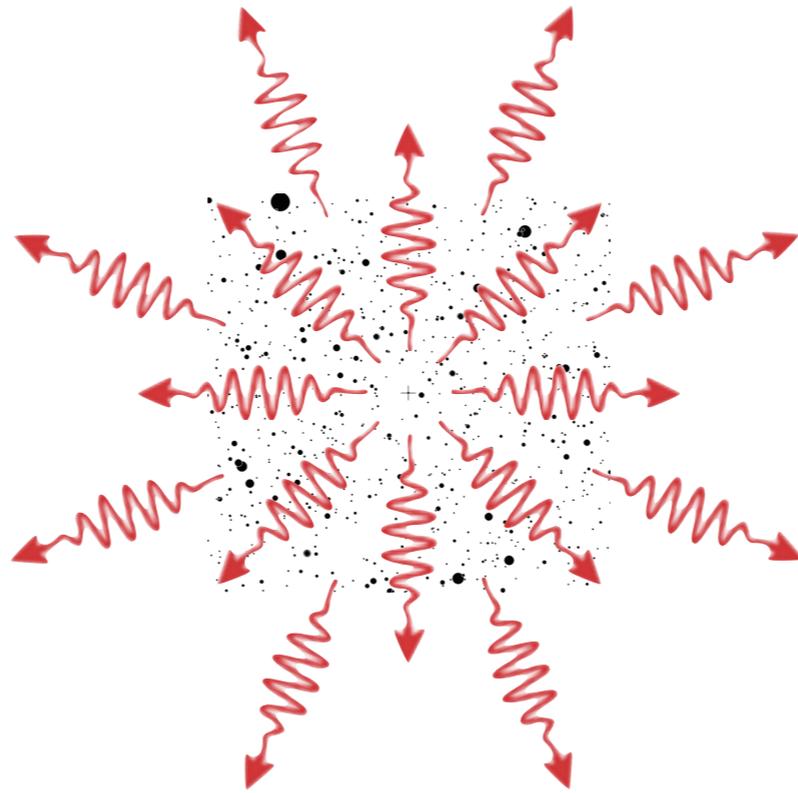
This “first moment” is the Big Bang!

Hot things glow (and so do you)

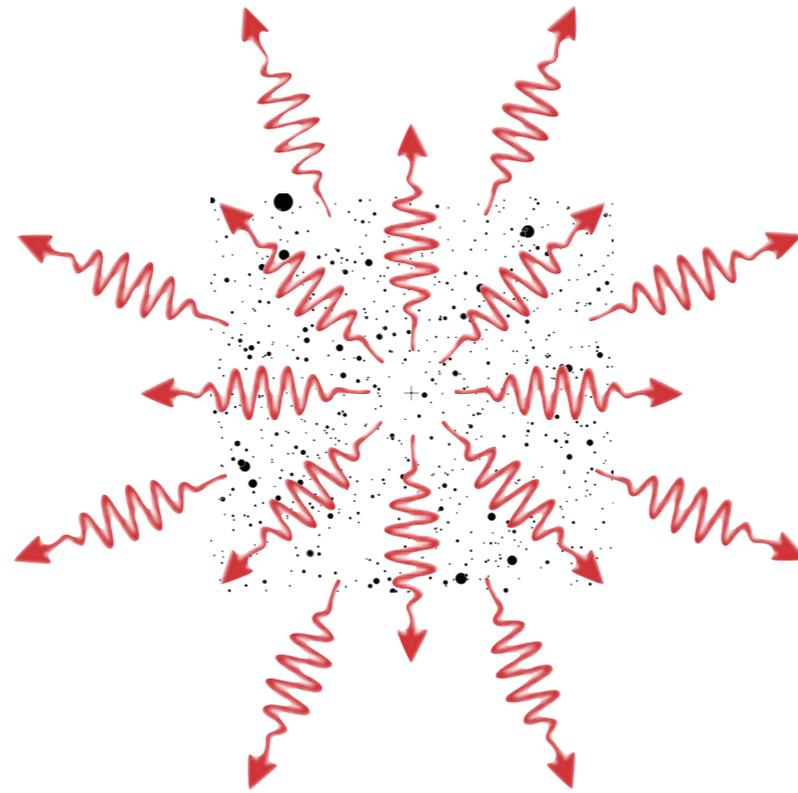


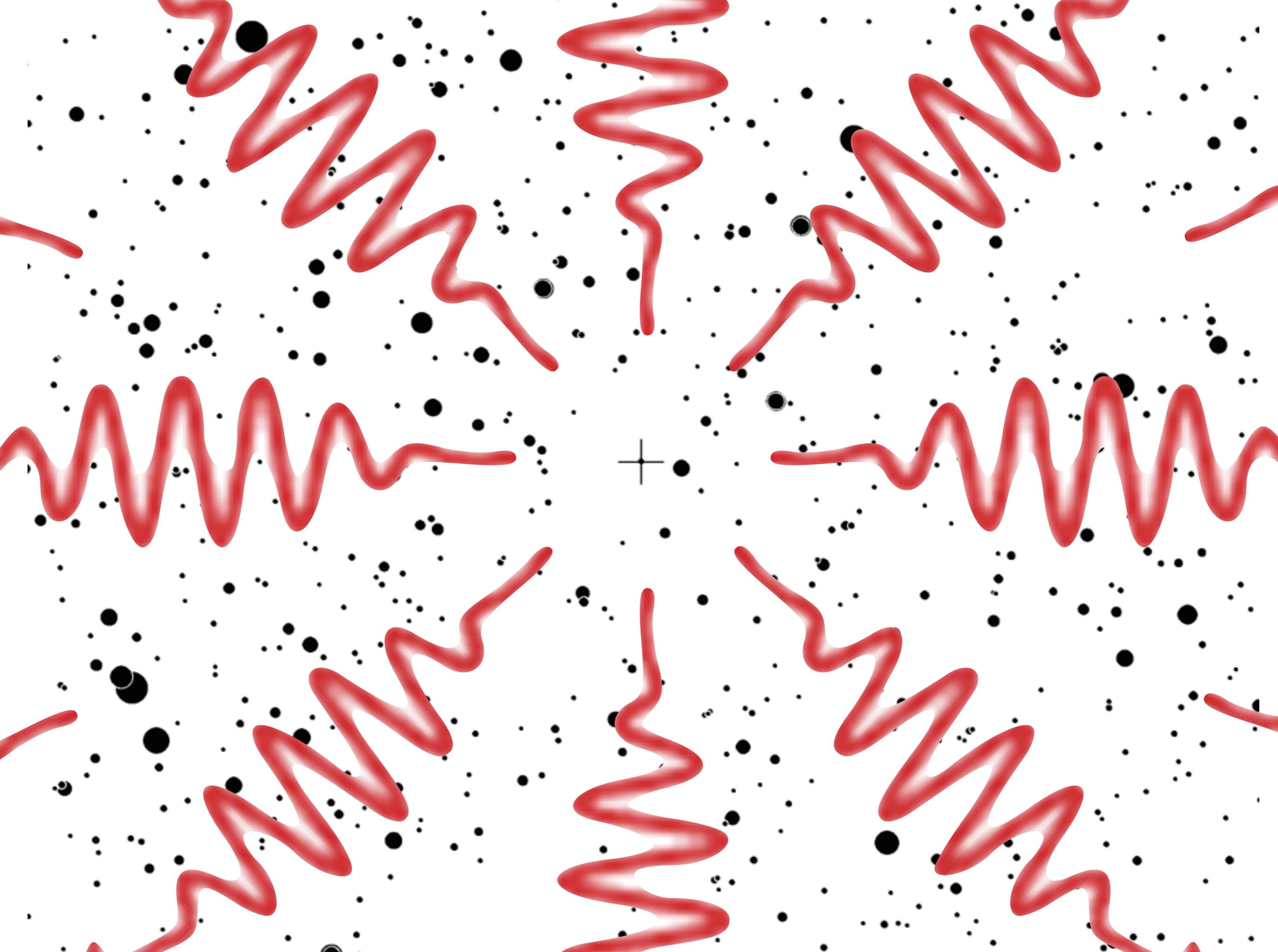
Gas in the early universe glows too

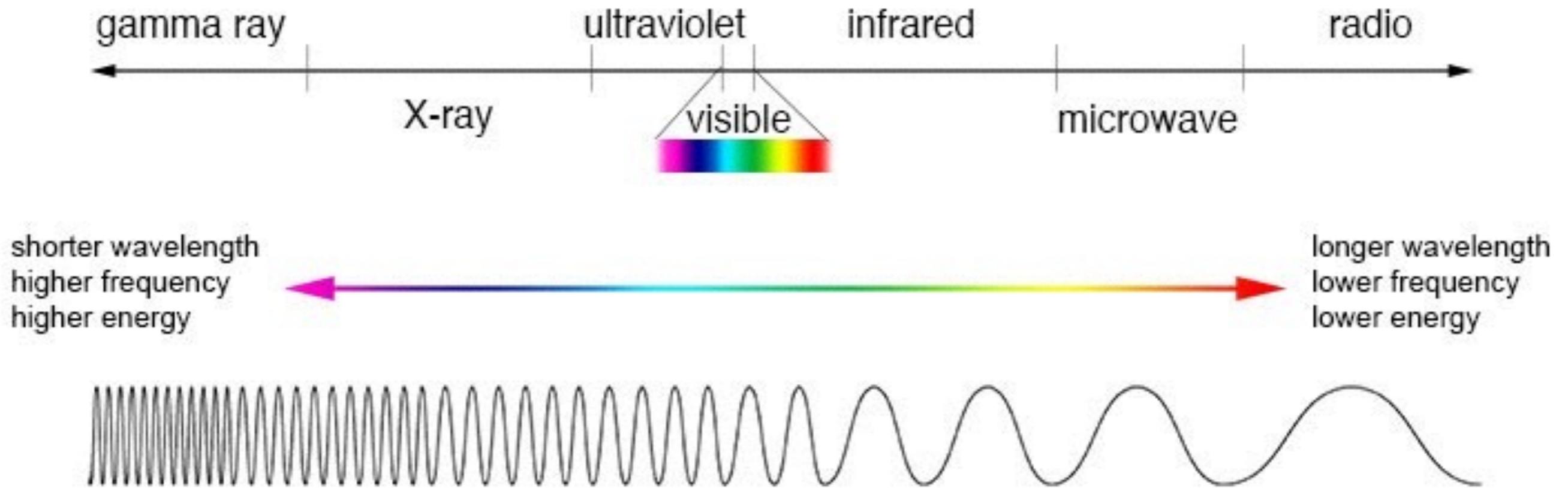
Hot things glow (and so do you)



As the universe expands and cools, this “after glow light of the Big Bang” stretches and cools with it.



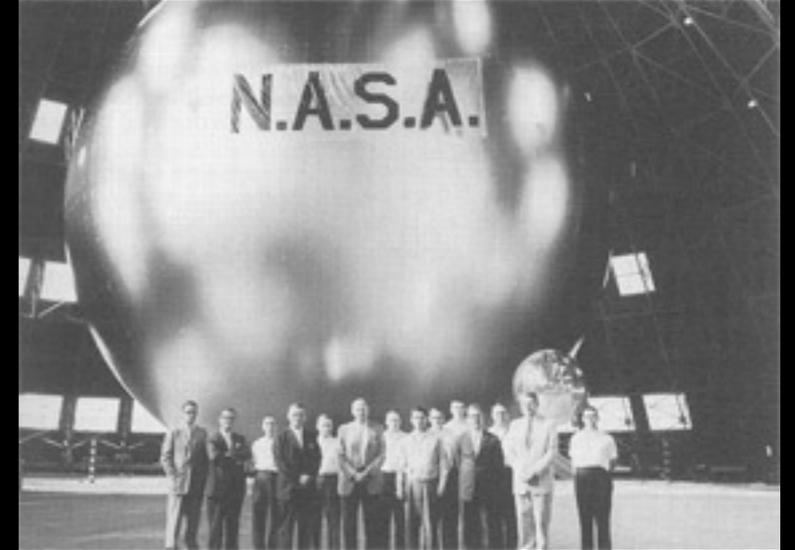




The light left over from the hot, young universe gets stretched further and further. What started as a **human-visible** glow is now **microwave** light. We call this afterglow the **Cosmic Microwave Background**.

So do we see this
afterglow?

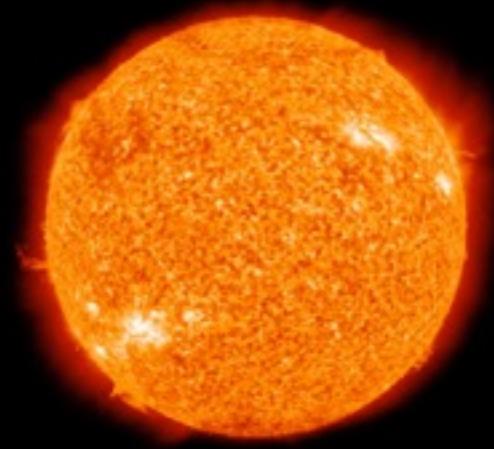
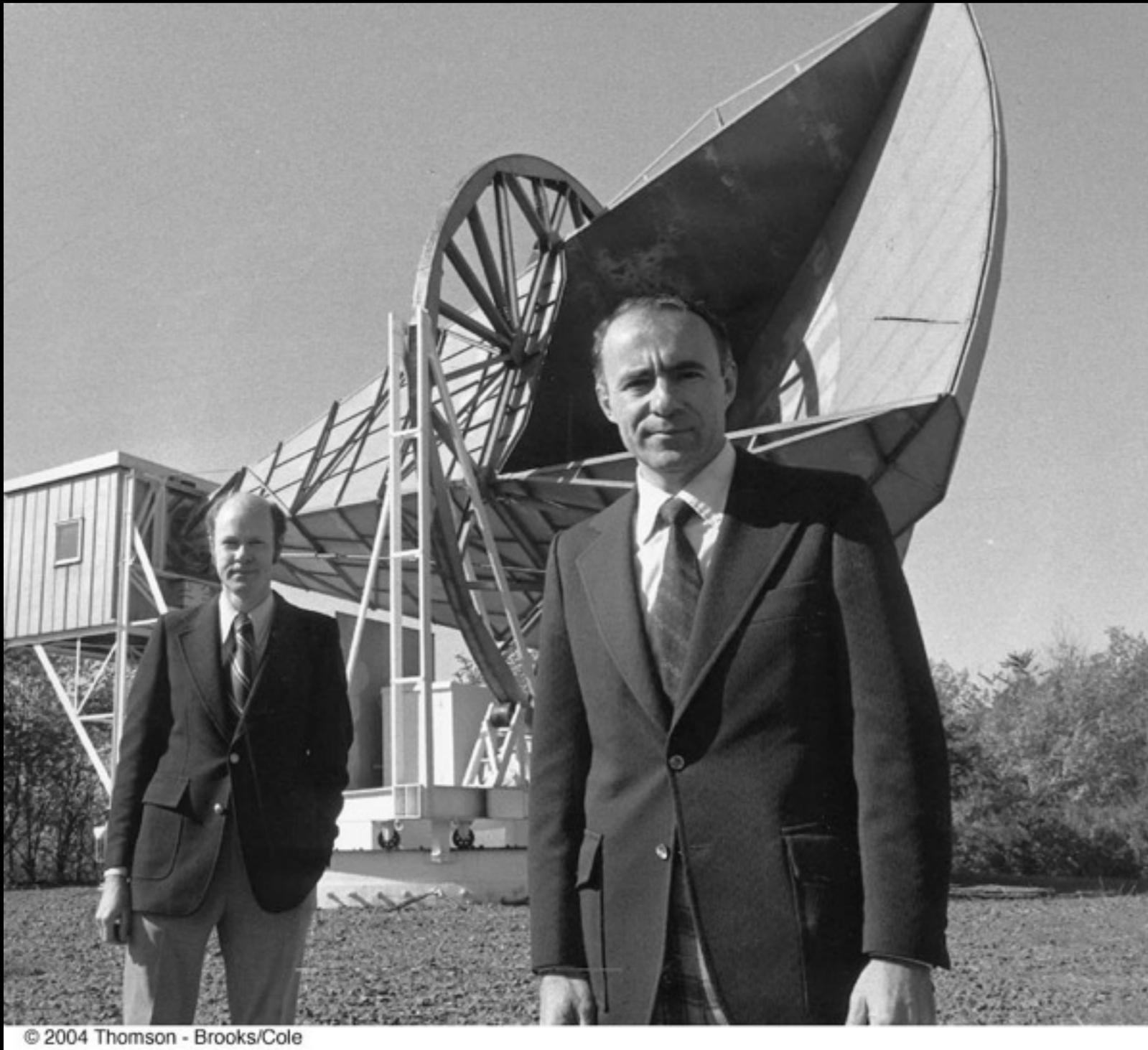
Penzias and Wilson



Trying to measure
radio waves bouncing
off metalized
high-altitude balloons
...
but lots of excess “static”

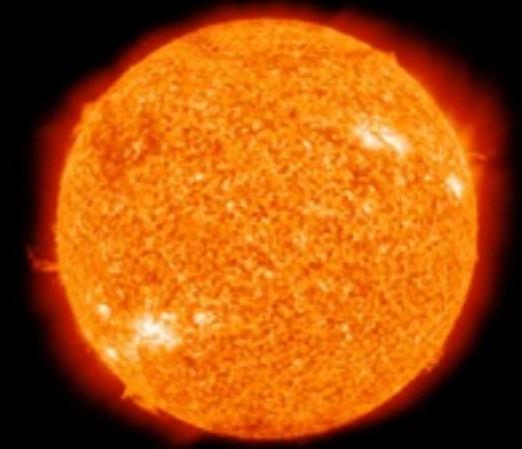
Bell Labs' Horn Antenna, NJ

Penzias and Wilson



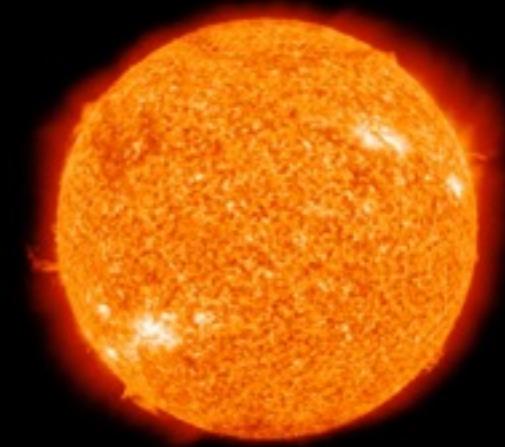
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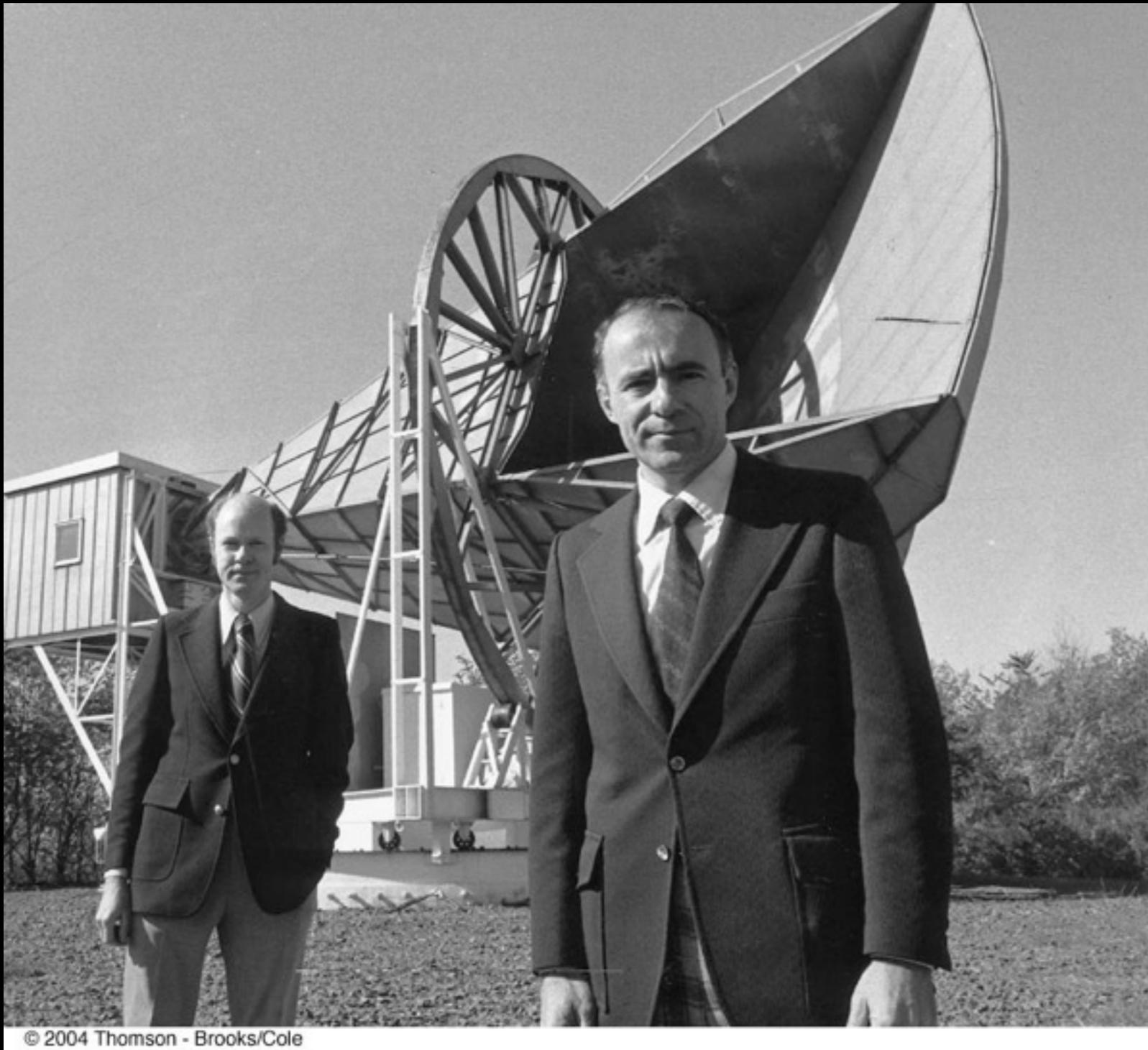
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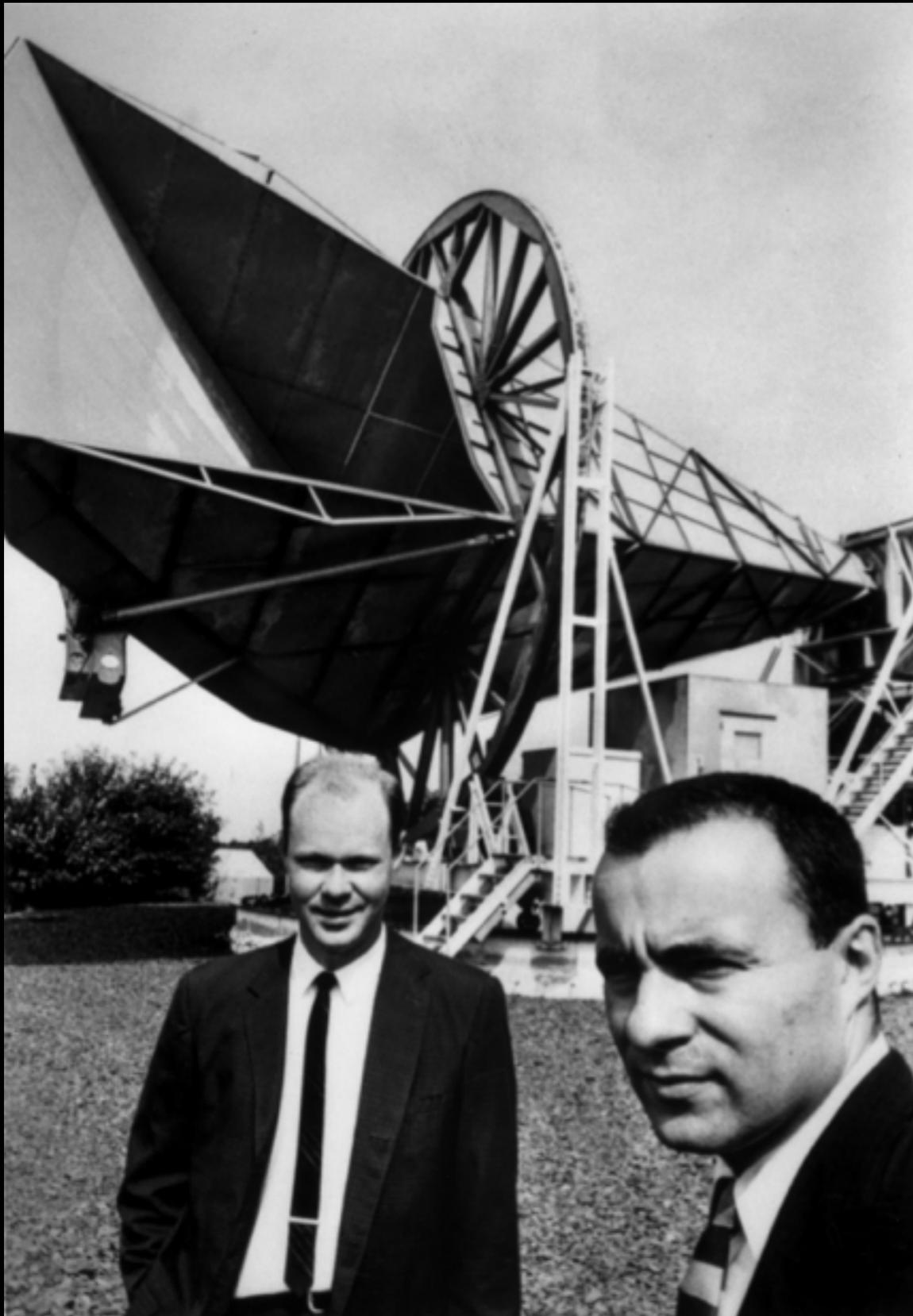
Bell Labs' Horn Antenna, NJ

Penzias and Wilson



Bell Labs' Horn Antenna, NJ

Penzias and Wilson



Bell Labs' Horn Antenna, NJ

Robert Dicke



Jim Peebles

Dave Wilkinson

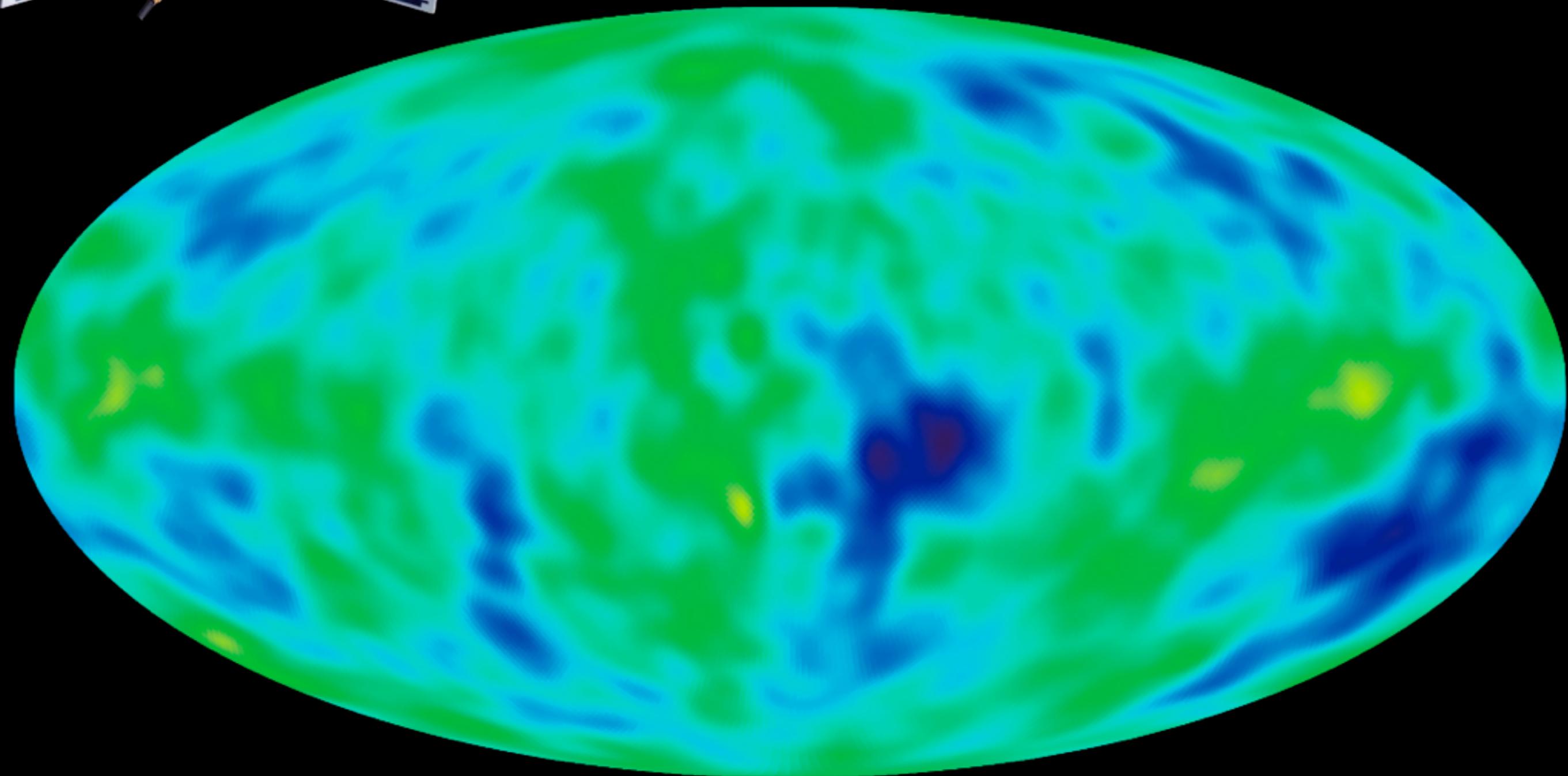


Penzias and Wilson - 1965 (Nobel Prize - 1978!)



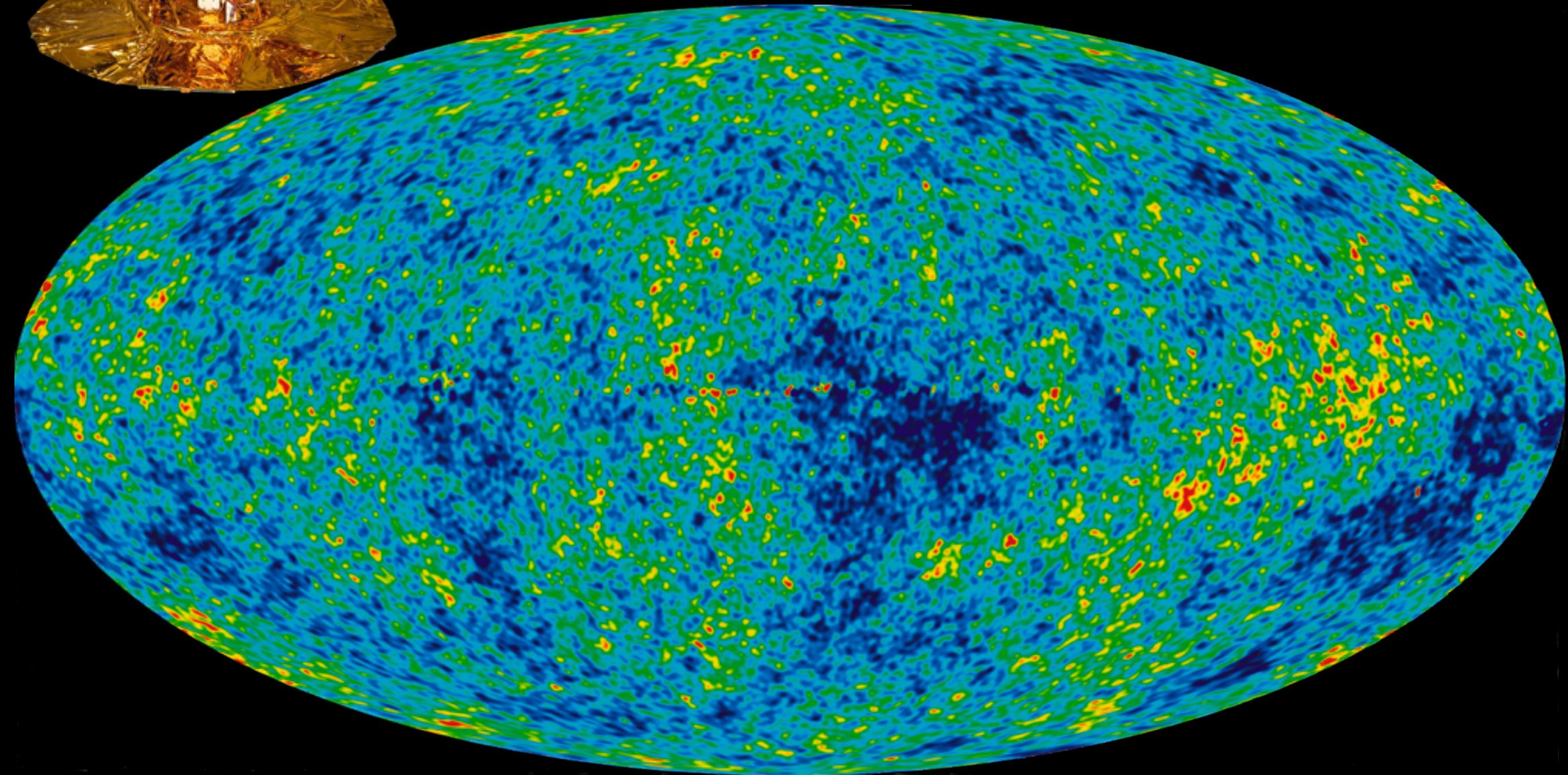
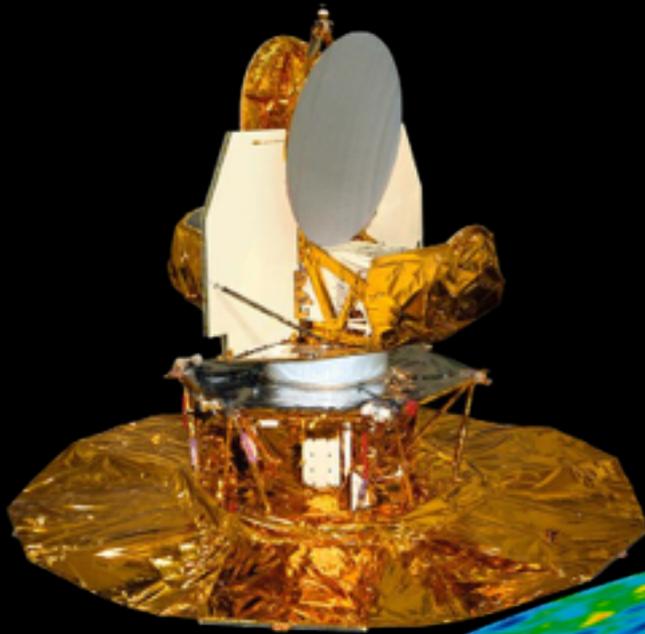
Uniform glow everywhere

COBE - 1989
(Nobel Prize - 2006!)



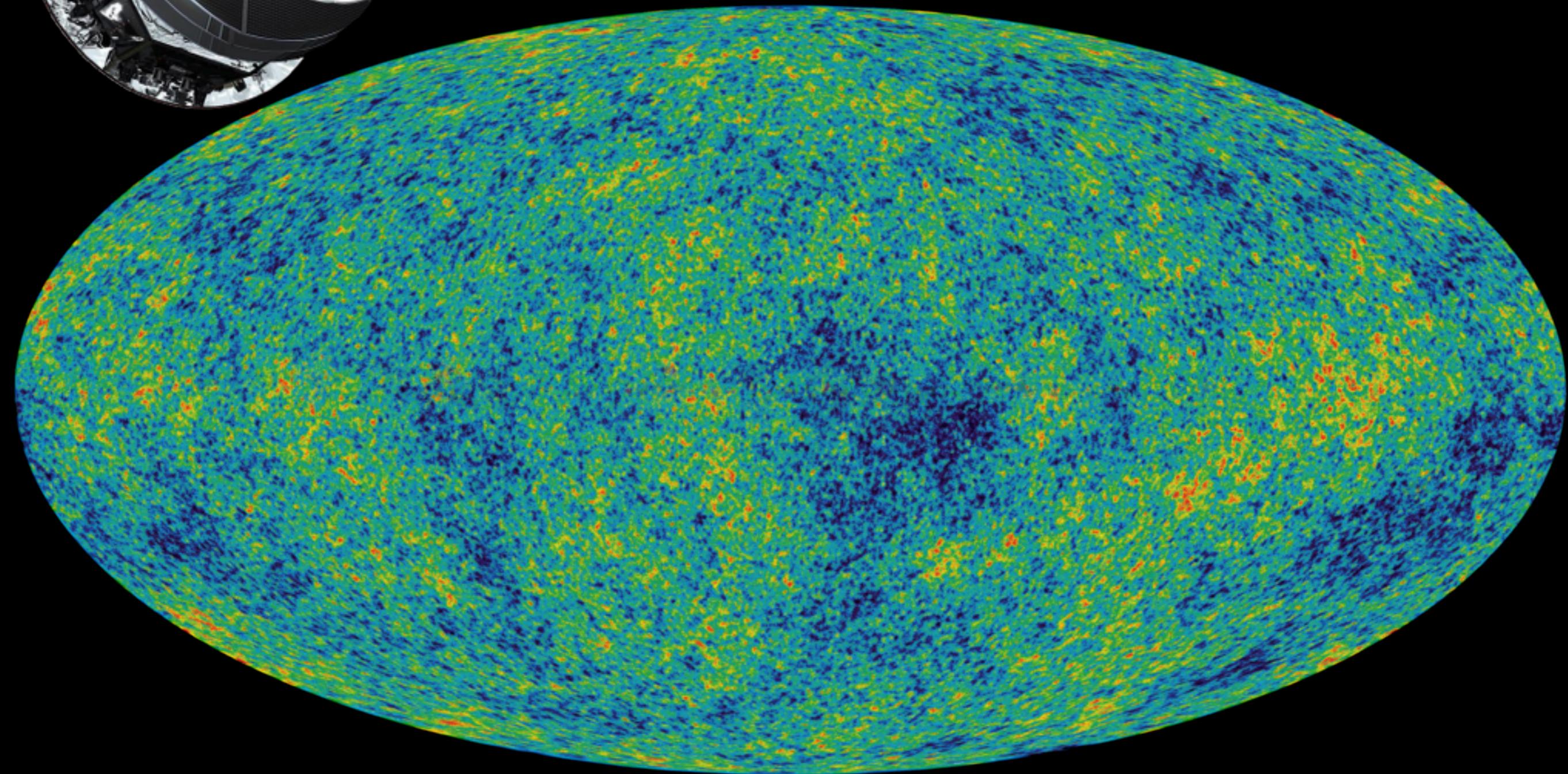
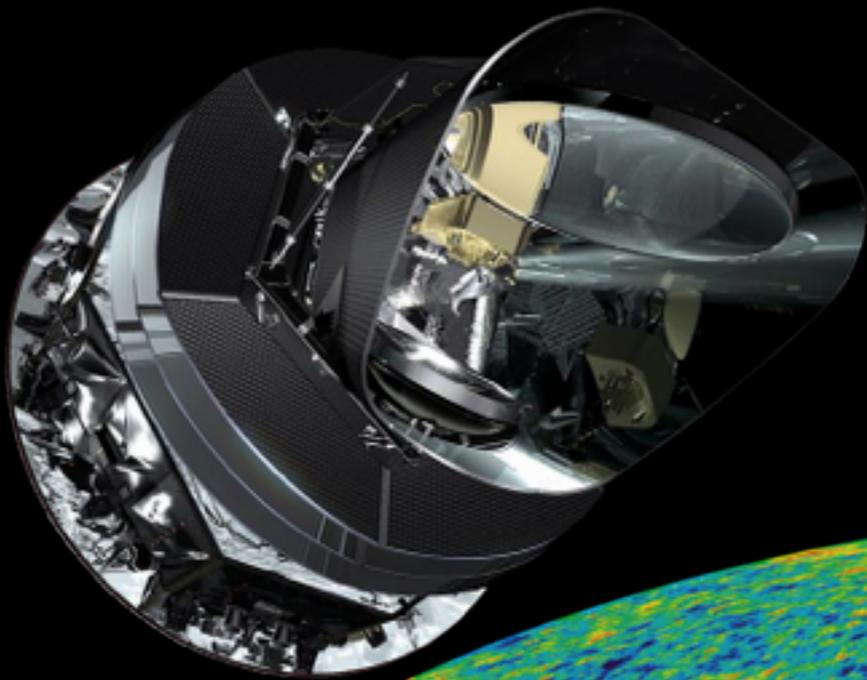
Turn up contrast by 100,000x ...

WMAP - 2001



Higher resolution...

Planck - 2009



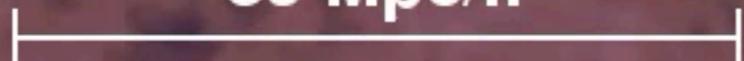
Even *higher* resolution...

The CMB is a Baby Picture Of the Universe

- Seeds of structure
 - Tiny variations in temperature reveal the distribution of matter in the early universe.
- Gravity acts over billions of years to make galaxies, stars, planets...

$z = 17.6$

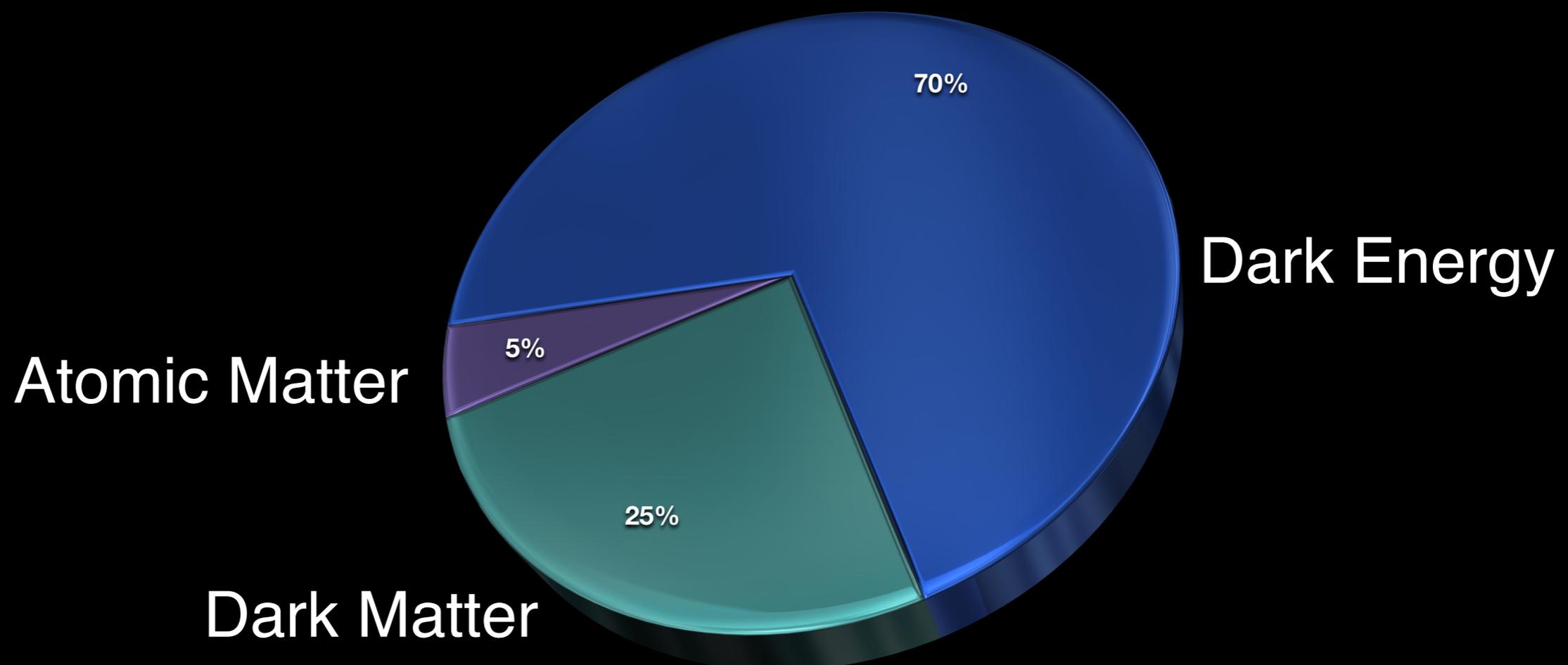
50 Mpc/h



Studying the Seeds of Structure

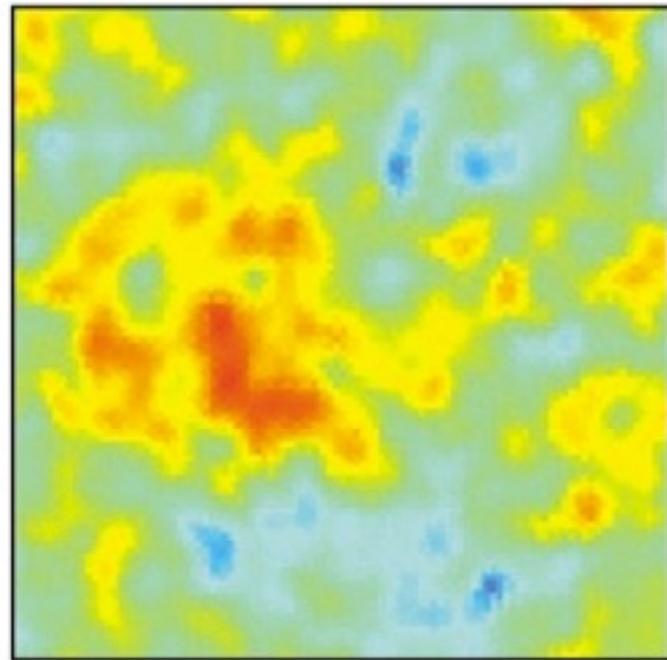
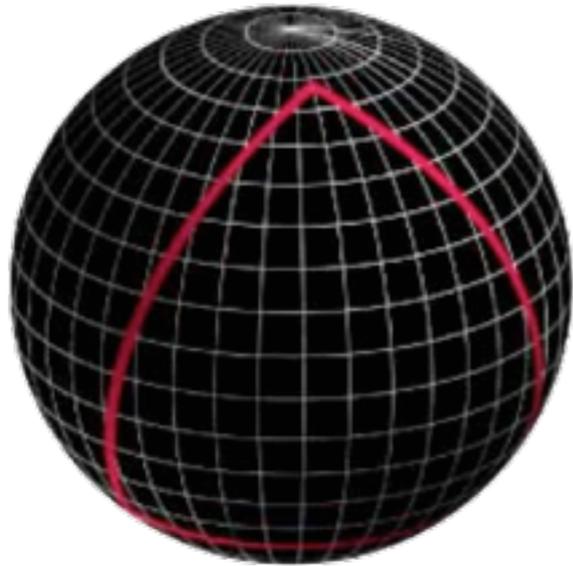
–What is the universe made of?

- Atoms make up only ~5% of the “stuff” that’s out there.
- The rest is really weird.
 - Dark Matter (~25%): Feels gravity but doesn’t interact with light.
 - Dark Energy (70%): ???... But it’s causing expansion to speed up.

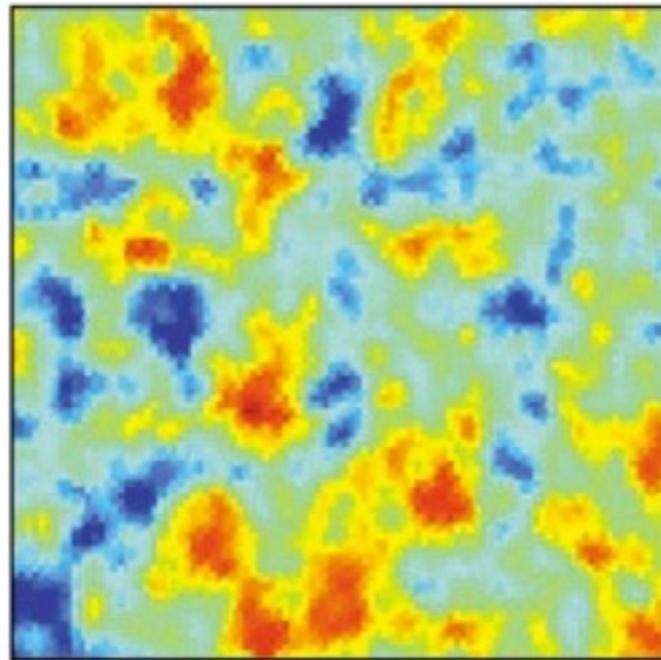
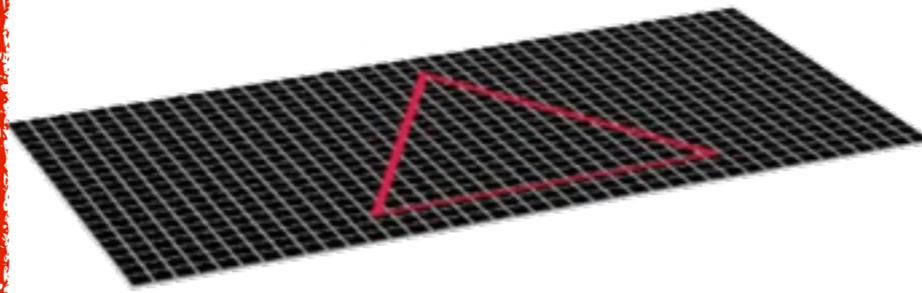


Measuring the “Shape” of the Universe with the CMB

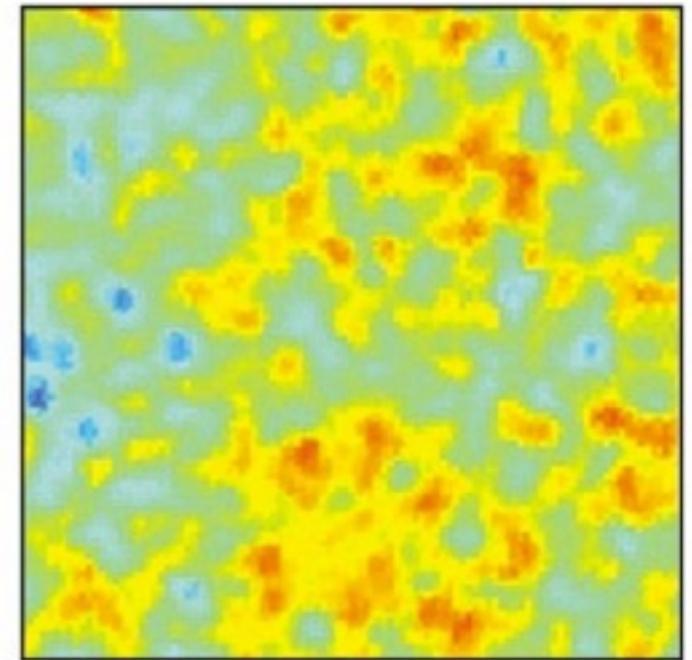
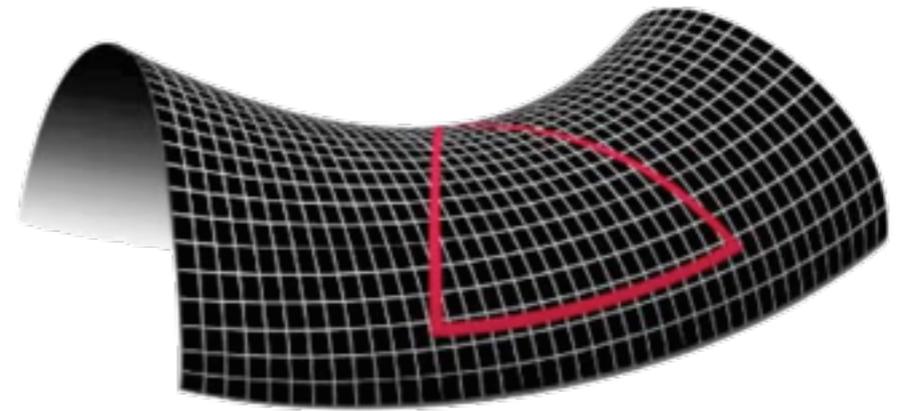
“Closed”



“Flat”



“Open”



We learn a lot from the CMB

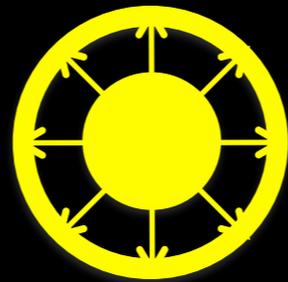
- Strong evidence for Big Bang
- Age of the universe
- What it's made of
- The shape of the universe
- History of structure formation
- ...

BUT...

Is the Big Bang the whole picture?

How can the CMB be so uniform?

–Time = 1 year

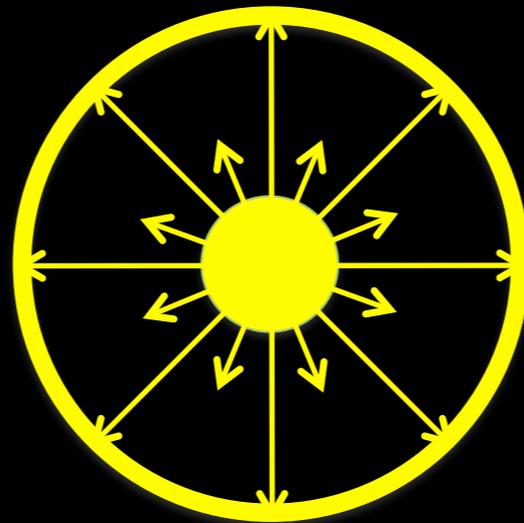


Space inside the circle can see the star.

Space outside cannot yet see it.

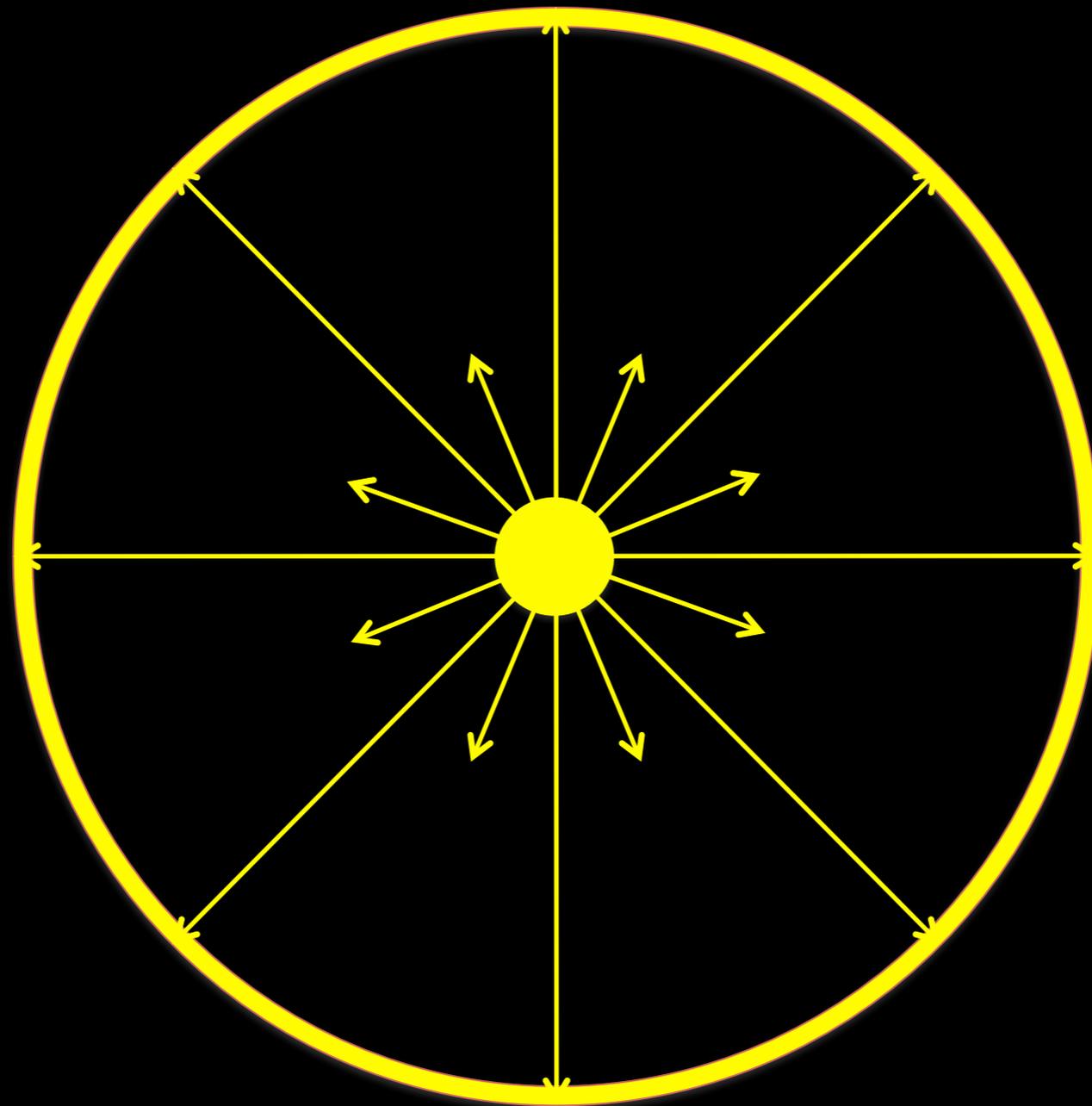
How can the CMB be so uniform?

–Time = 5 years



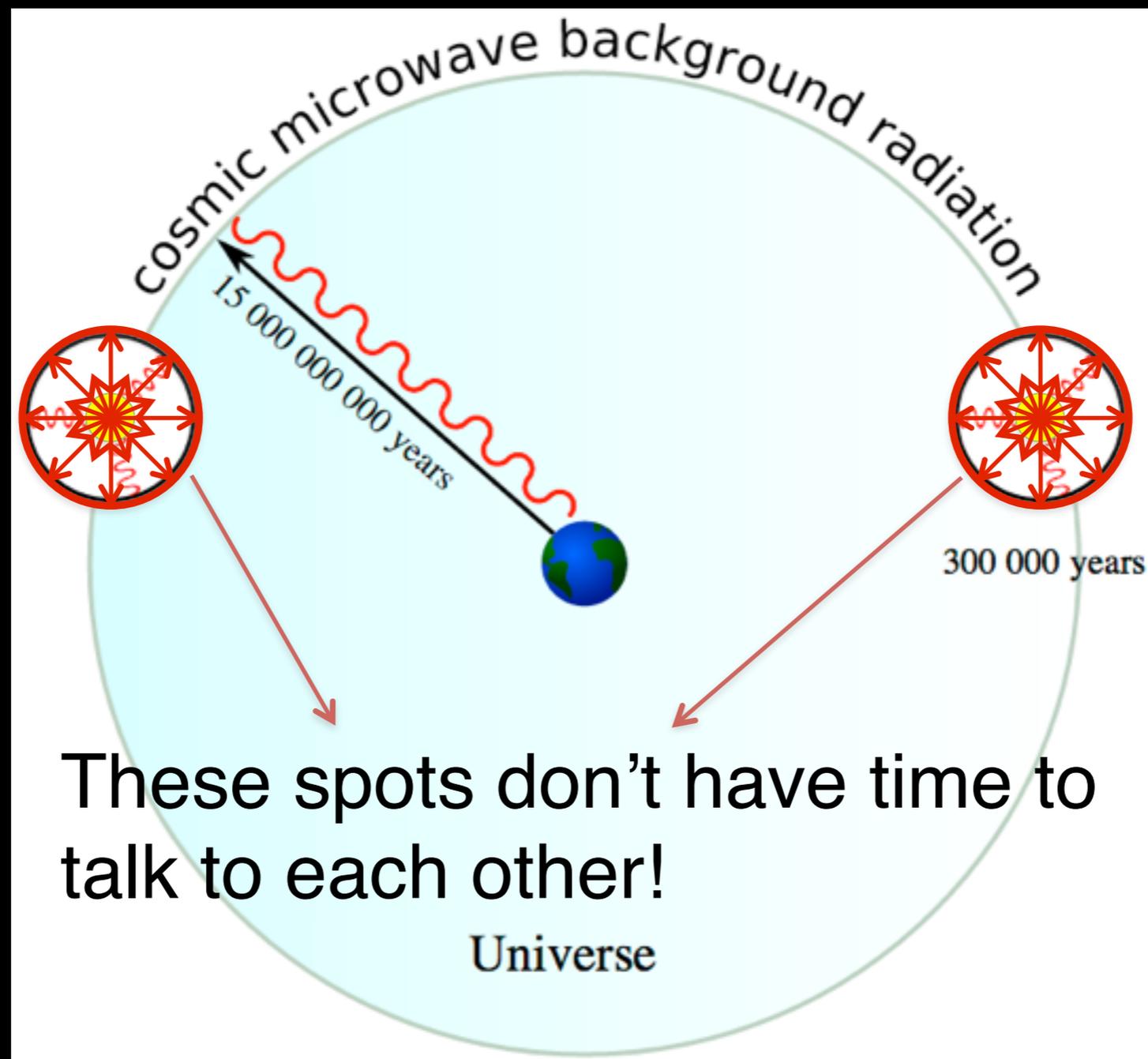
How can the CMB be so uniform?

–Time = 15 years



How can the CMB be so uniform?

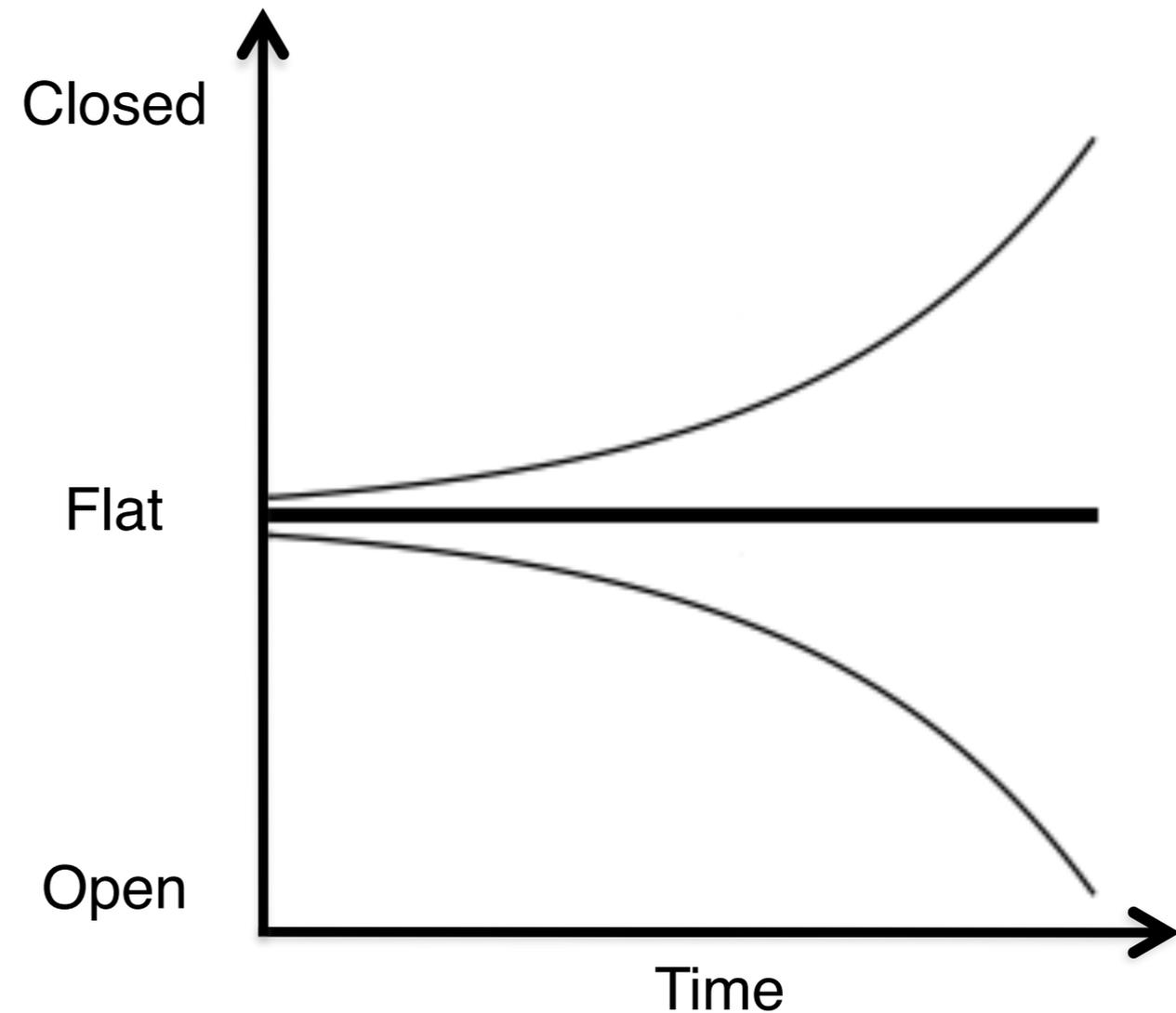
- How does the CMB “know” to be almost the same temperature everywhere?



Why is the Universe so flat?

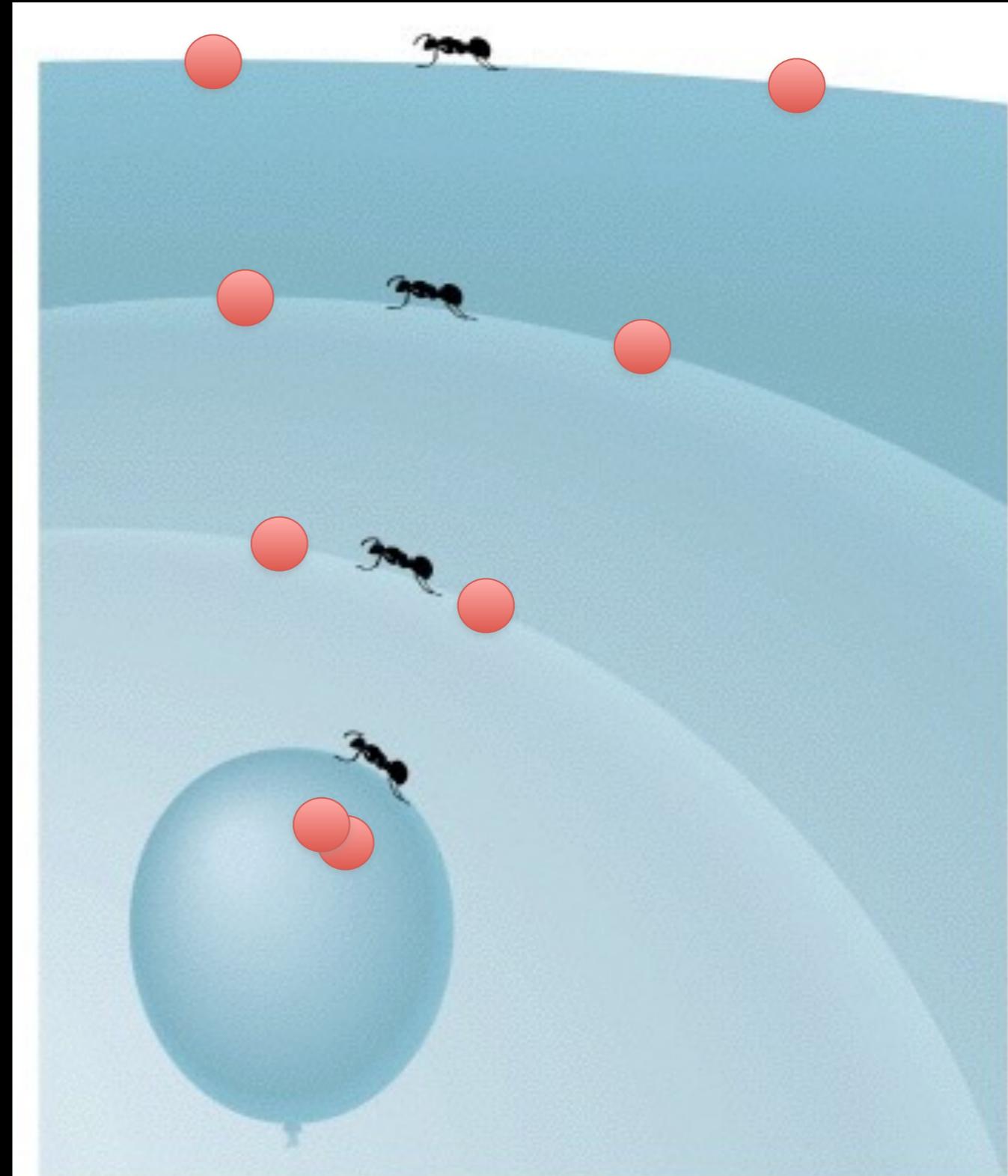
“Flat” is a special case.

Shape of universe
changes over time.



A Possible Solution: Inflation!

- Solves both problems.
 - Any curvature is stretched out.
 - Two things close enough together to talk are afterward very far apart.
- Nice idea, but no direct evidence...

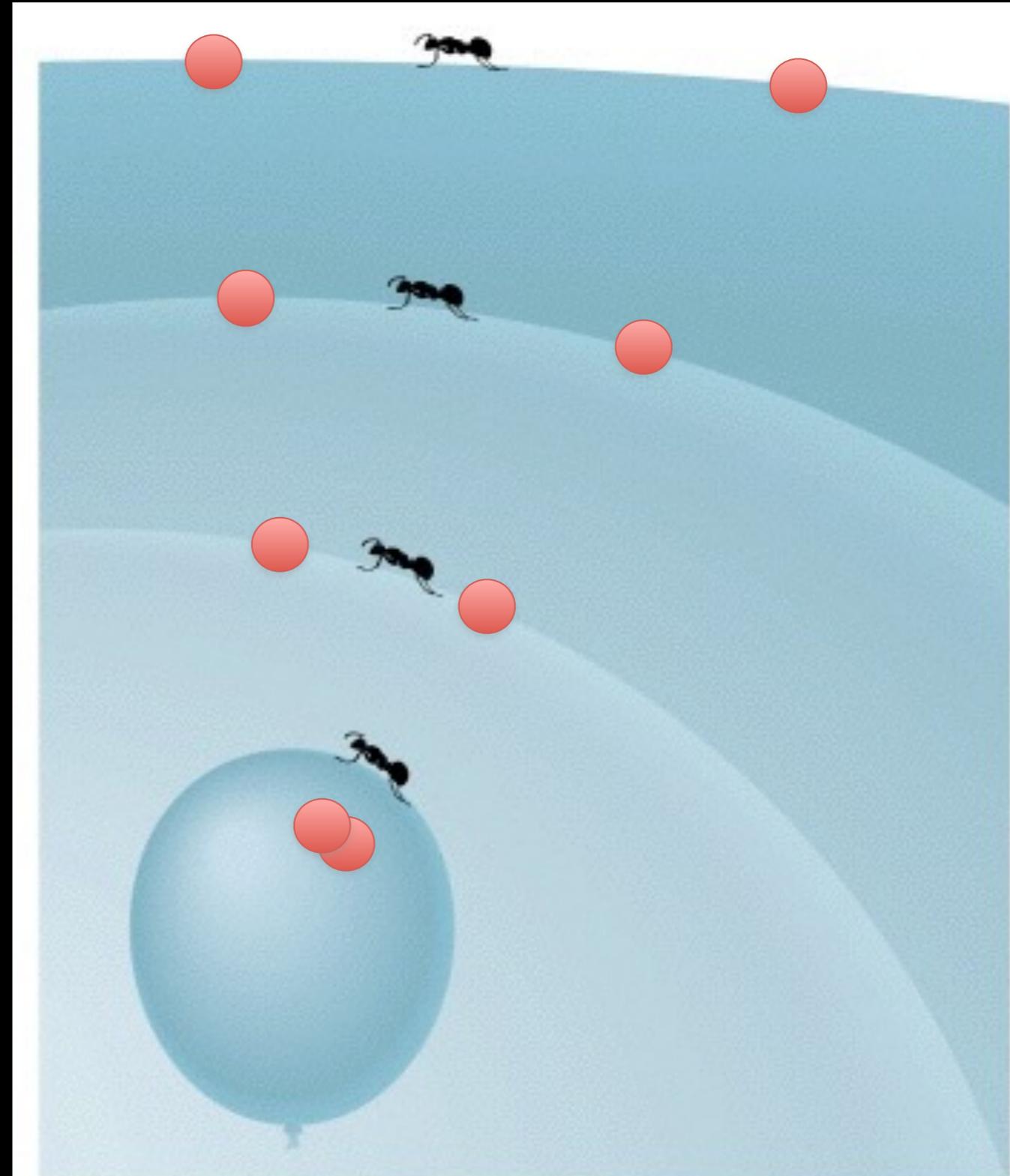


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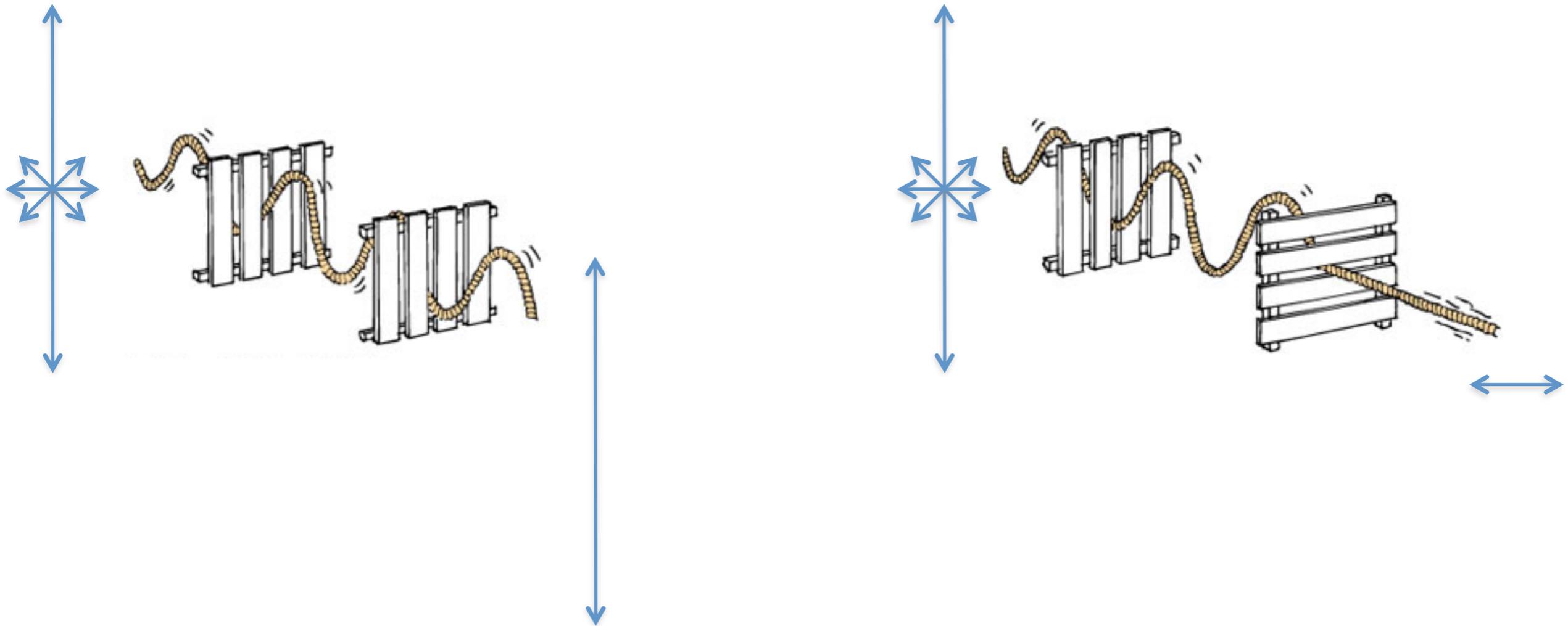
CMB can help us again!

–Polarization



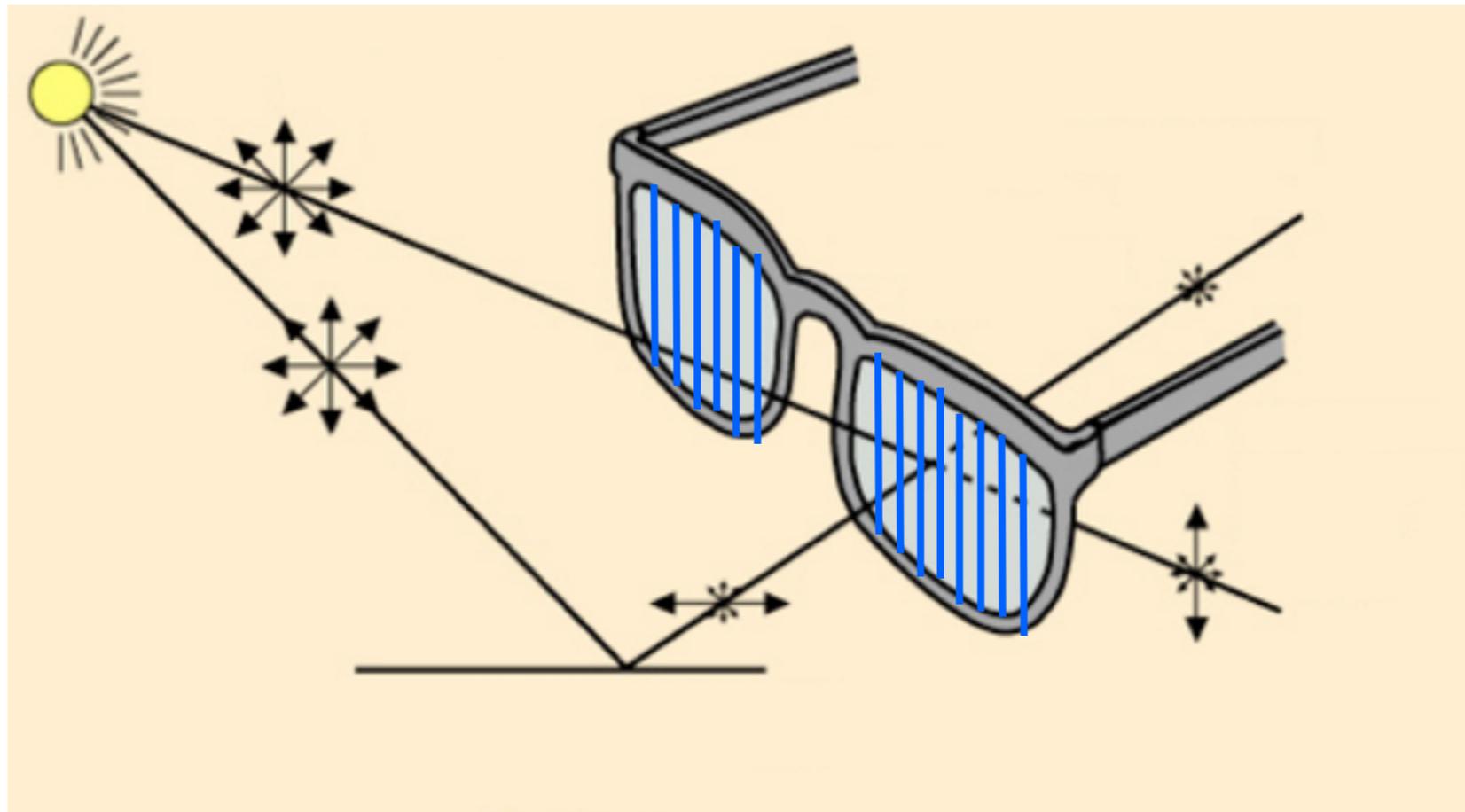
The CMB is Polarized

Light is a *wave*

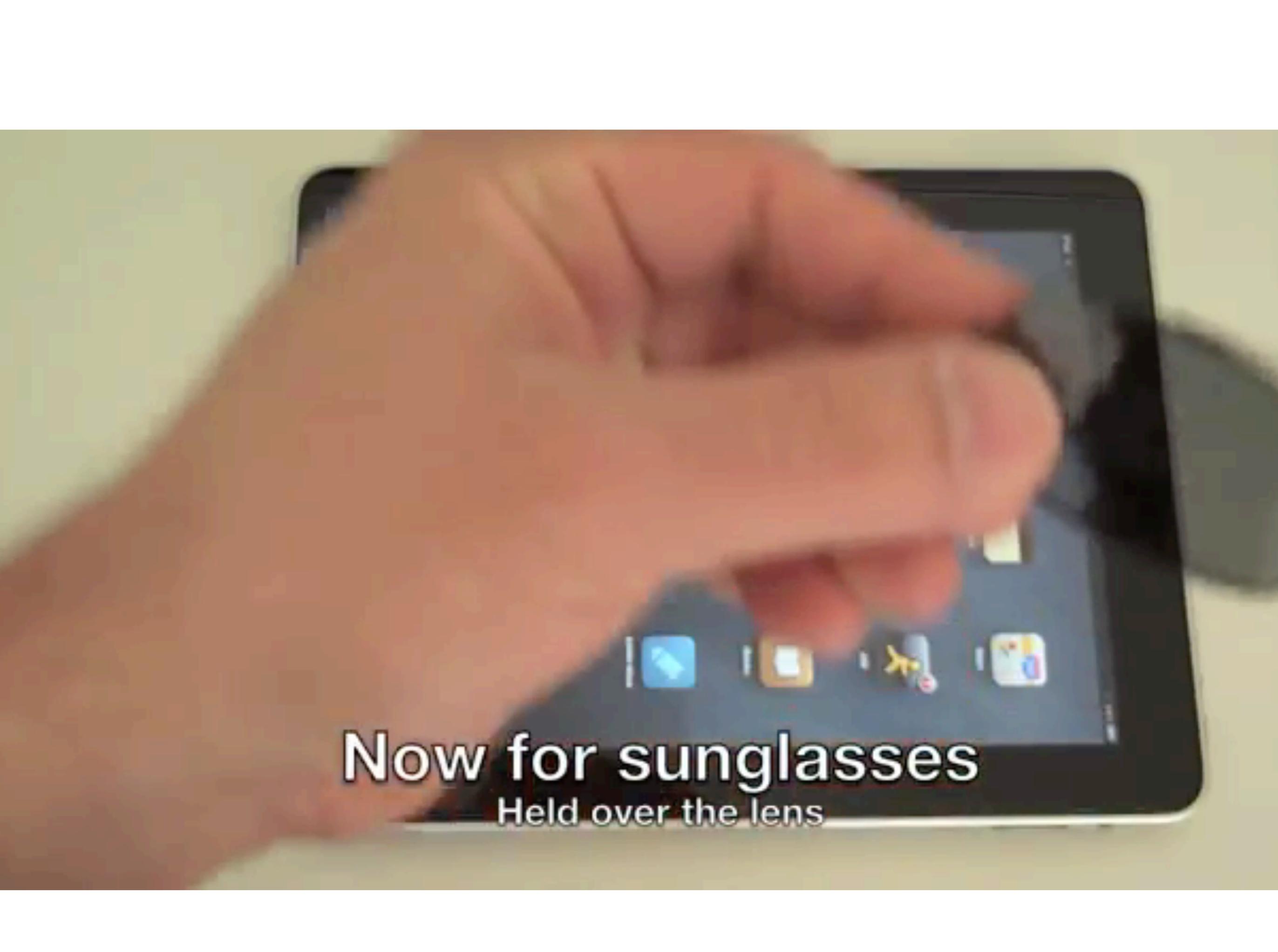


There is information in the direction of the waving!

The CMB is Polarized

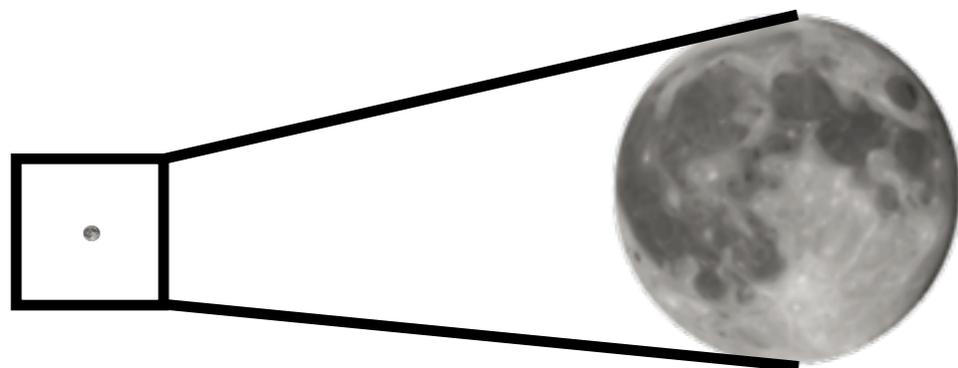
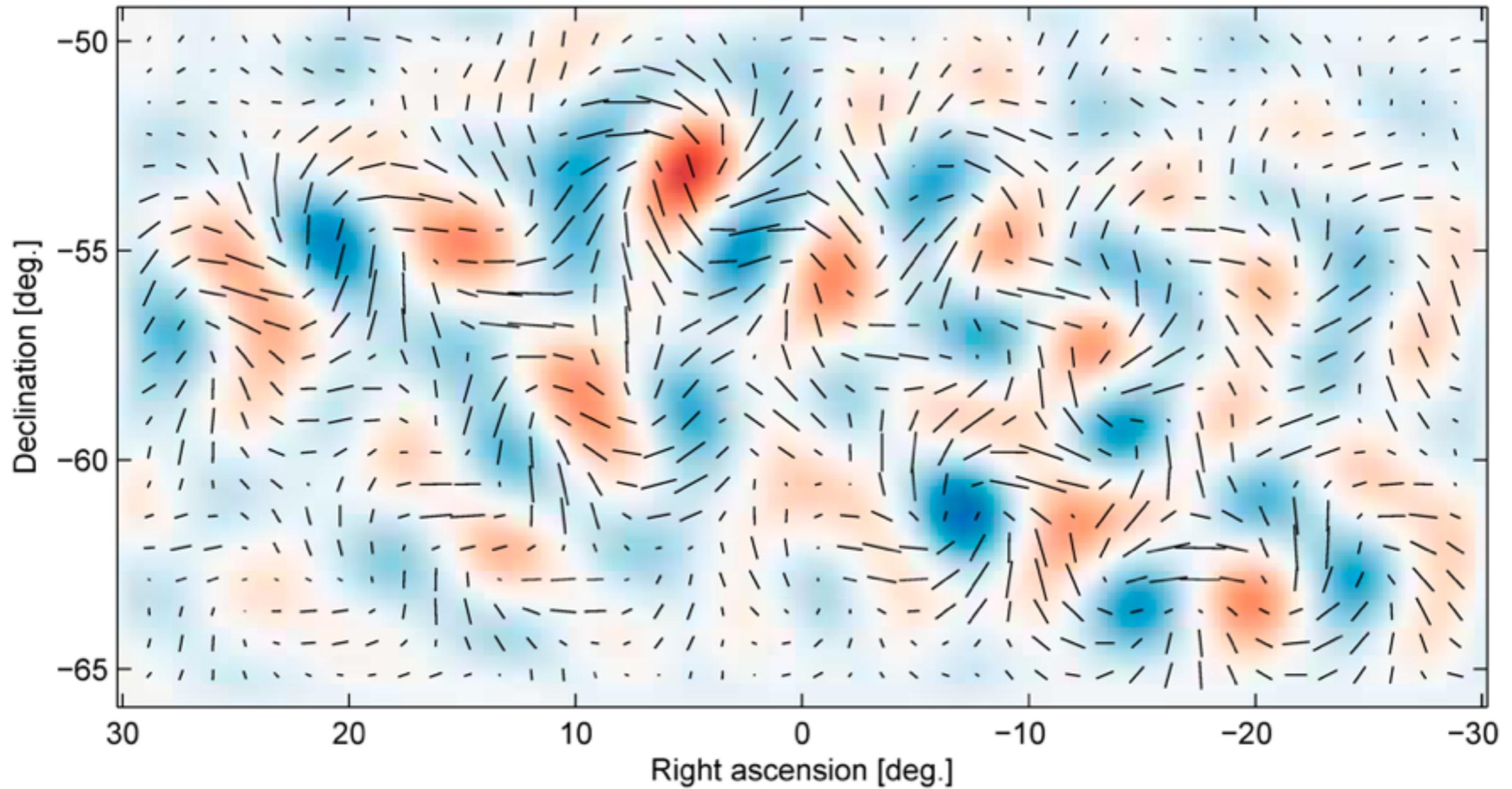


This is how polarized sunglasses work.

A close-up photograph showing a person's hand holding a tablet computer over a lens. The tablet screen is visible, displaying a dock with four application icons: a blue square with a white arrow, a brown square with a white document icon, a yellow airplane icon, and a white square with a blue and red icon. The text 'Now for sunglasses' is overlaid in large white font, with 'Held over the lens' in smaller white font below it.

Now for sunglasses
Held over the lens

Polarization of CMB



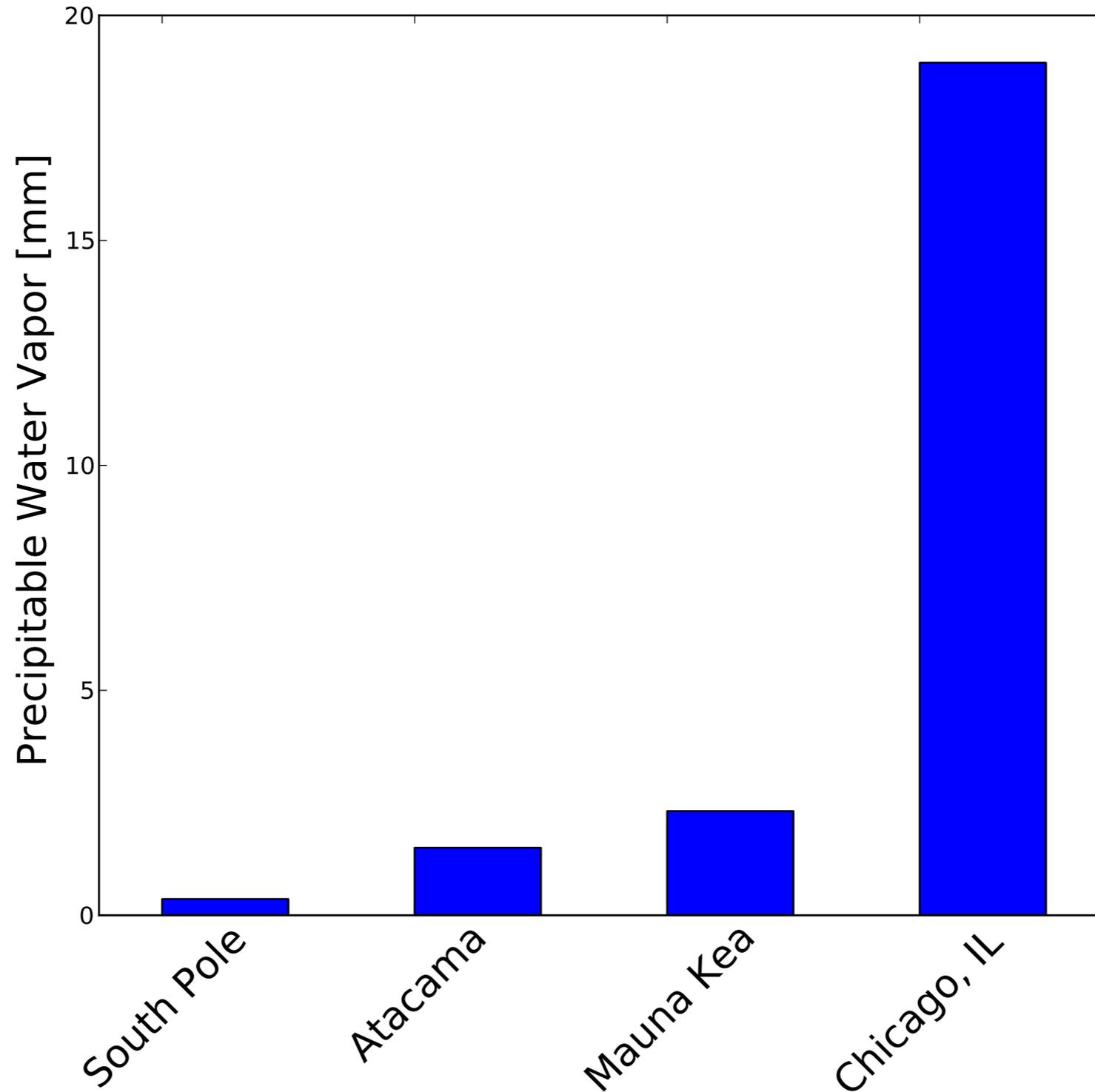
More information from Polarization

- What universe is made of
- The shape of the universe
- History of structure formation
- ...
- ***Did inflation happen, and how?***

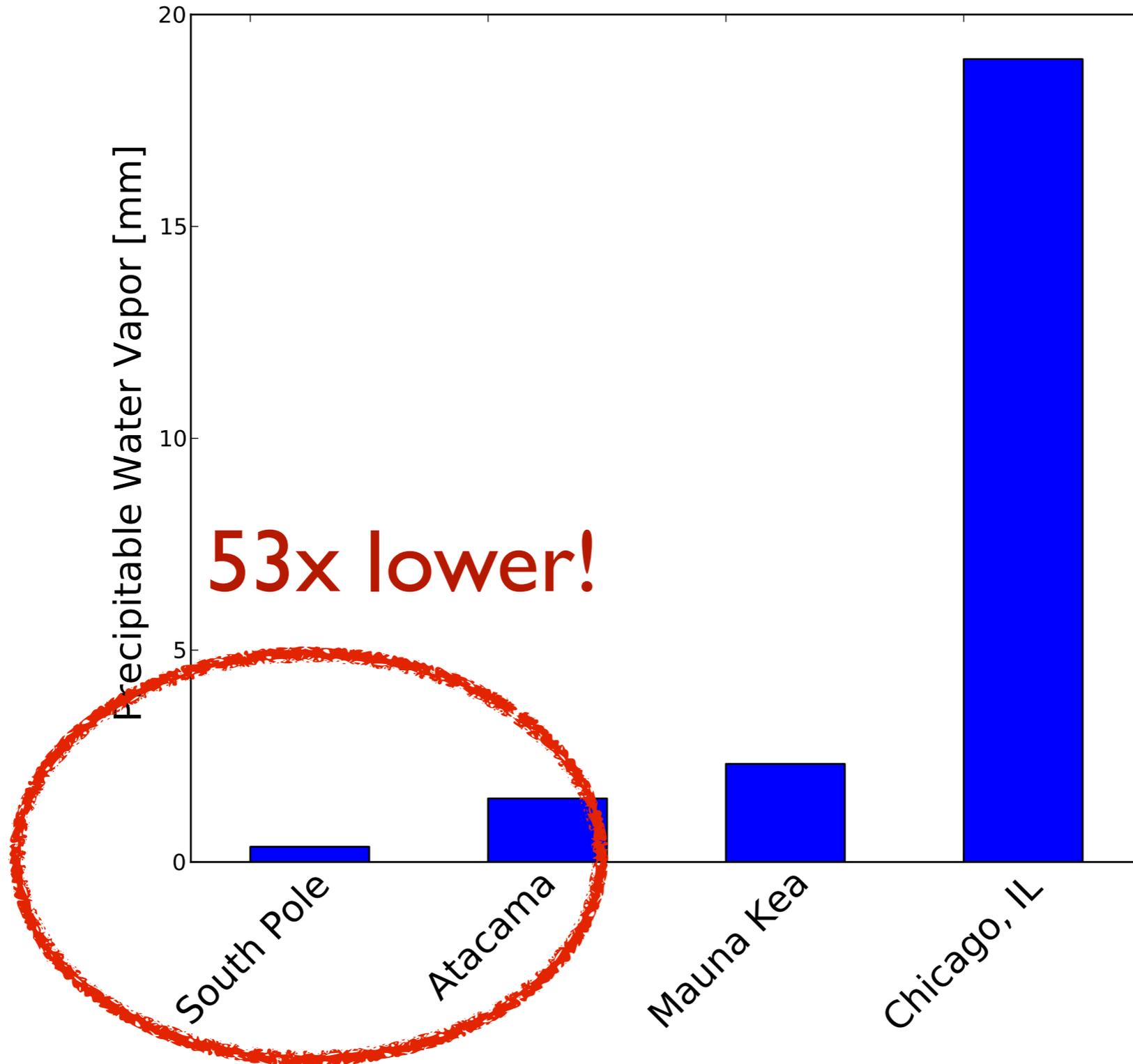
The South Pole Telescope

Why the South Pole?

Why the South Pole?



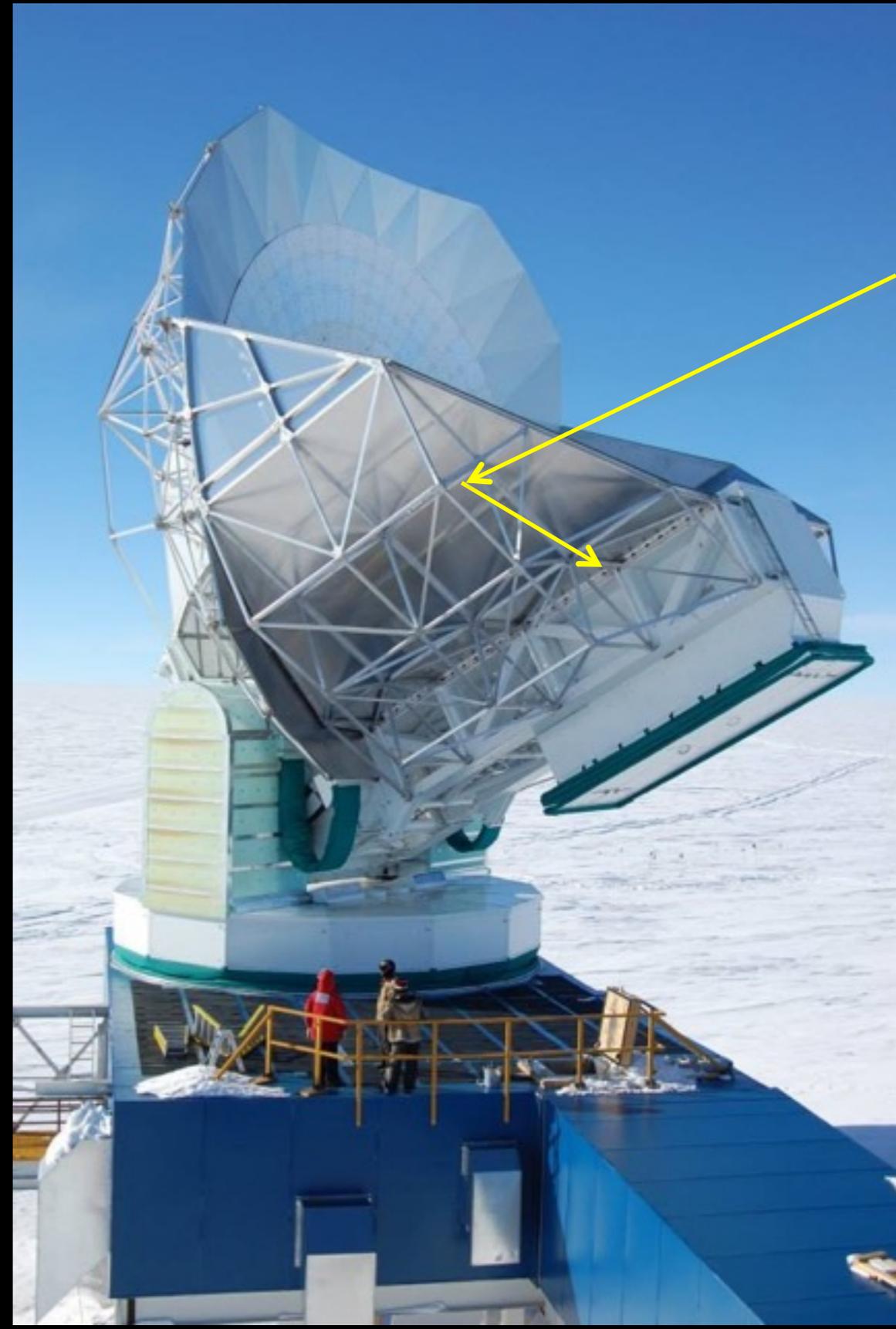
Why the South Pole?

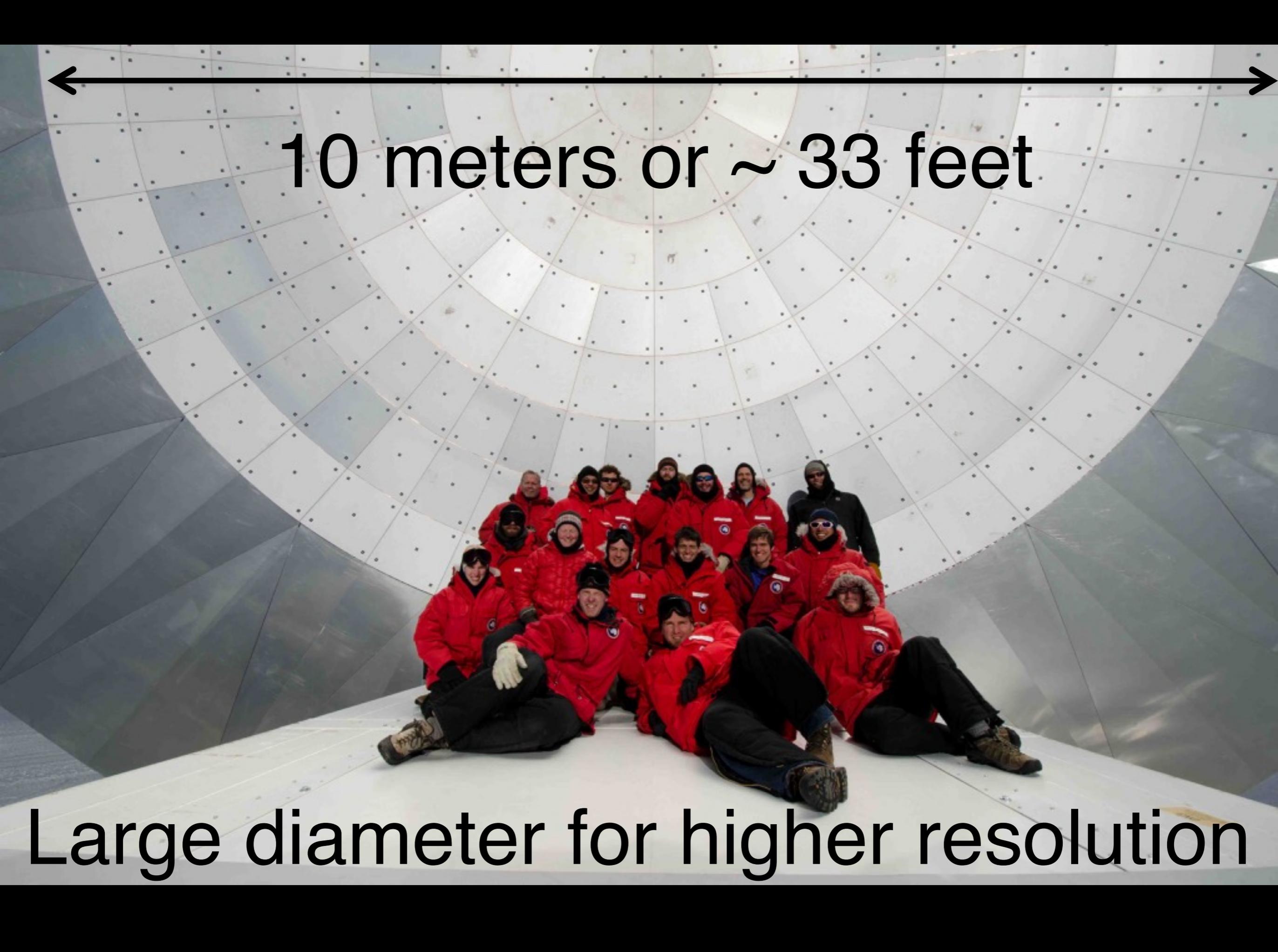


The South Pole Telescope



Credit: Robert
Schwarz

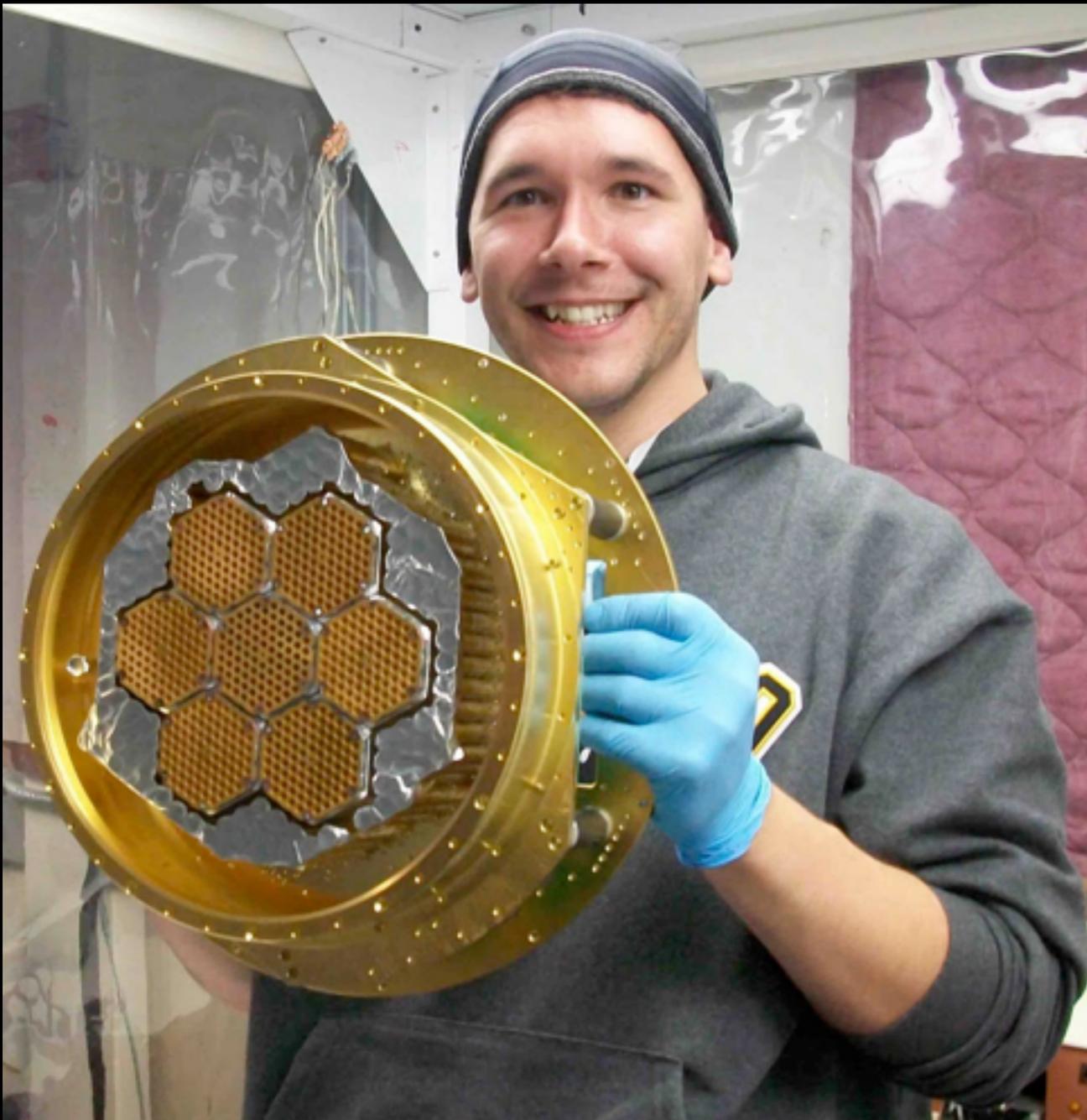




10 meters or \sim 33 feet

Large diameter for higher resolution

SPTpol - 2012



SPTpol

800 pixels

Two colors (95, 150 GHz)

+Polarization

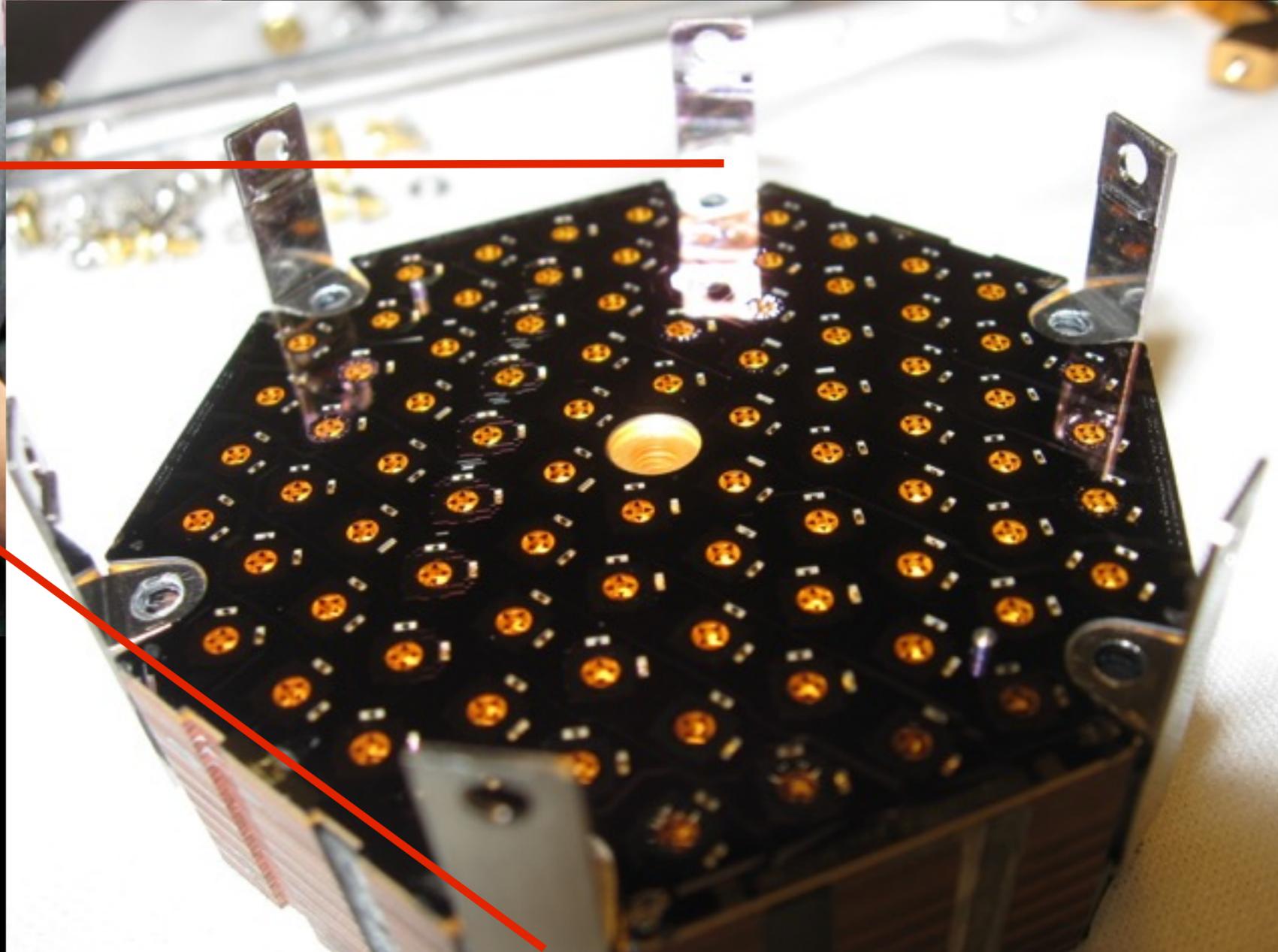
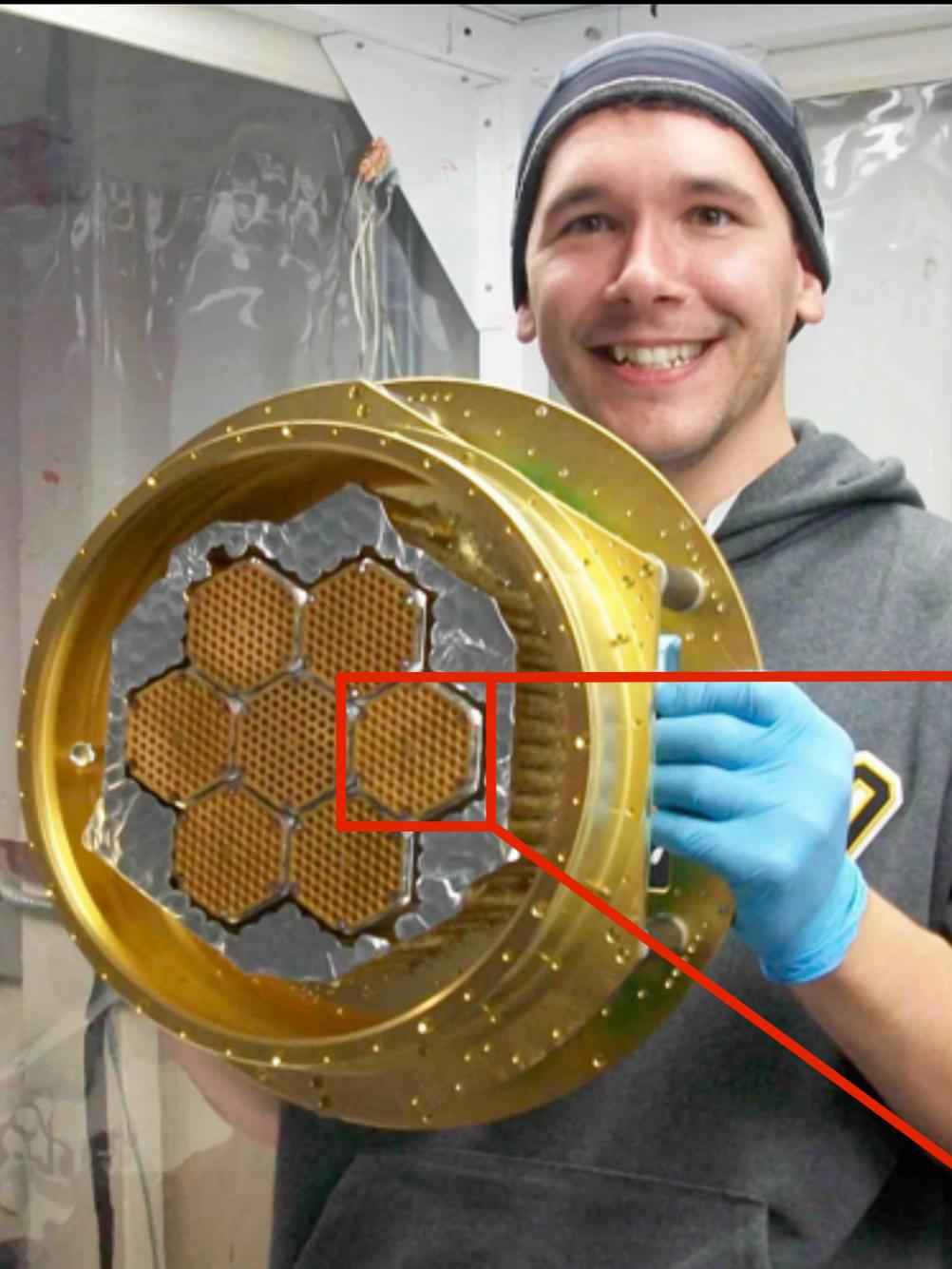


18 MILLION pixels

Three colors (red, green, blue)

SPTpol - 2012

2.3"



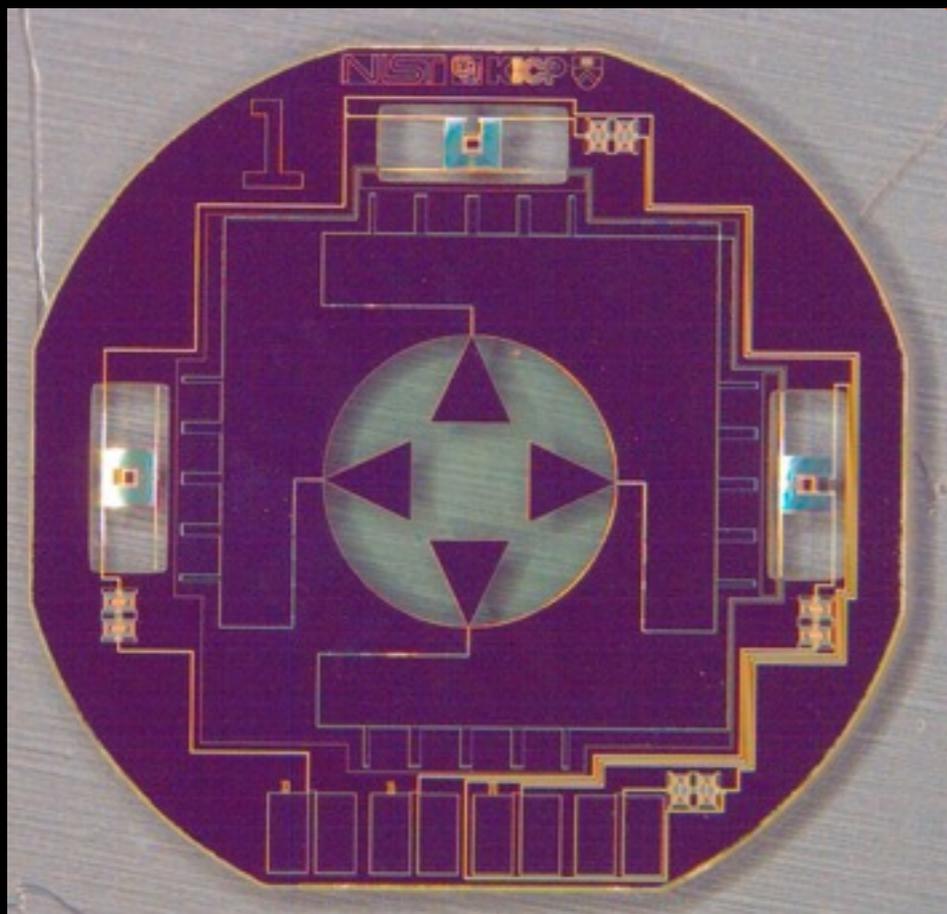
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800 pixels

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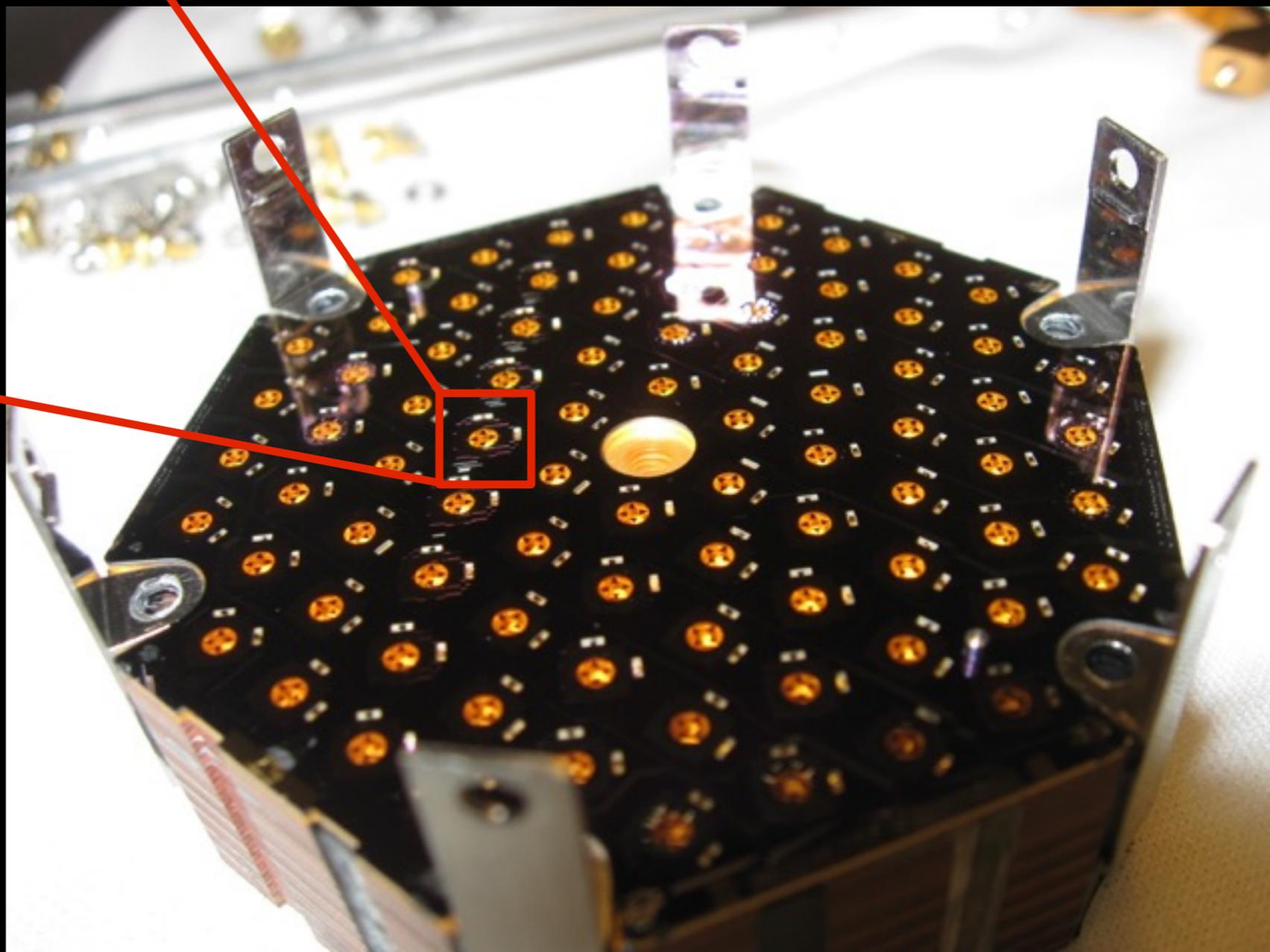
SPTpol - 2012



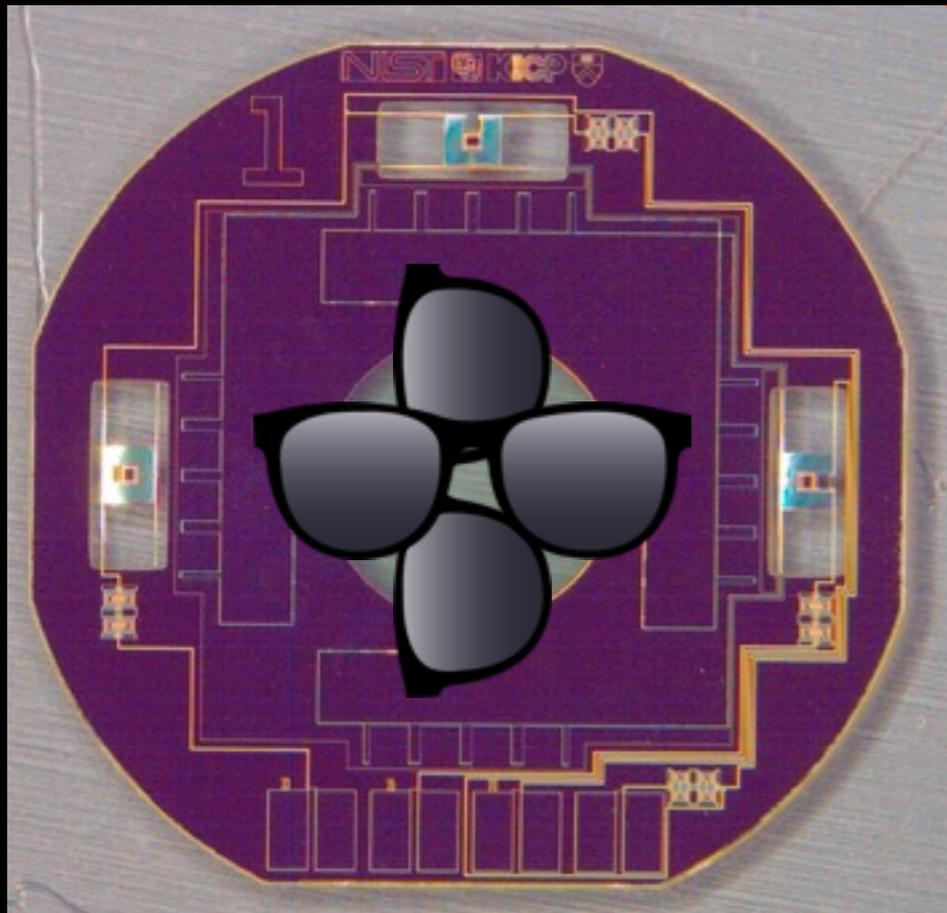
0.2"

2.3"

Big pixels for "big" light



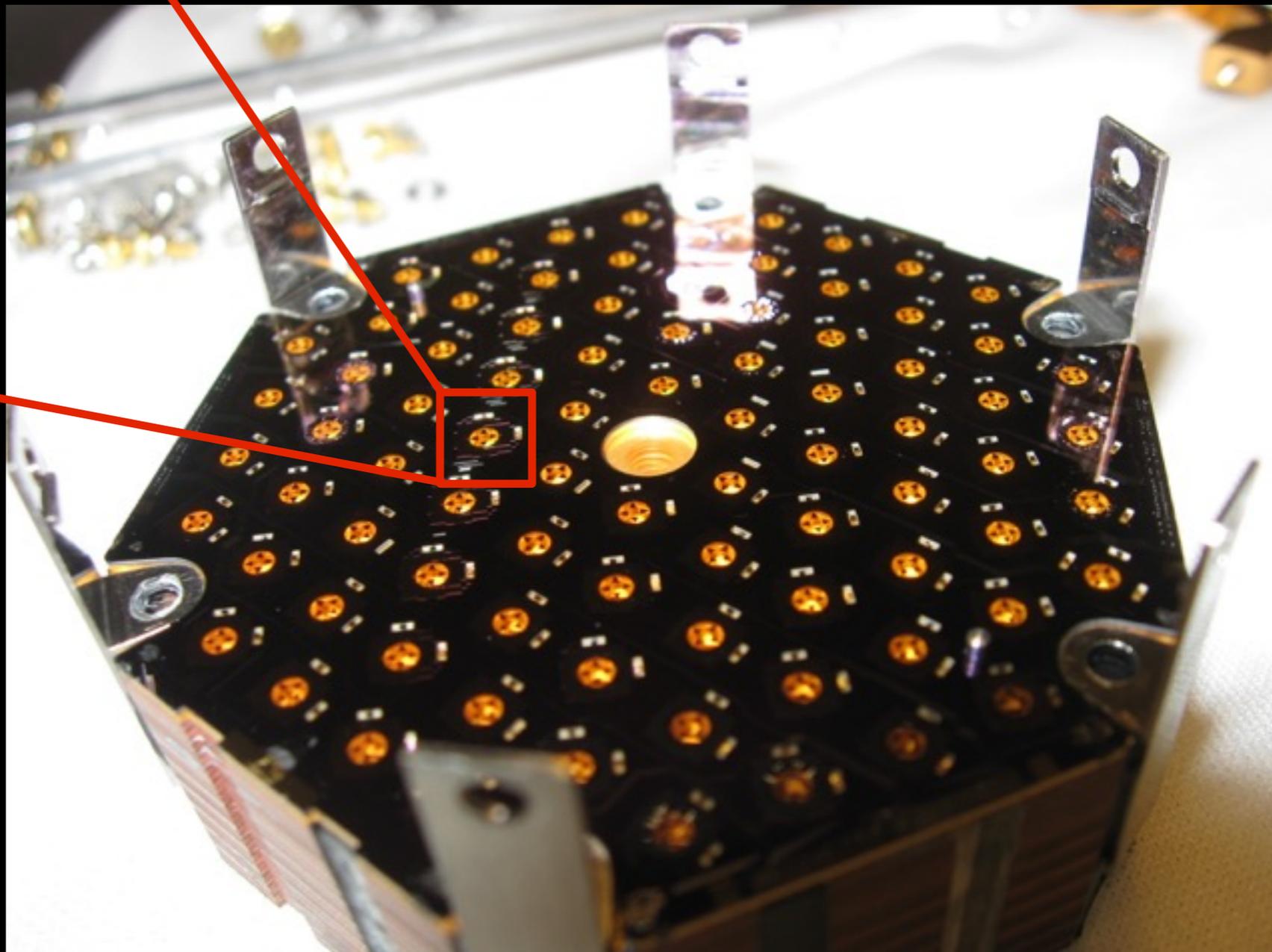
SPTpol - 2012



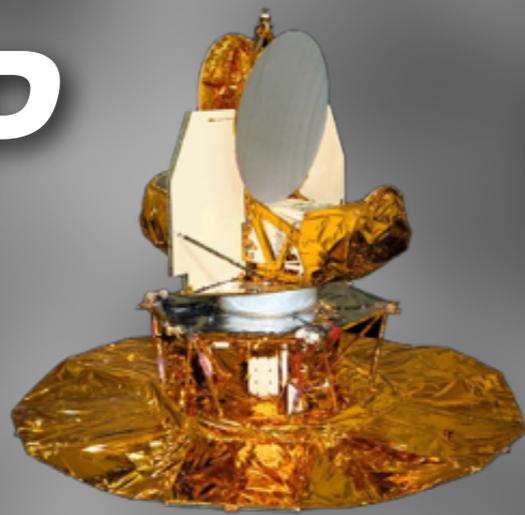
0.2"

Big pixels for "big" light

2.3"



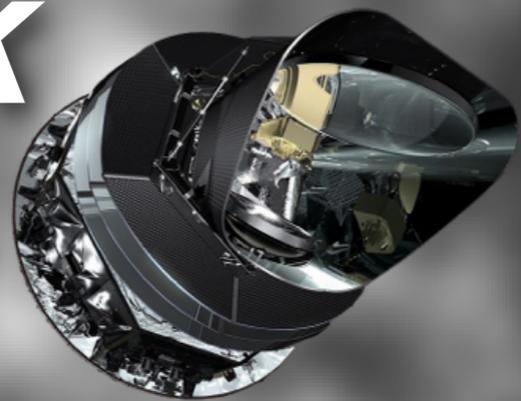
WMAP
W-band
30 deg²



Planck

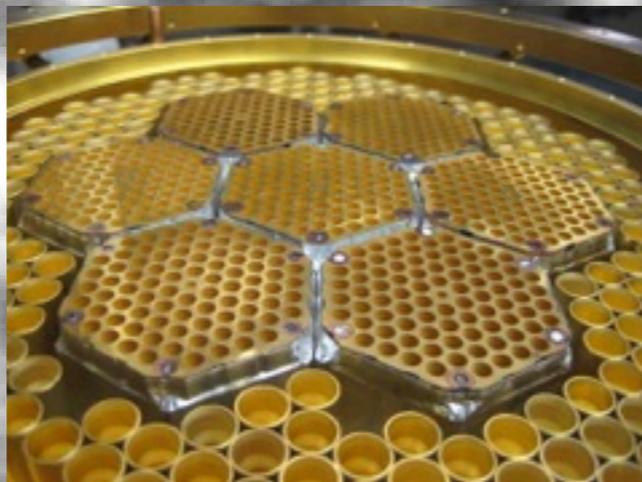
143 GHz

30 deg²



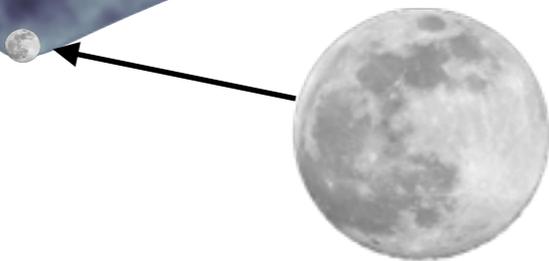
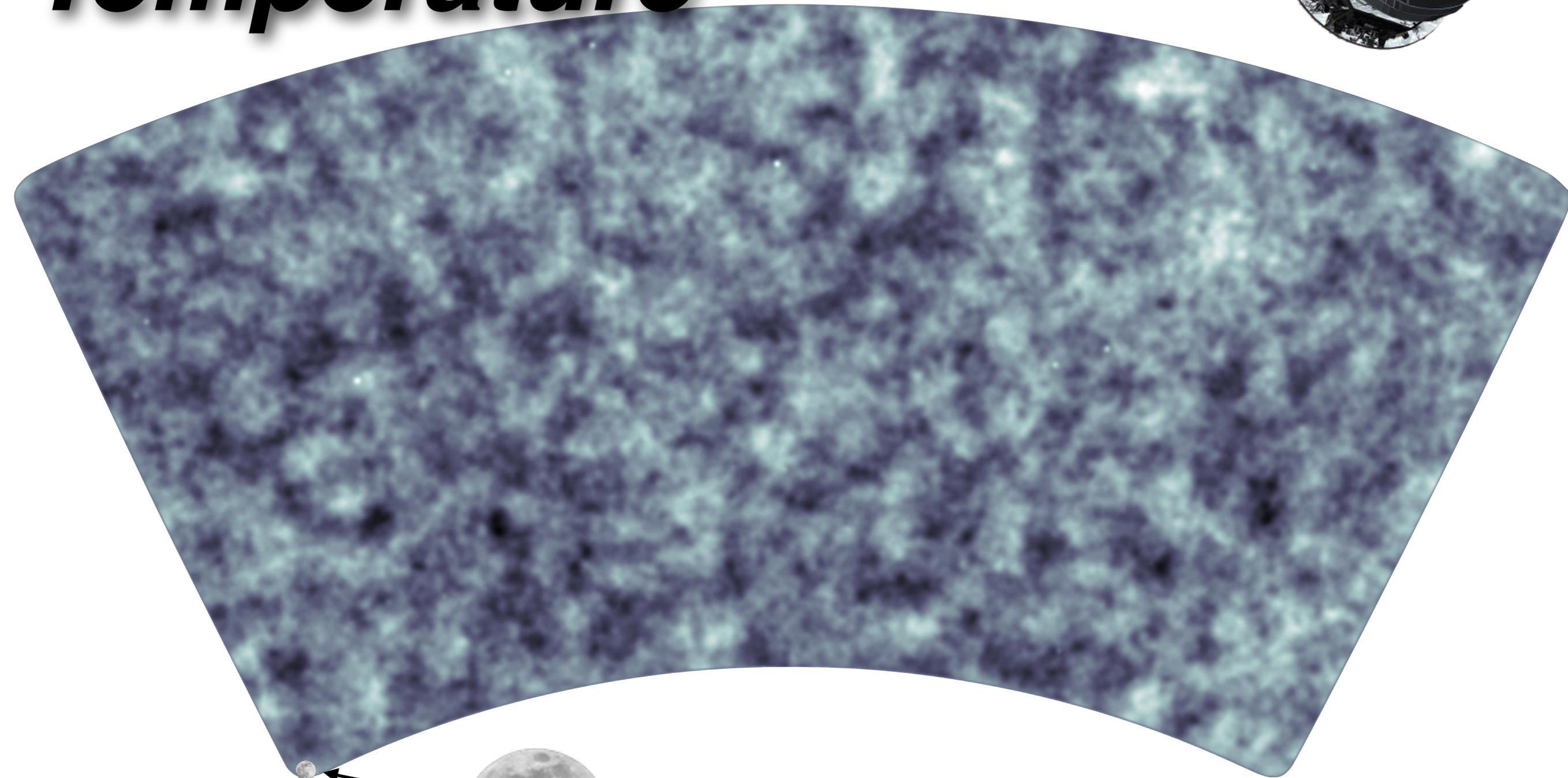
2x resolution

SPTpol
150 GHz
30 deg²

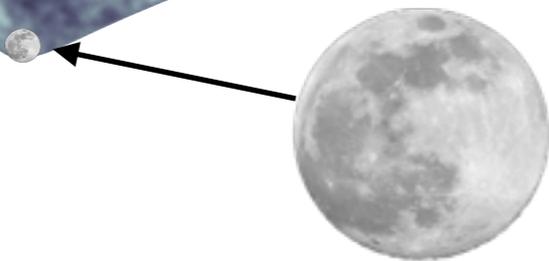
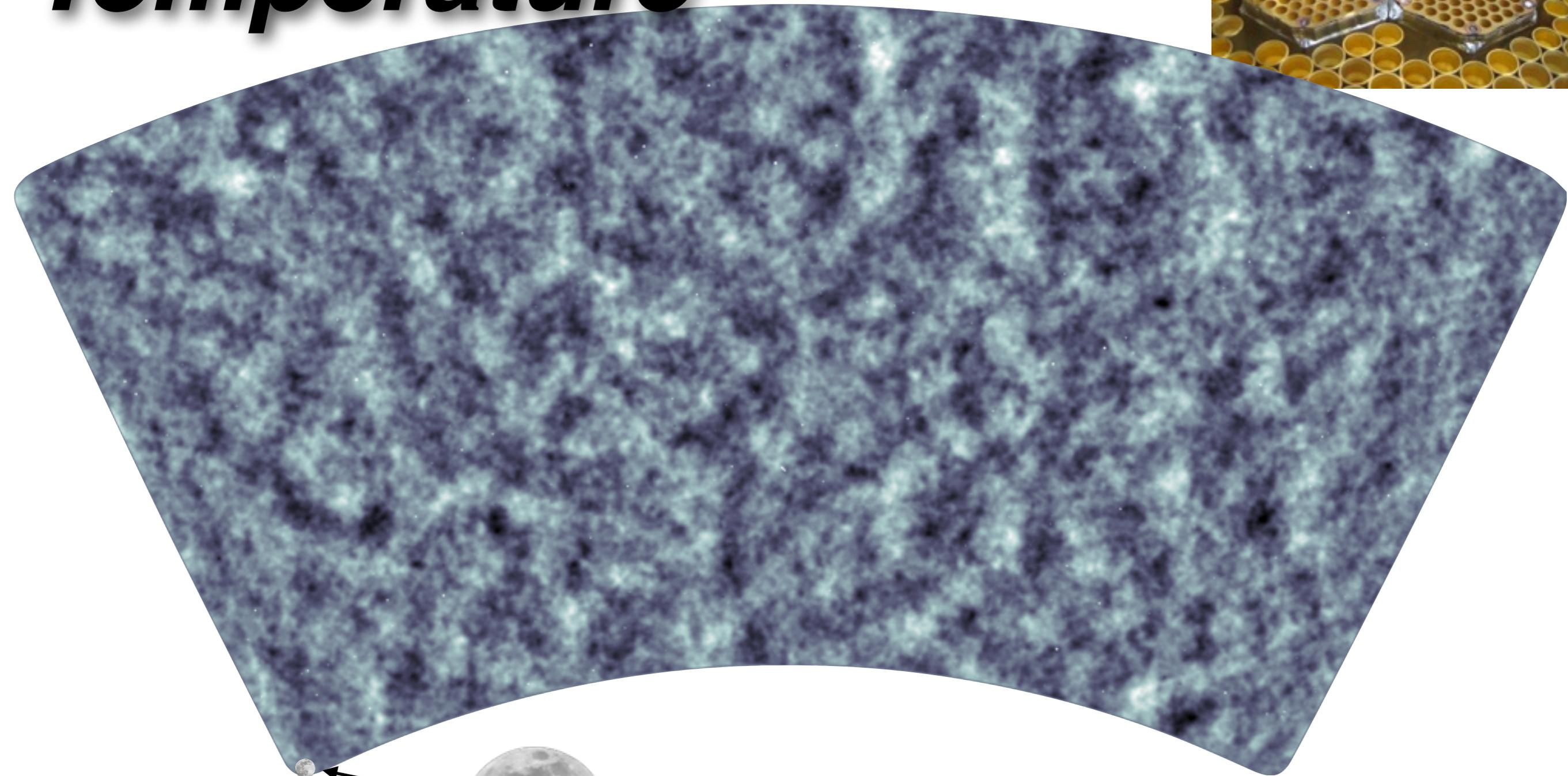
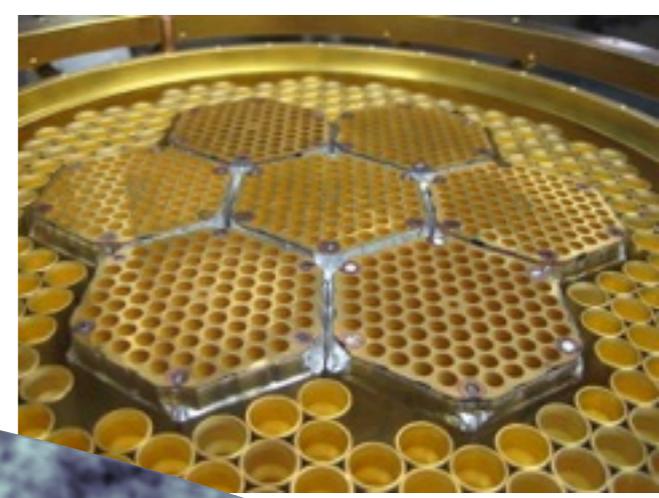


7x resolution

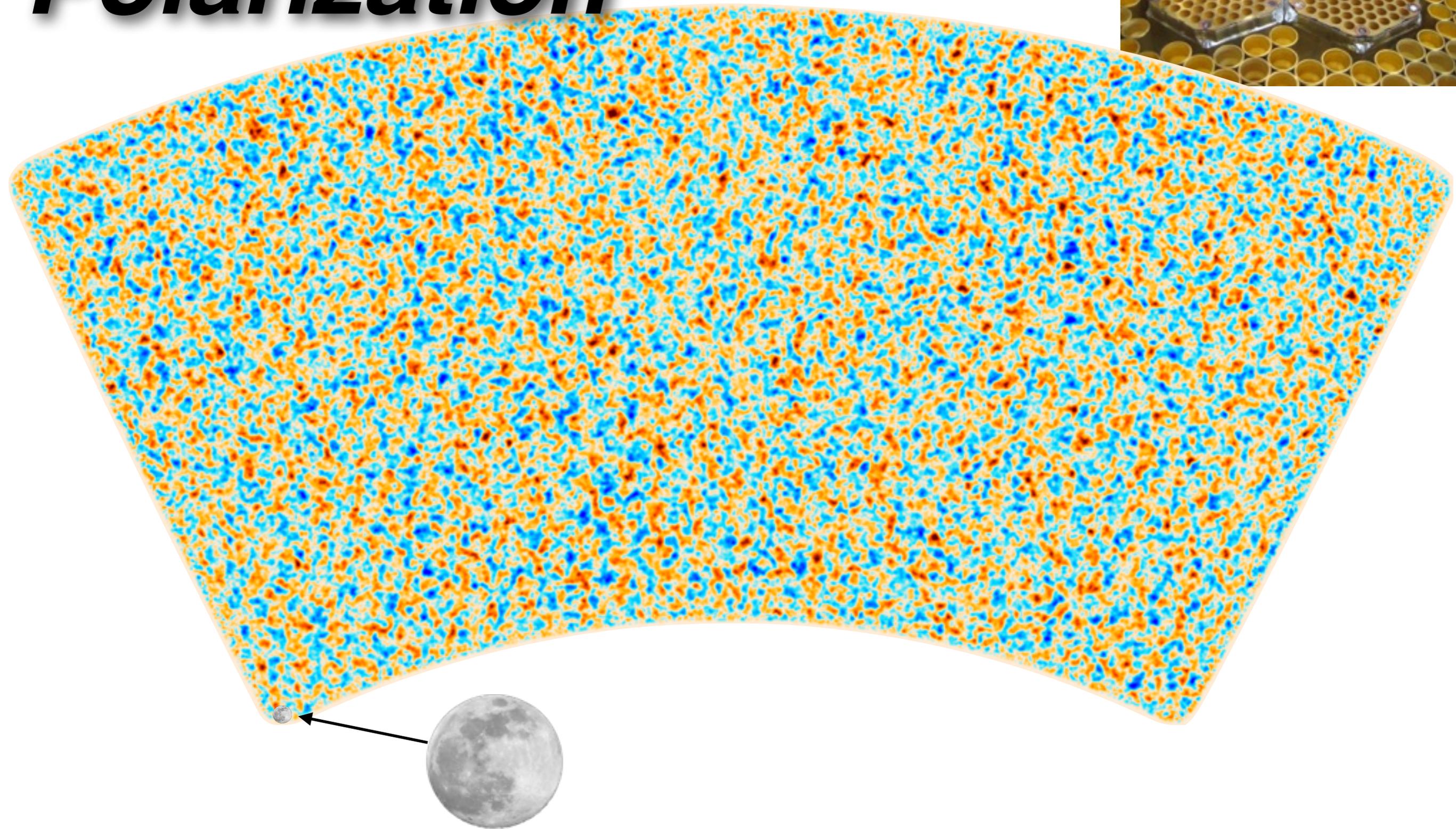
Planck Temperature



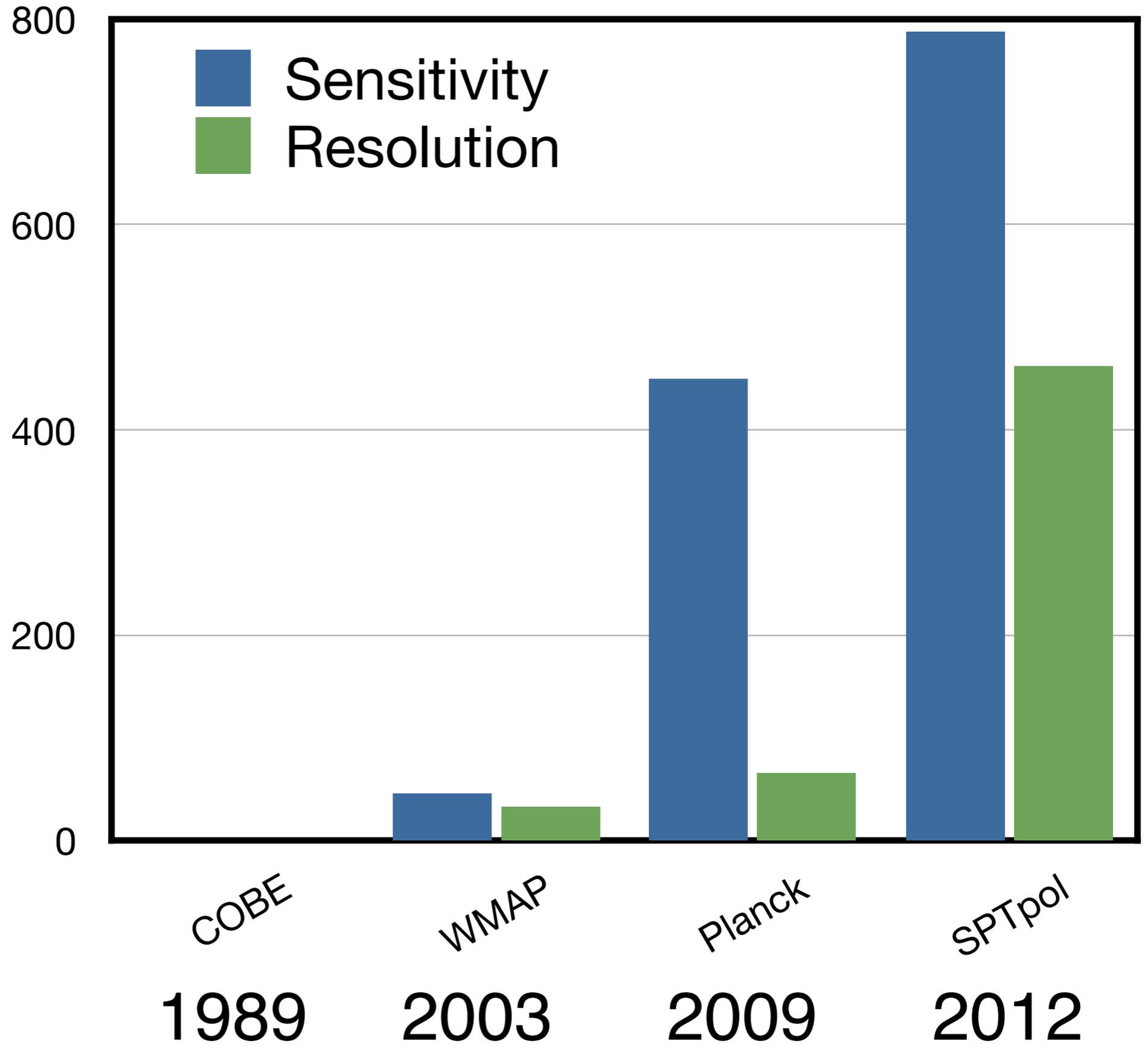
SPTpol Temperature



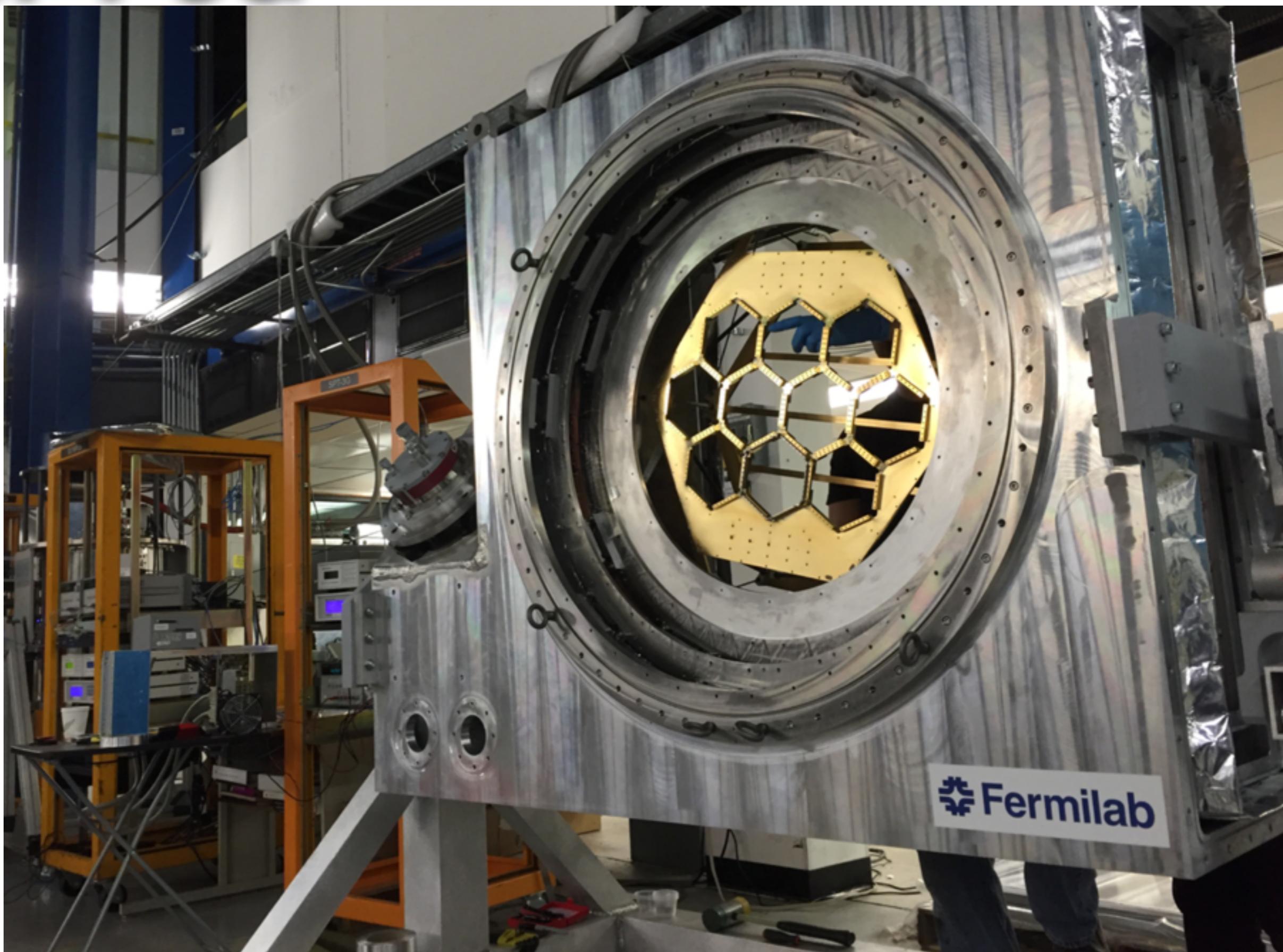
SPTpol Polarization



Rapid Improvement



SPT-3G



SPT-3G

10x the number of detectors of SPTpol!

Three colors
(95, 150, 220 GHz)

Polarization



SPT - studying the beginning of the universe from the end of the earth

- South Pole is incredibly dry
- Stable weather for uninterrupted observing
- Large telescope for high resolution
- Sensitive camera that can measure polarization and “quickly” map the sky.
- Deploying a camera 10x more sensitive this Fall!

The South Pole



South Orkney Is
Signy (UK)

Palmer (USA)

Rotheis (UK)

Halley (UK)

Antarctica
South Pole
Amundsen-Scott (USA)

McMurdo (USA)



U.S. AIR FORCE

8195
62nd AW
445th AW

TOYOTA





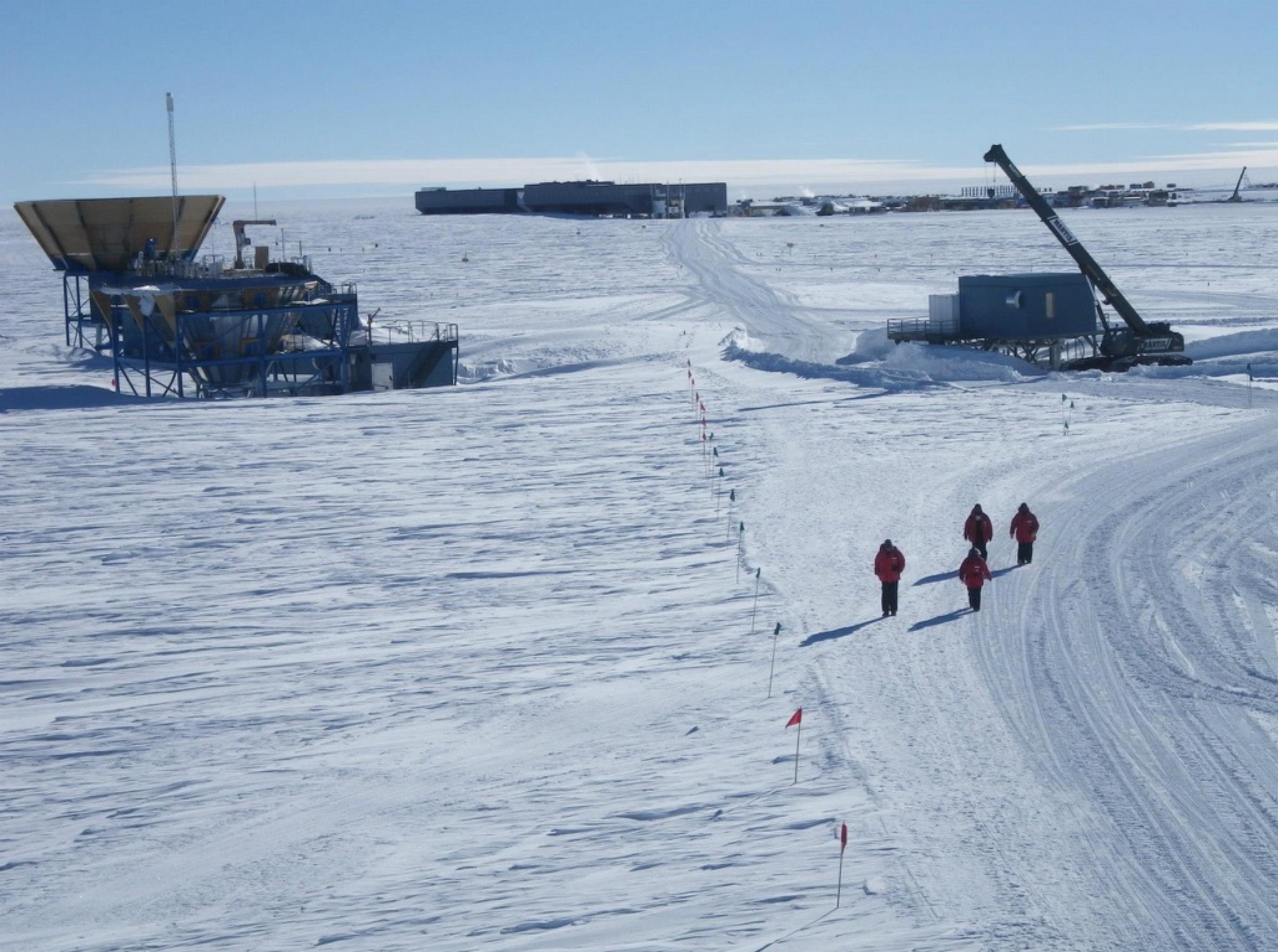




















Geographic South Pole

Roald Amundsen

December 14, 1911

"So we arrived and were able to plant our flag at the geographical South Pole."



elevation 9,301 ft

Robert F. Scott

January 17, 1912

...es, but different from ..."



JASON HEWING







Questions?

















