

# A journey to our cosmic origins with the oldest light in the Universe

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# **The Cosmic Microwave Background & a (very) brief history of our Universe**

# The Big Bang – $t = 0s$

## Hot & Dense

- Thermal agitation is extremely high
- All possible reactions are happening at the same time, nothing is stable

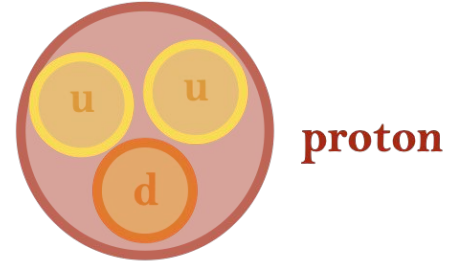
## Expanding & Cooling

- Thermal agitation decreases
- Reactions start **freezing** = stop happening in both directions



# Baryogenesis

**Quarks** = fundamental, sub-atomic particles that assemble to form **baryons**



**Baryons** = assembly of 3 quarks - typically neutrons & protons

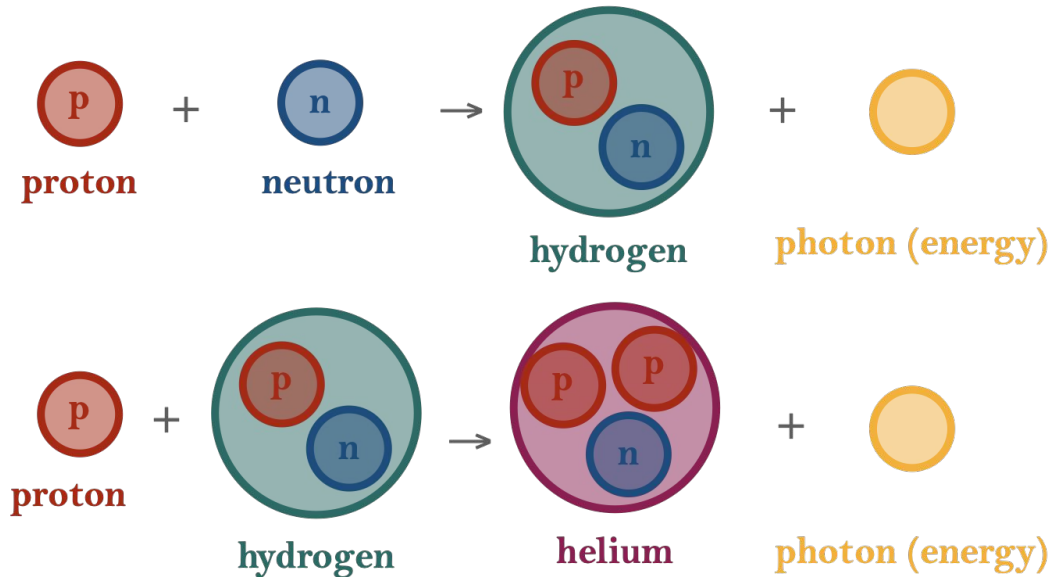
- Quarks are formed as independent particles, not yet bound into bigger particles
- Then as cooling continues, they start forming baryons



# Primordial nucleosynthesis

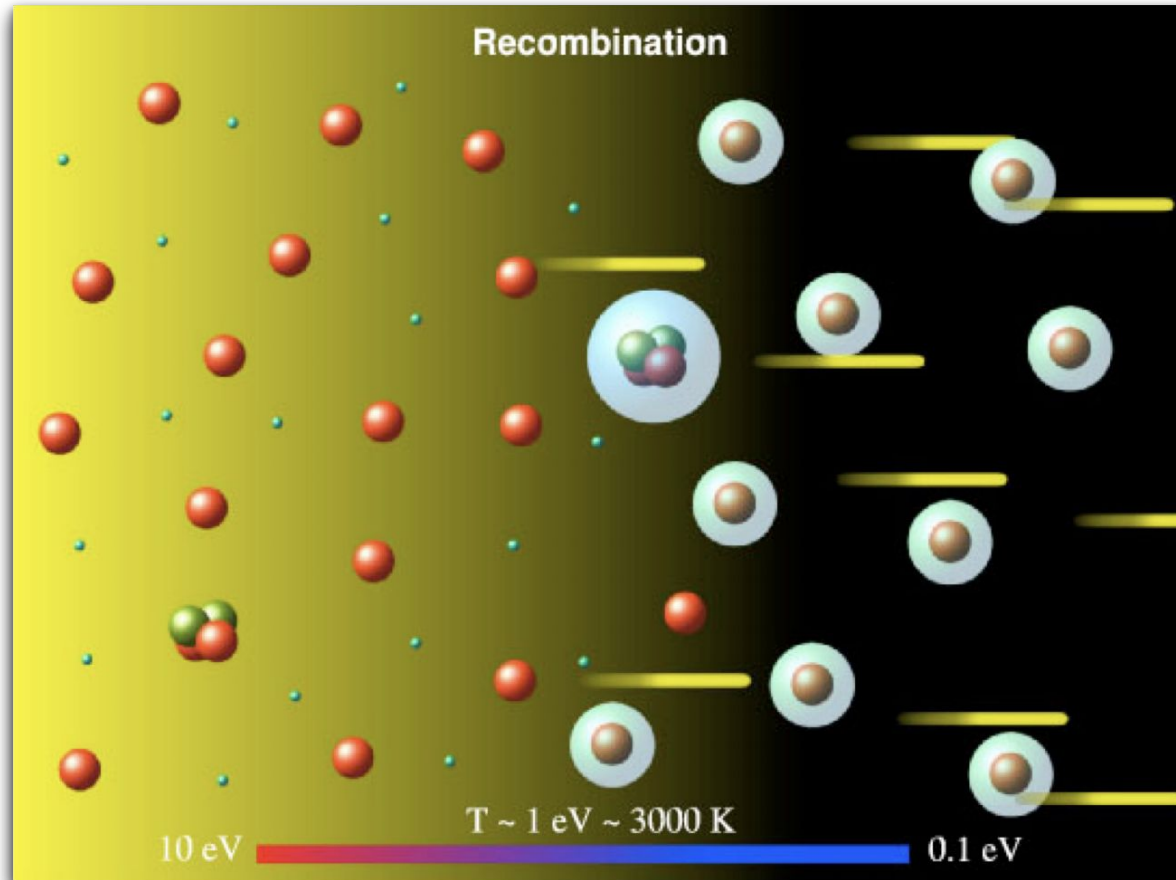
**Nucleus** = assembly of protons & neutrons

**Primordial** = initial, in the early Universe (opposed to stellar nucleosynthesis that happens in stars and forms heavier atoms)



There is a total of 7 chain reactions happening in the early Universe to produce hydrogen & helium

# The recombination – $t = 380,000$ years



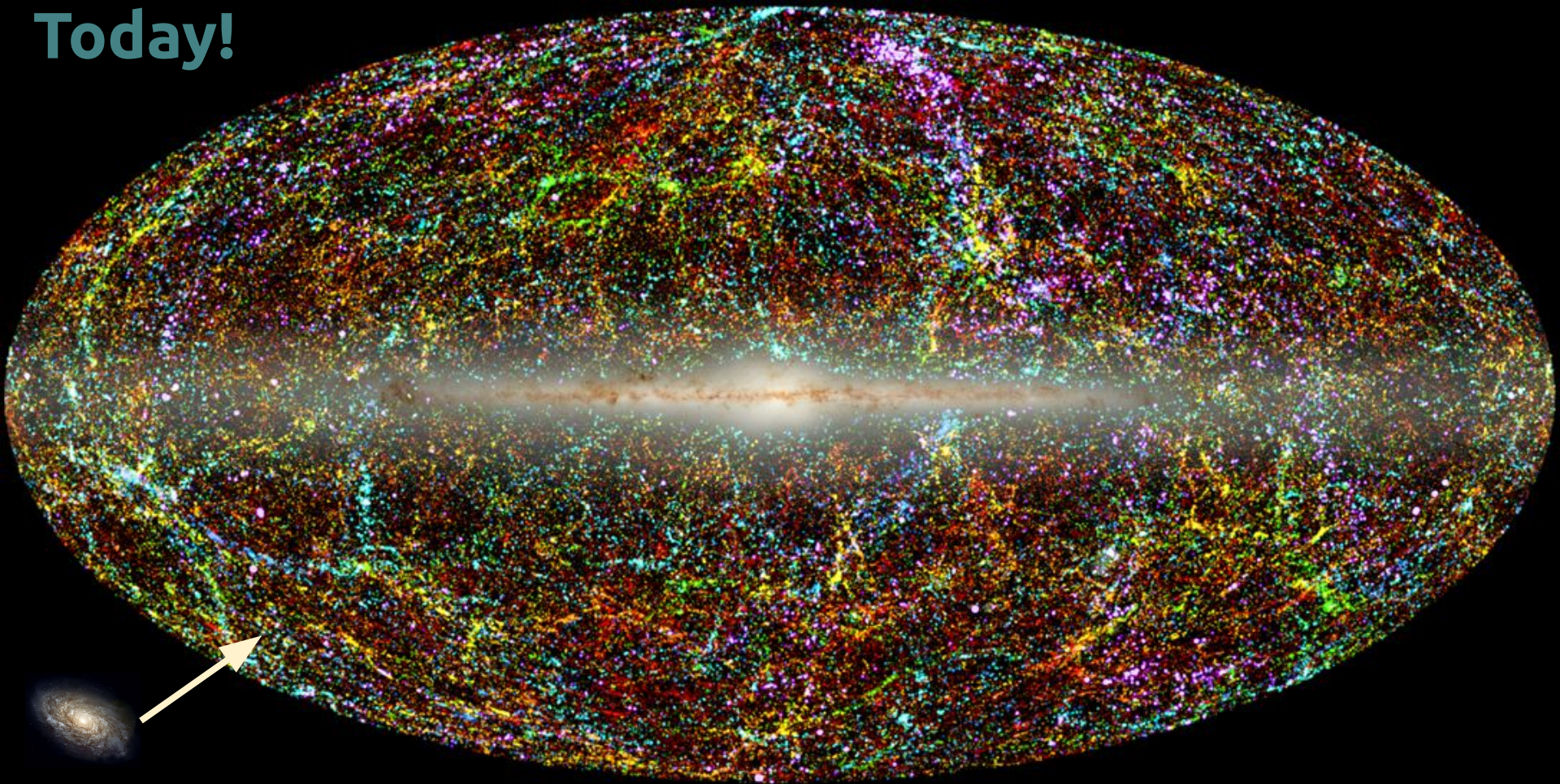
# The CMB – $t = 380,000$ years



**Anisotropies = seeds for future structures (stars, galaxies, etc.)**



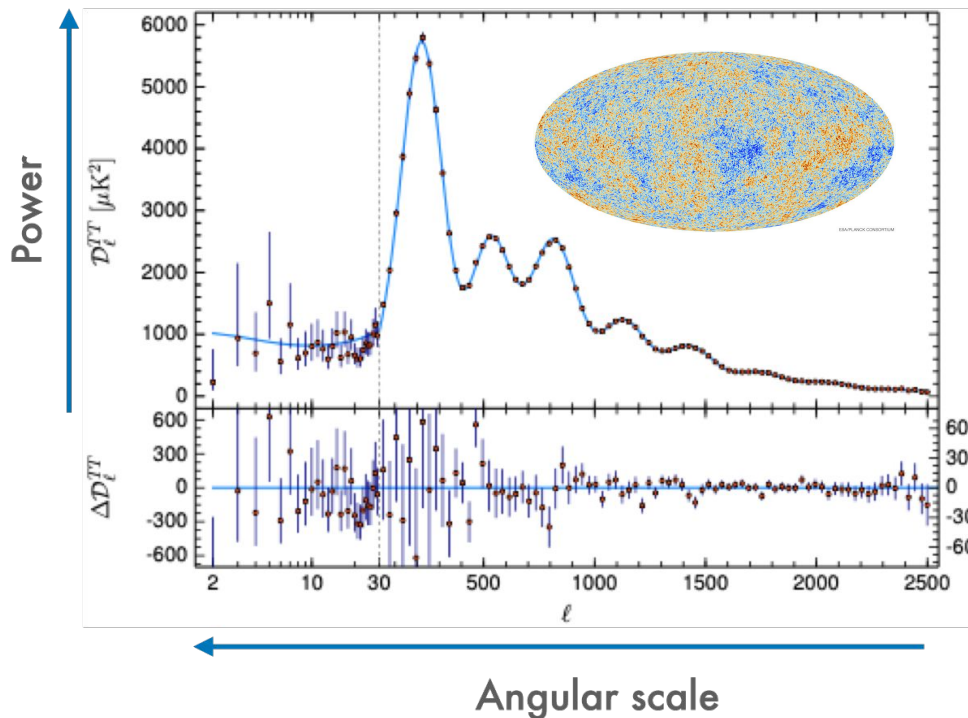
Today!





# What is the Universe made of today?

- 5% baryonic matter = us!
- 25% dark matter = "invisible" matter
- 70% dark energy = a mysterious force that drives the Universe expansion



<https://chrisnorth.github.io/planckapps/Simulator/#>

The background of the slide is a deep space image featuring a vibrant nebula with shades of orange, yellow, and pink. Numerous small, bright white stars are scattered across the dark cosmic background, creating a sense of vastness and mystery.

# **Cosmic mysteries... and solution!**

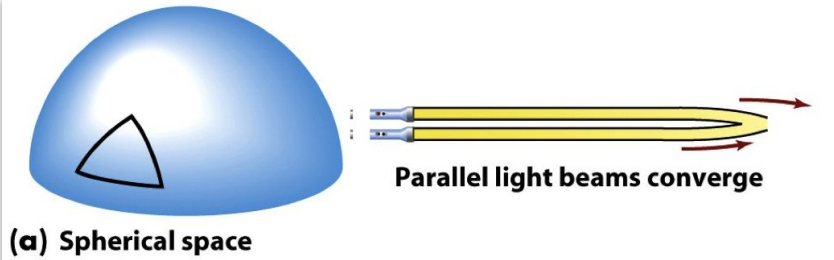
# Initial conditions puzzle – I: homogeneity



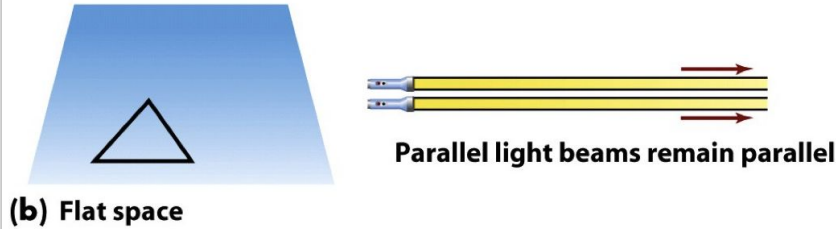
**Distance  $\gg$  age of the Universe  $\times$  speed of light**

# Initial conditions puzzle – II: curvature

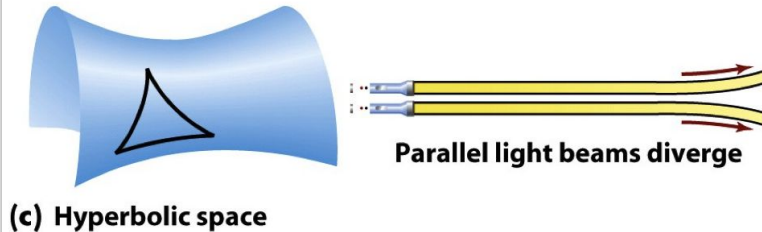
$$k > 0$$



$$k = 0$$

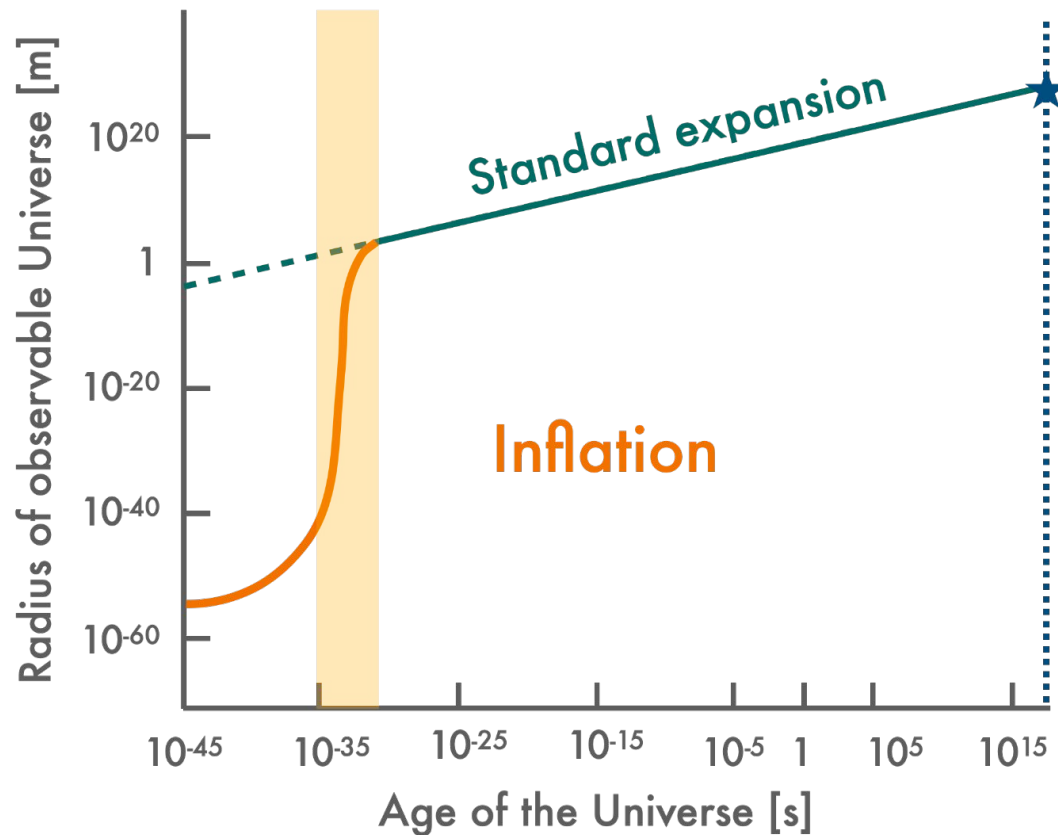


$$k < 0$$

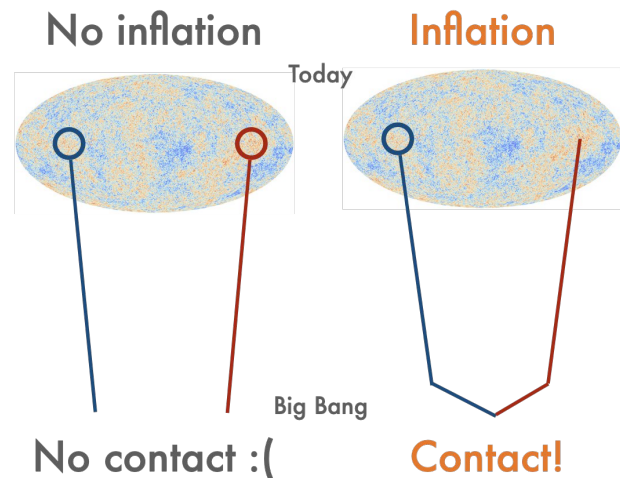




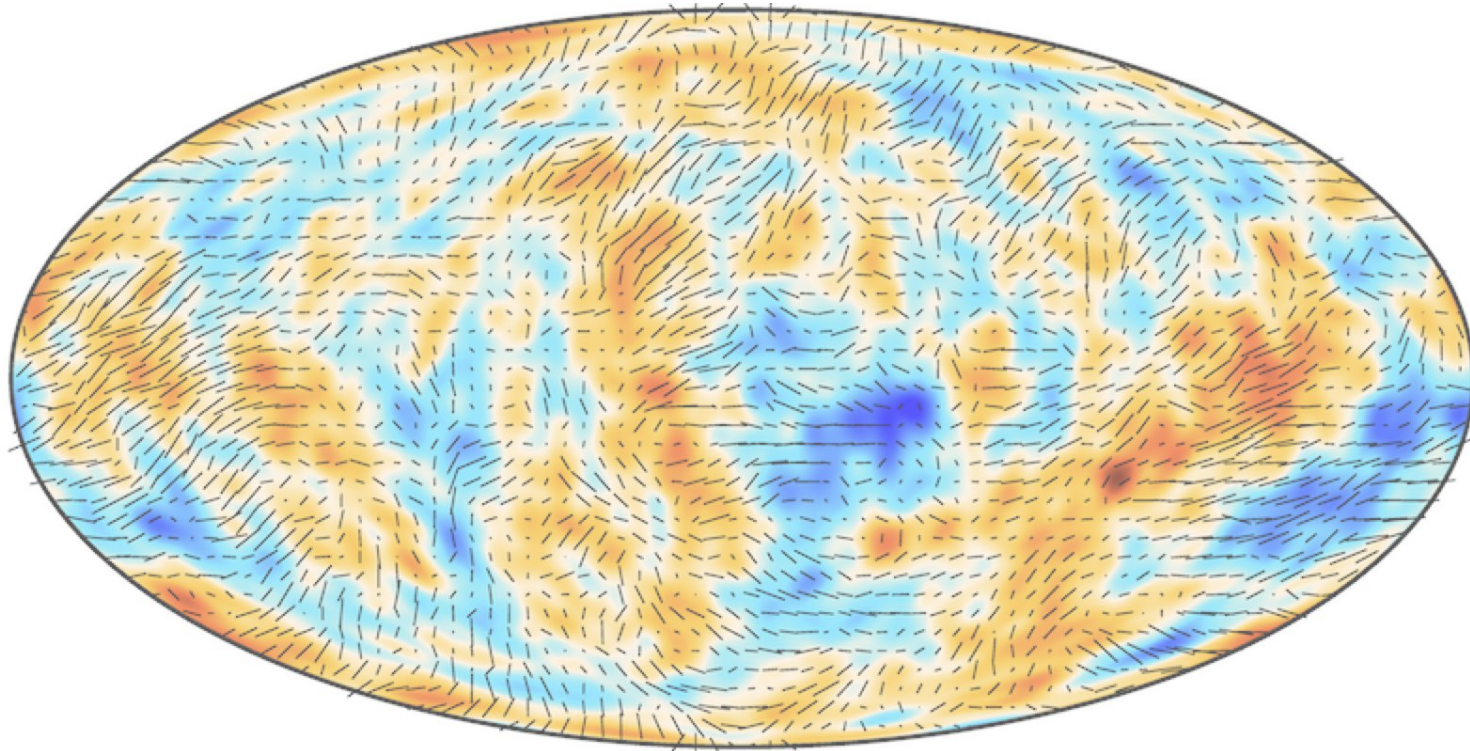
# Initial conditions puzzle – solution!



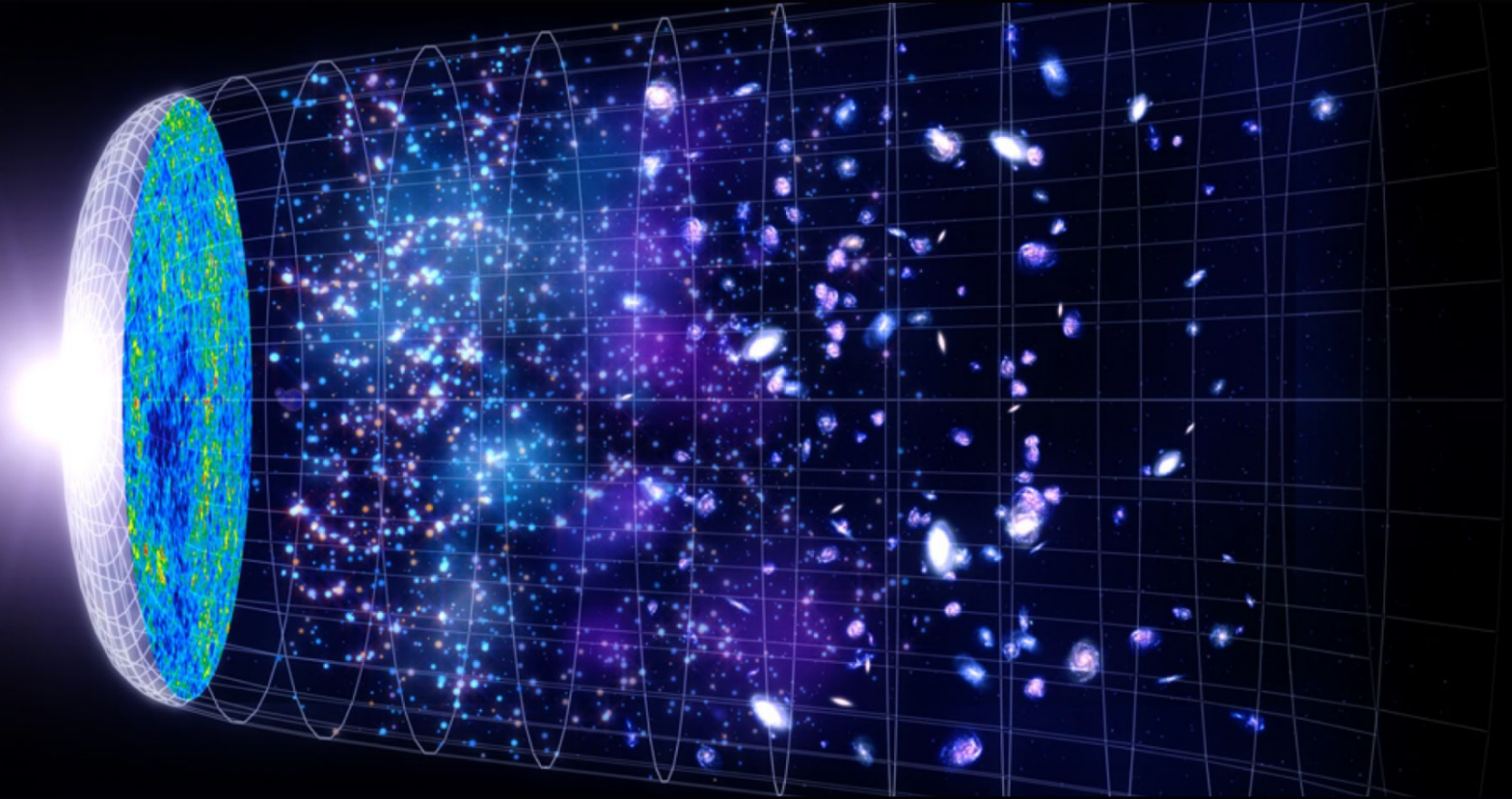
We are here - and now!



The CMB is our messenger for inflation!



**... and for many other things! 13.8 billion years to explore!**





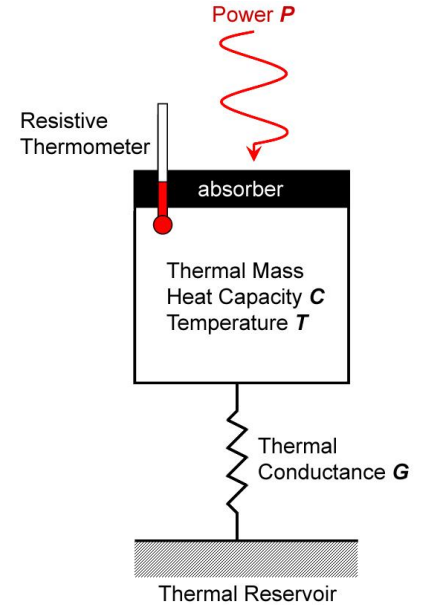
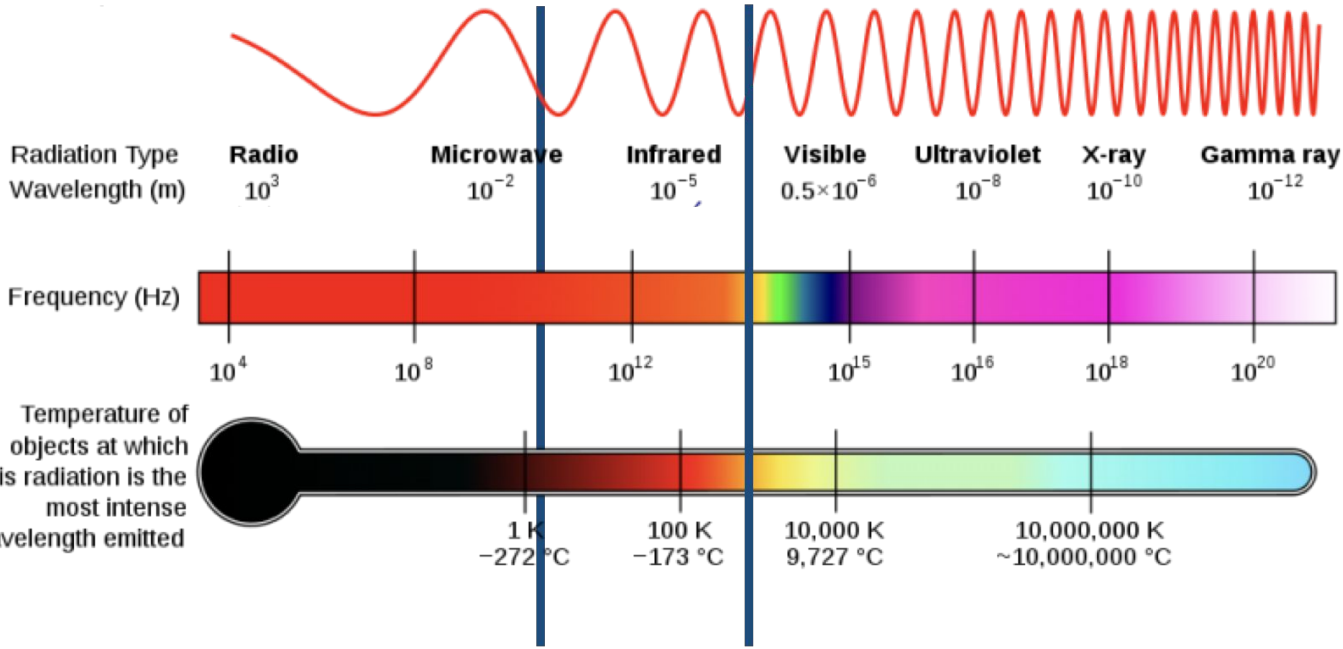
# Measuring the CMB

A wide-angle, fisheye photograph of a large radio telescope dish. The dish is made of many white, rectangular panels that reflect the bright sunlight. In the center of the dish, a green, box-like instrument is mounted on a white platform. The instrument is connected to the dish's structure by several thin cables. The background shows a bright sky with a rainbow visible in the upper right corner. The overall scene is a high-contrast, bright environment.

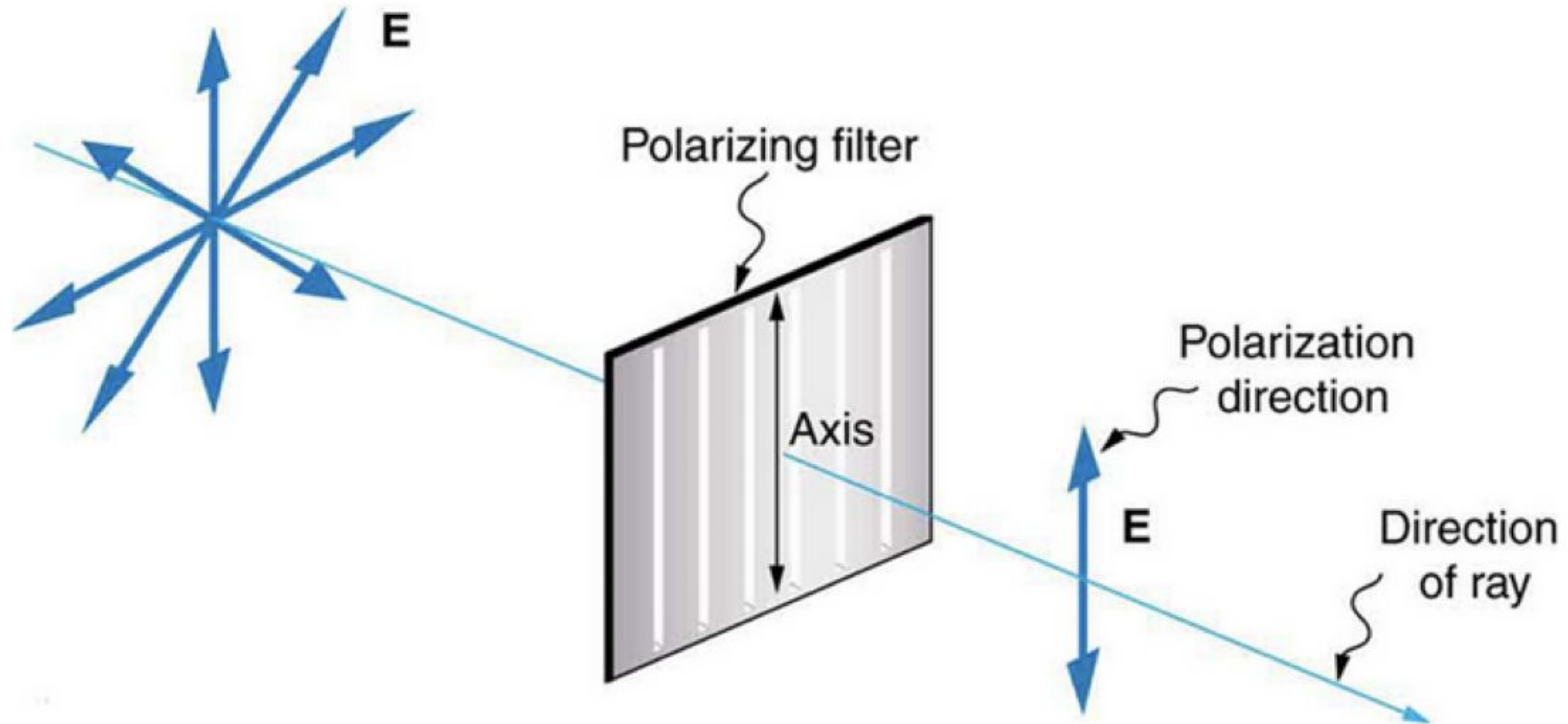


# Basic principle

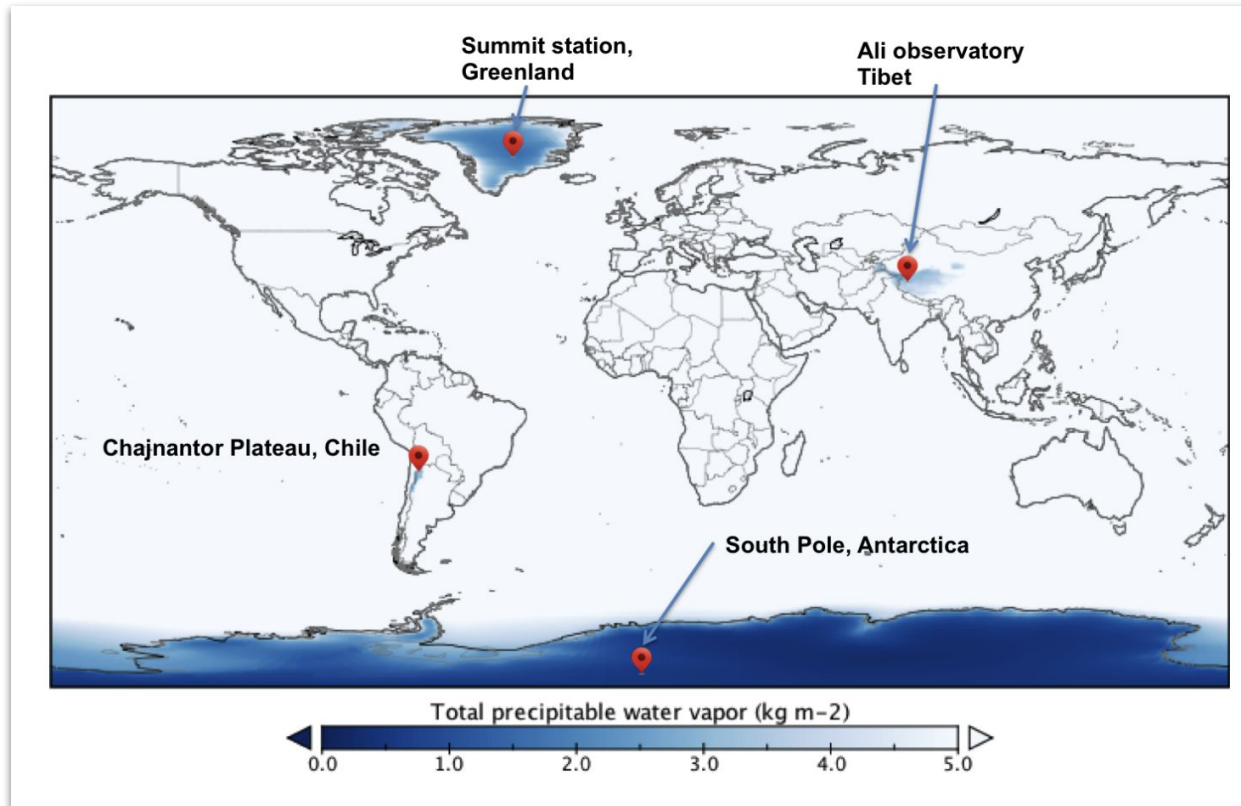
← **Redshift**



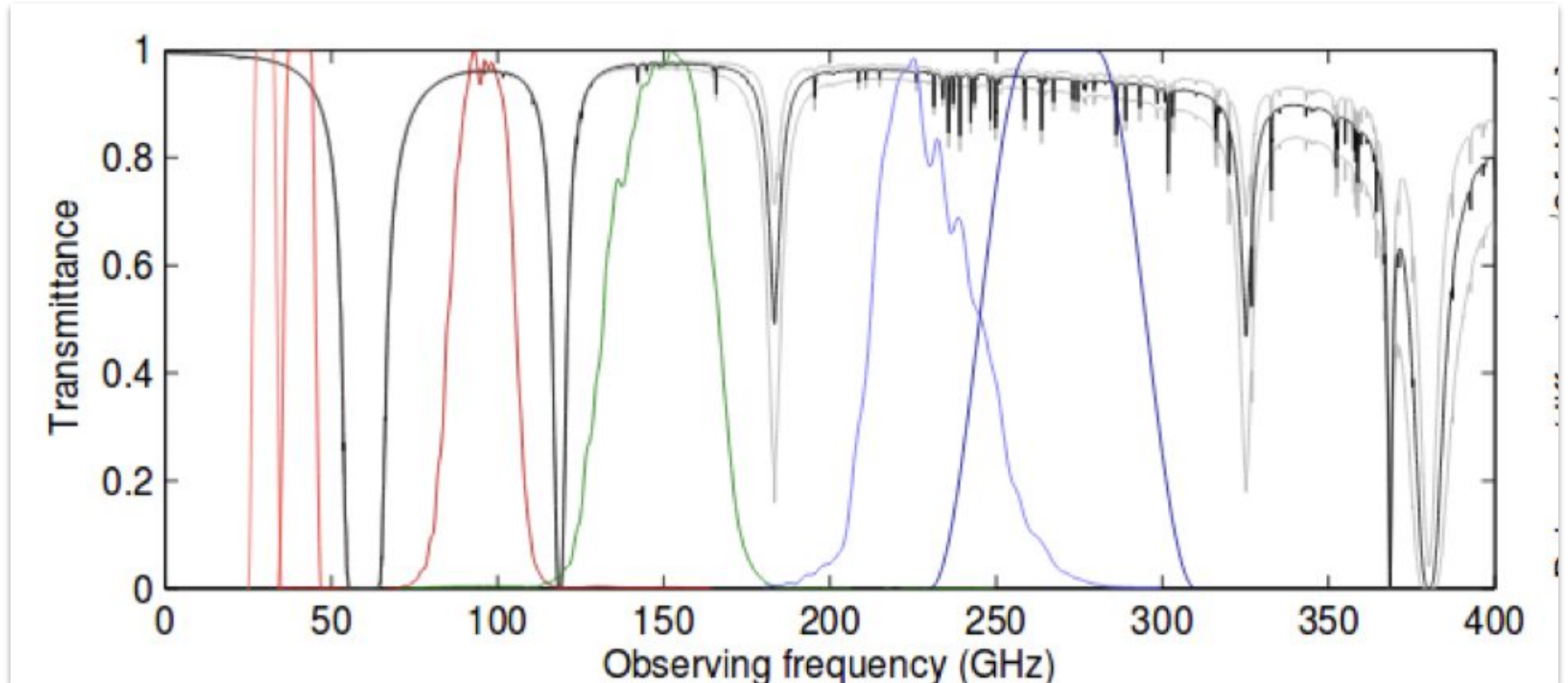
# Polarisation



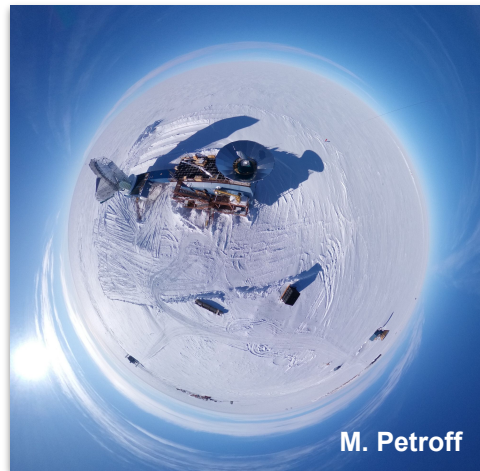
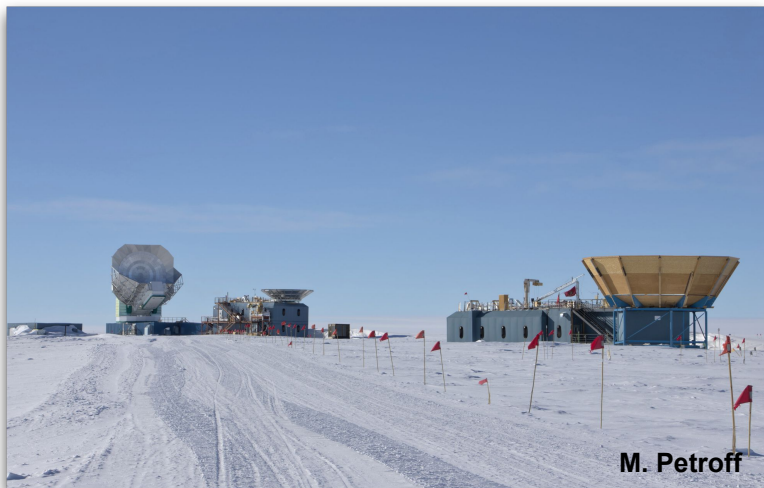
# Where to go?



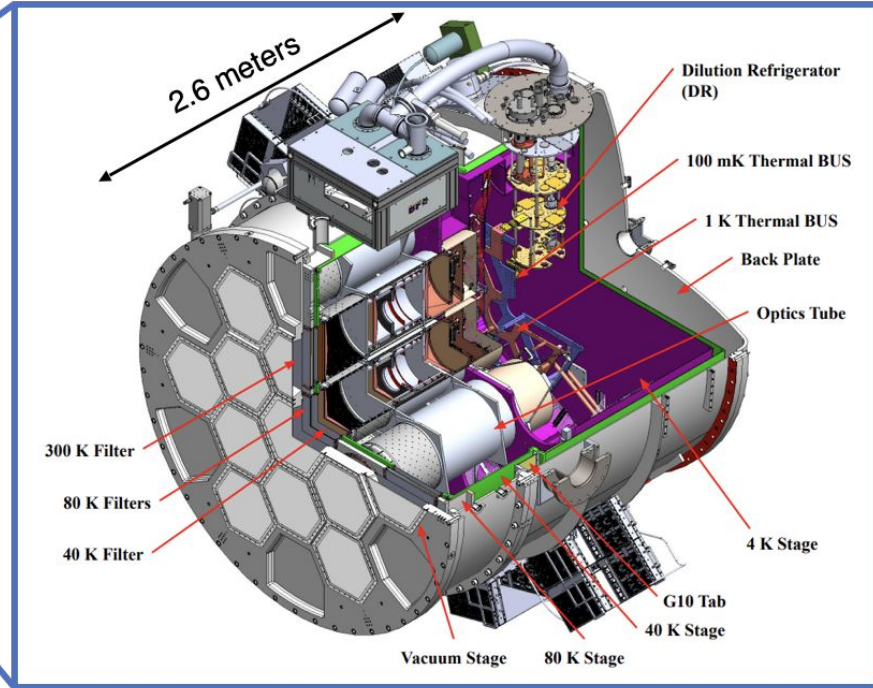
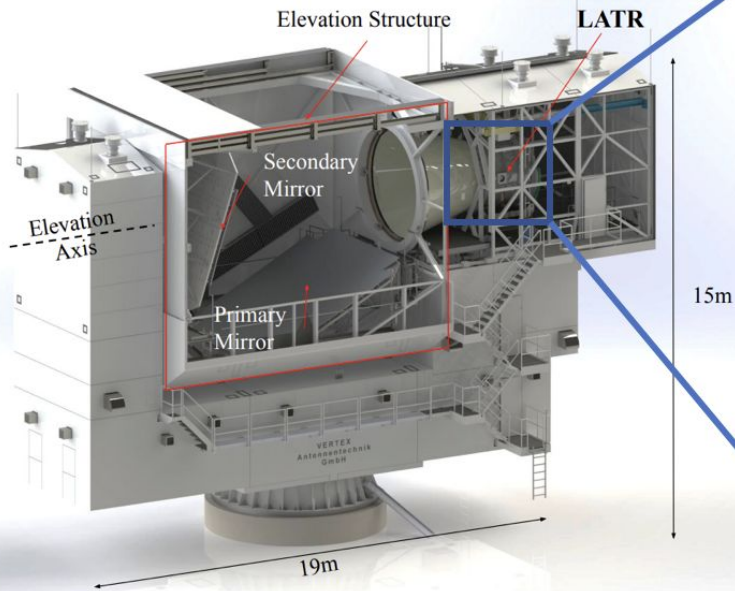
## Still avoiding the atmosphere





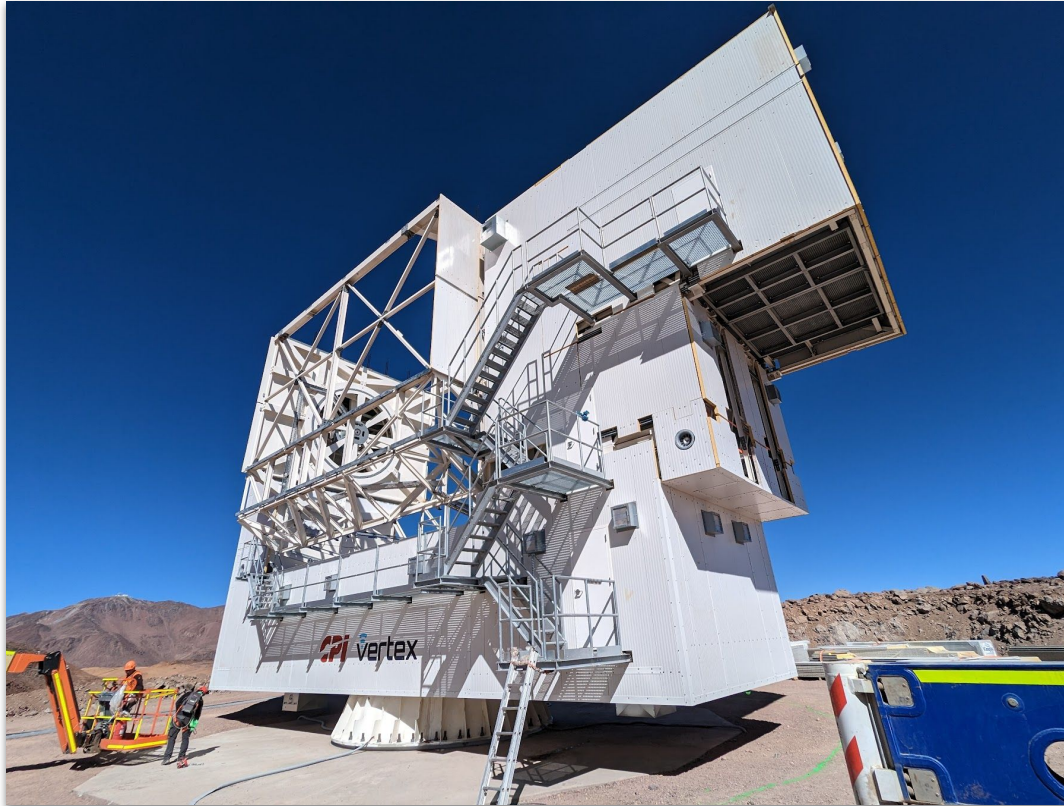


# Large aperture telescope



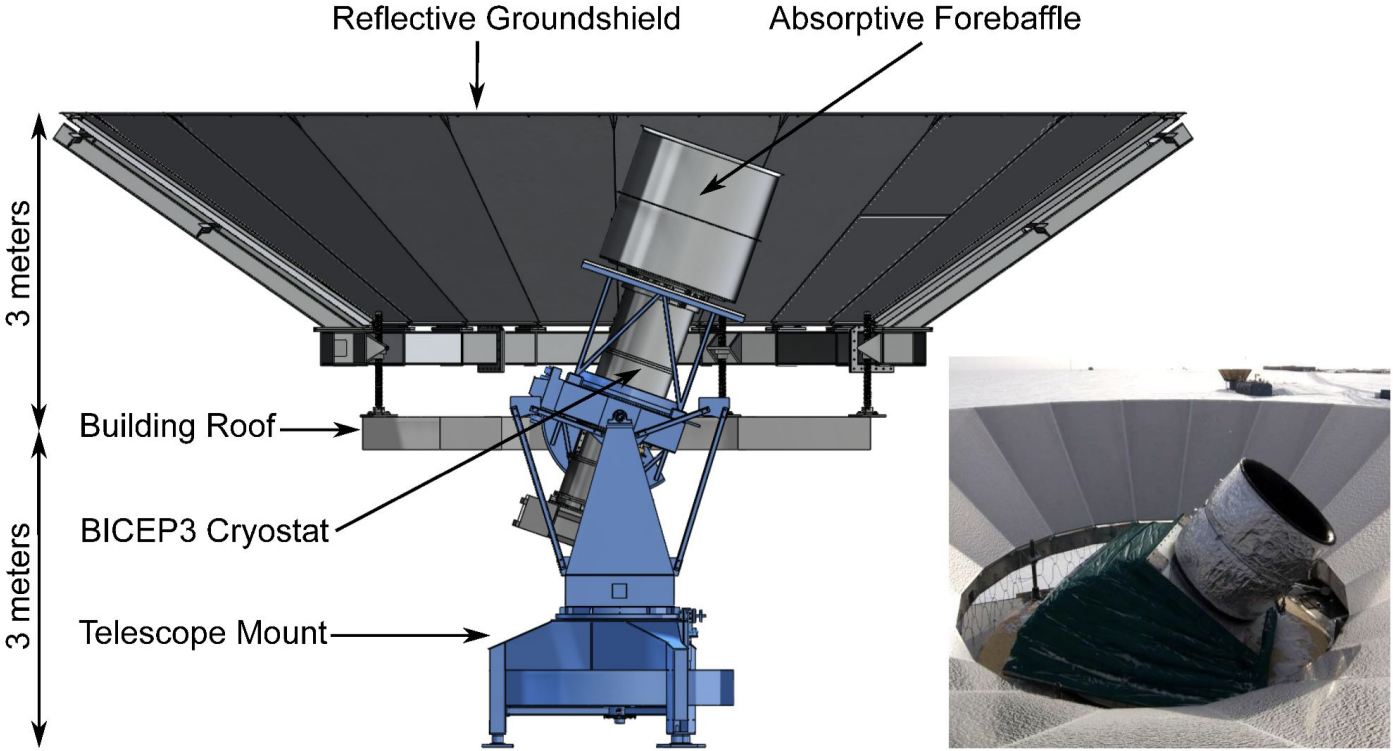


# Large aperture telescope

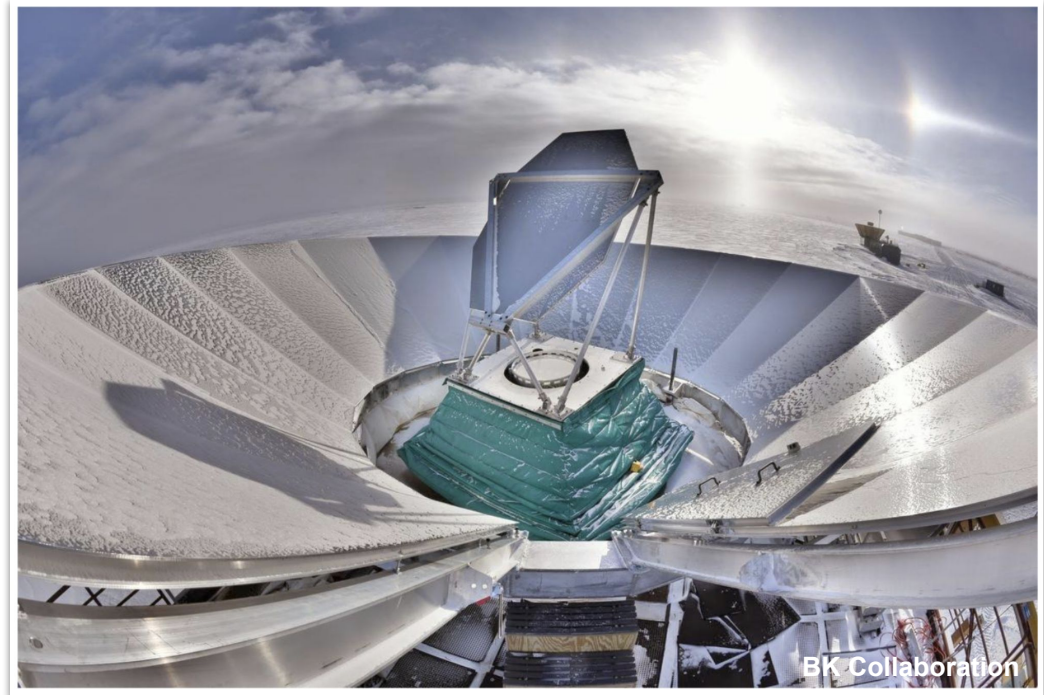
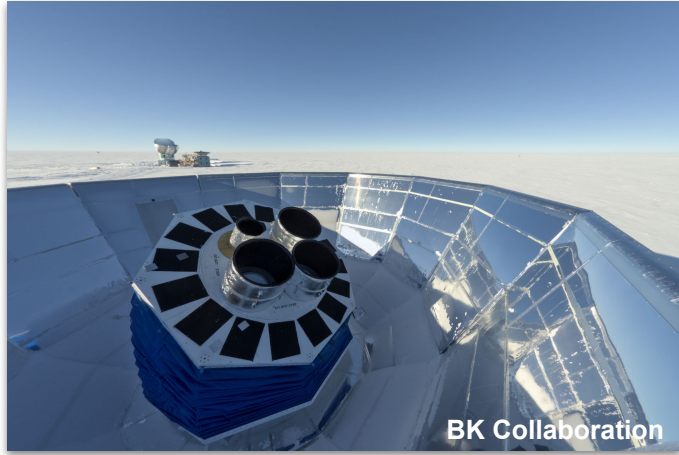




# Small aperture telescope



# External view



# Tubes and mount





# Inside a CMB telescope



Vacuum window

Optics  
(lenses, filters, etc.)

Detectors

Fridge

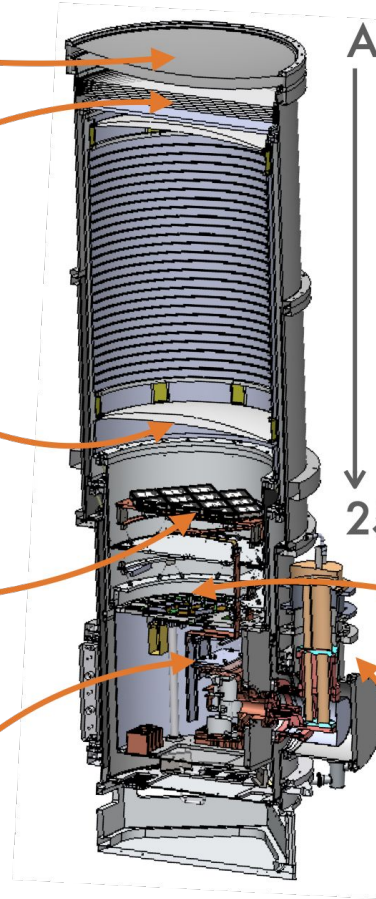
Ambient temperature

Getting colder!

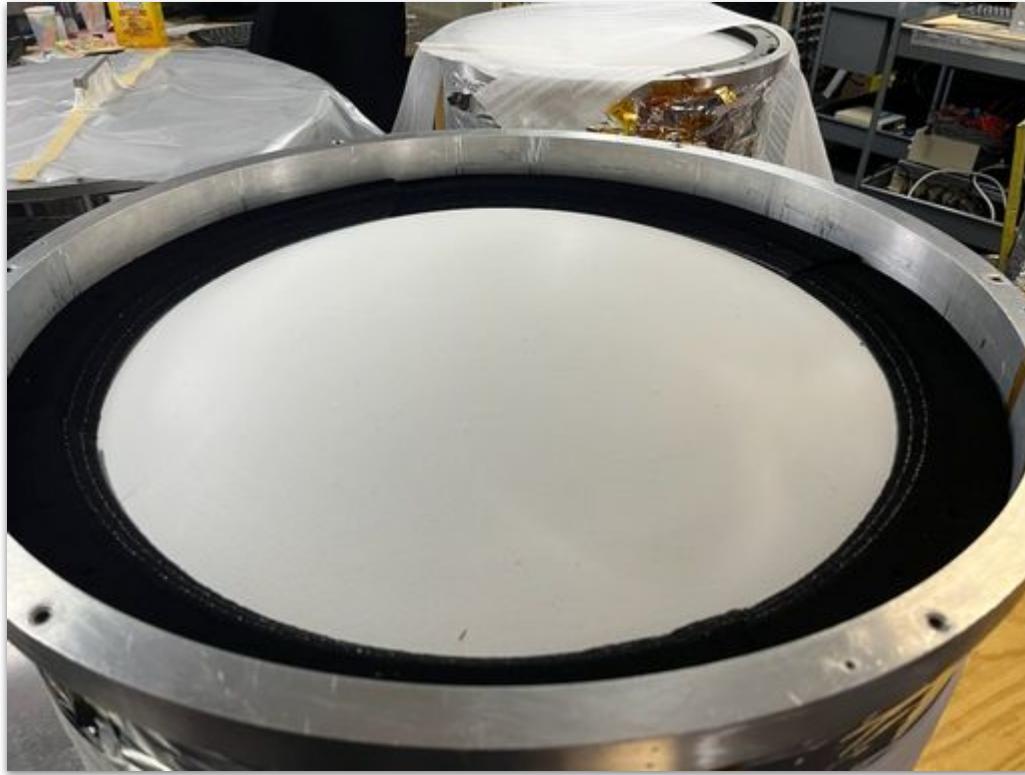
250mK/-273C/-460F

Readout electronics

Cryogenic system



# Inside a CMB telescope



# Small aperture telescope



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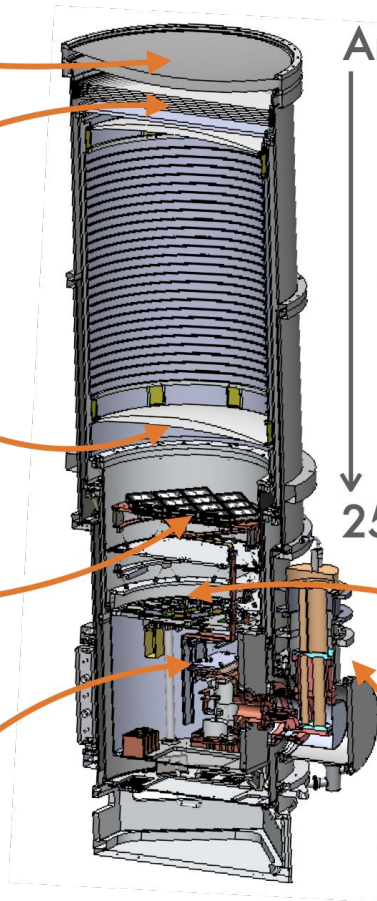
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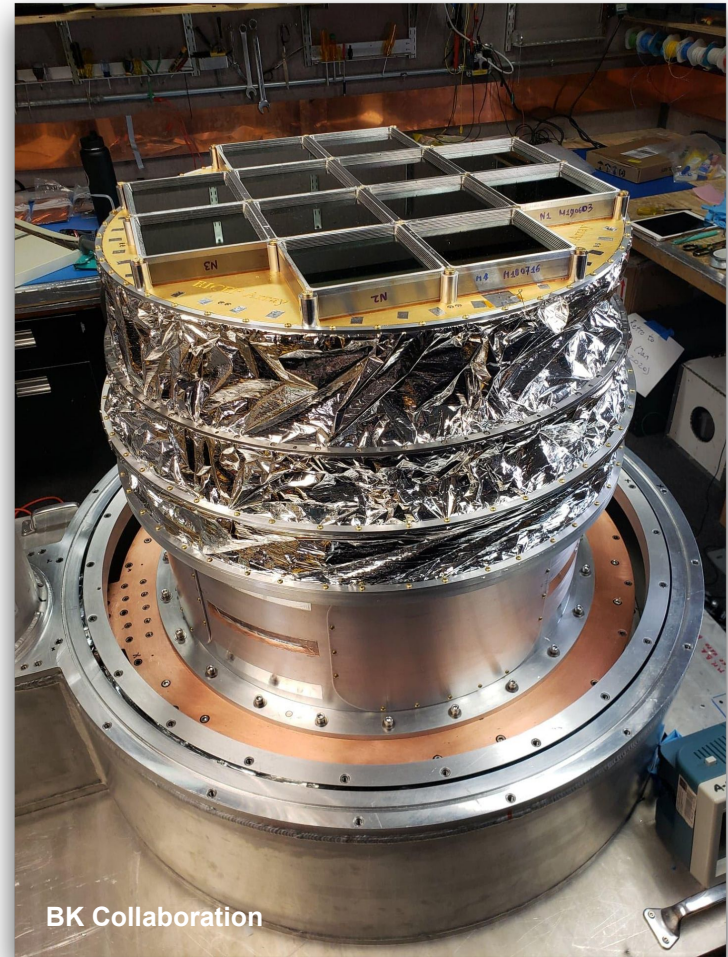
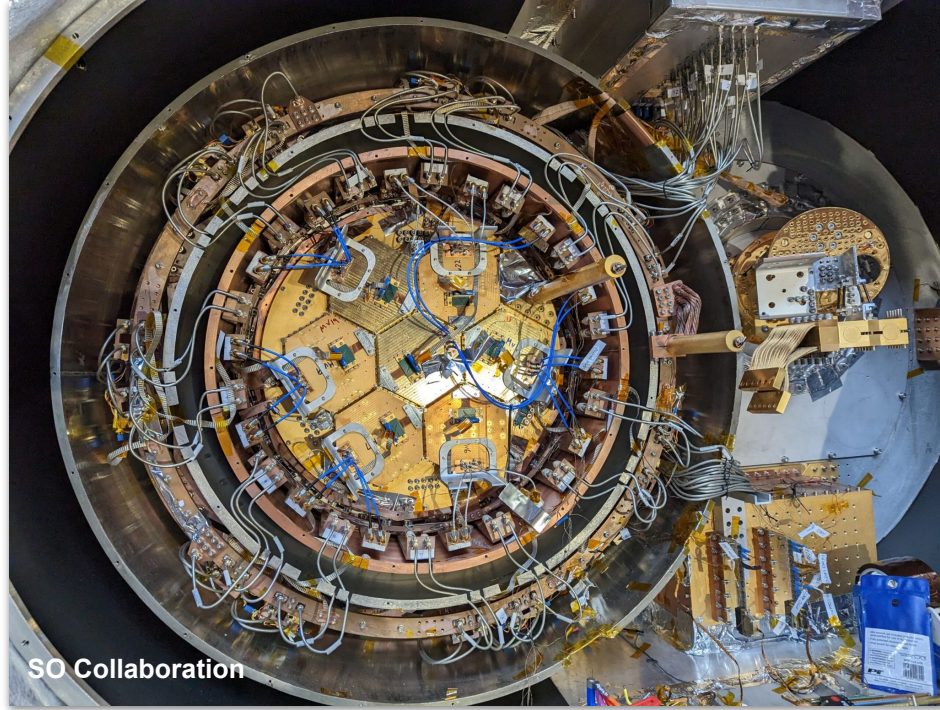
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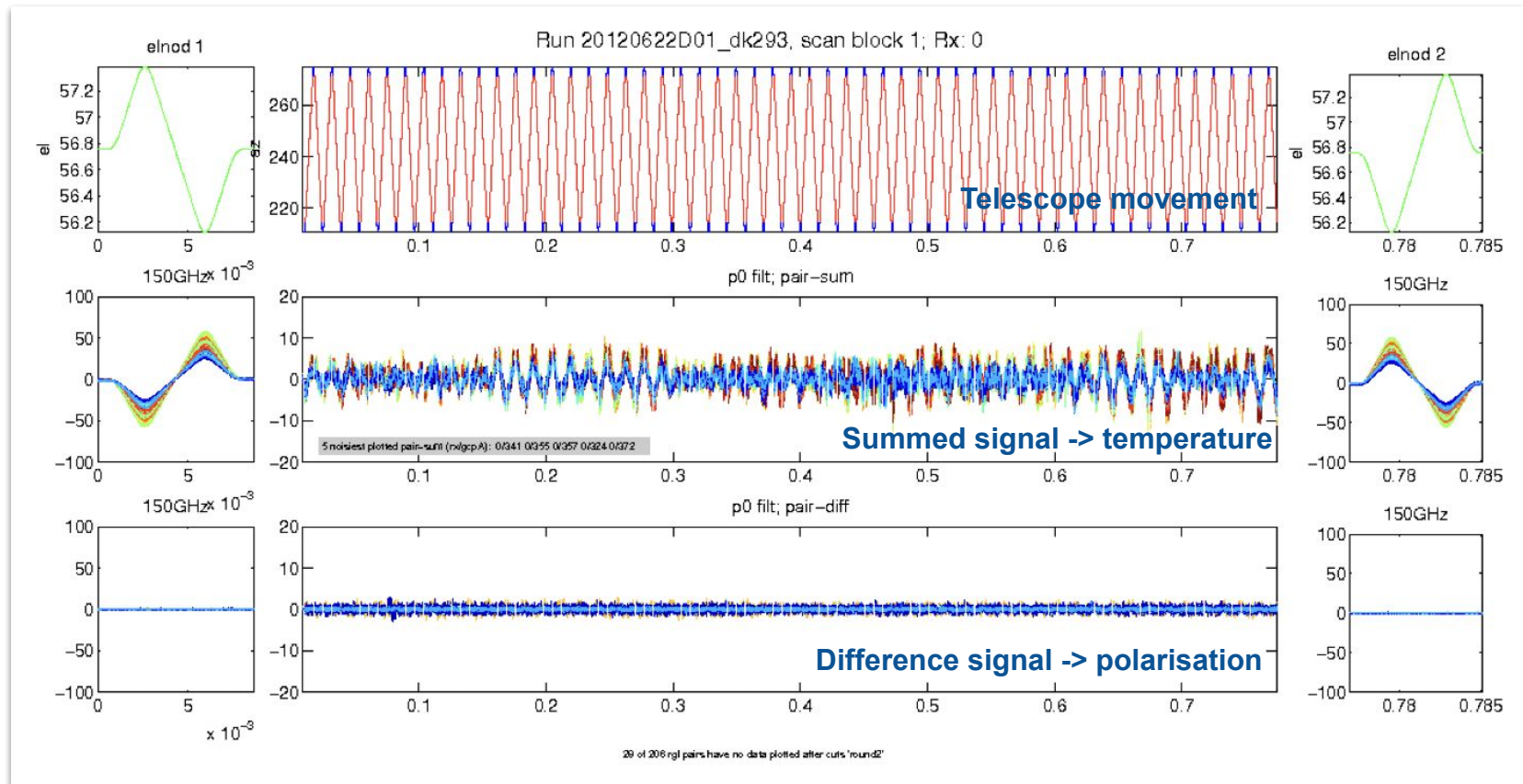




# Inside a CMB telescope

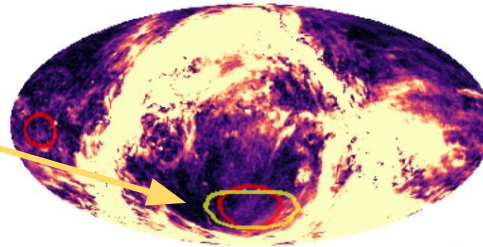
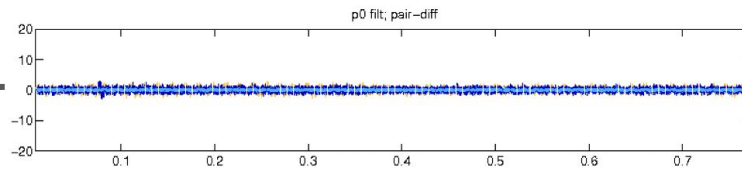


# What do raw data look like?



# Making maps

One pair, single scanset





# Thank you!

