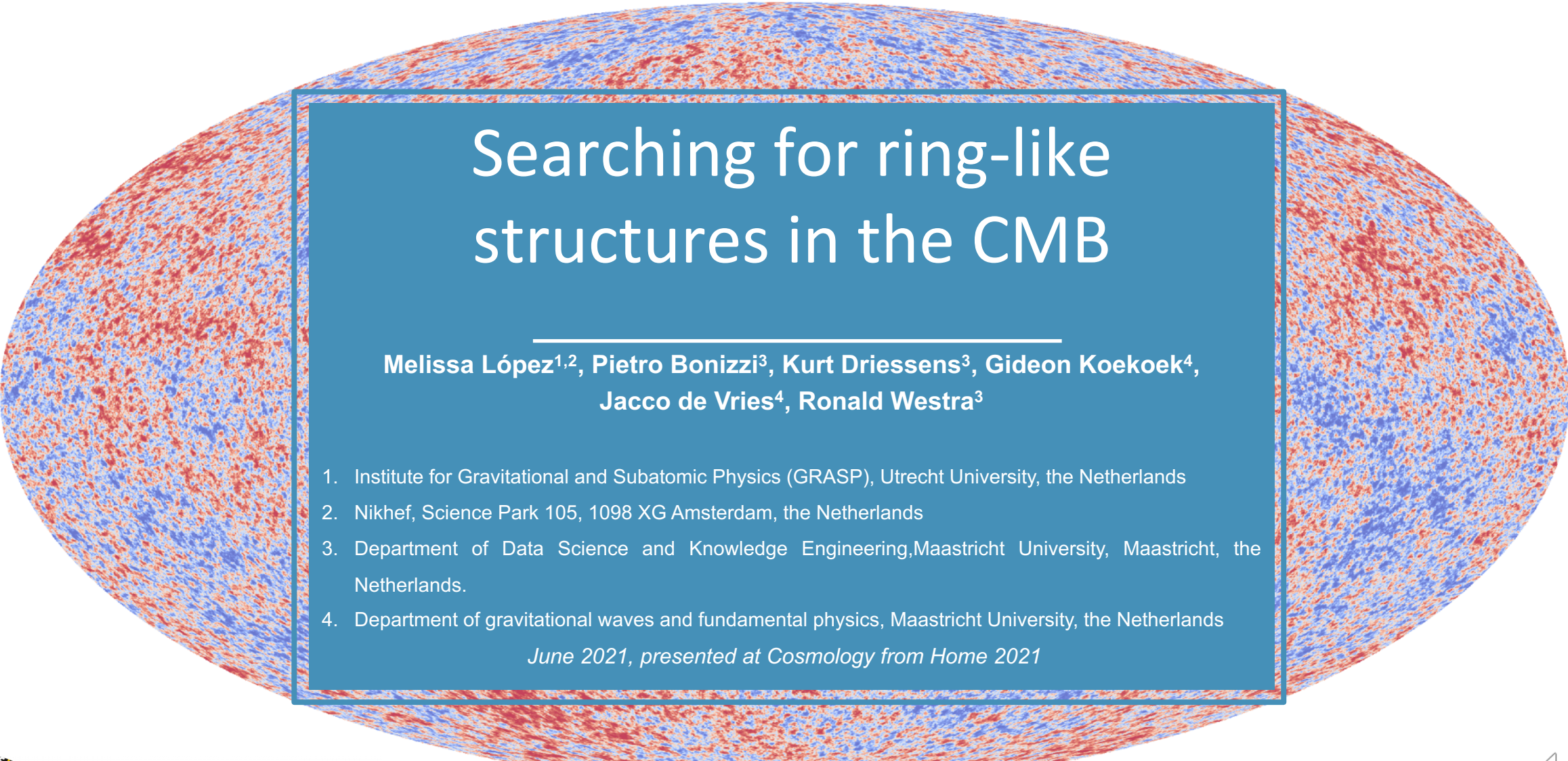


A large, oval-shaped map of the Cosmic Microwave Background (CMB) fluctuations, showing a complex pattern of red and blue speckles representing temperature variations across the sky. The map is centered behind a blue rectangular text box.

Searching for ring-like structures in the CMB

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4. Department of gravitational waves and fundamental physics, Maastricht University, the Netherlands

June 2021, presented at Cosmology from Home 2021



Motivation

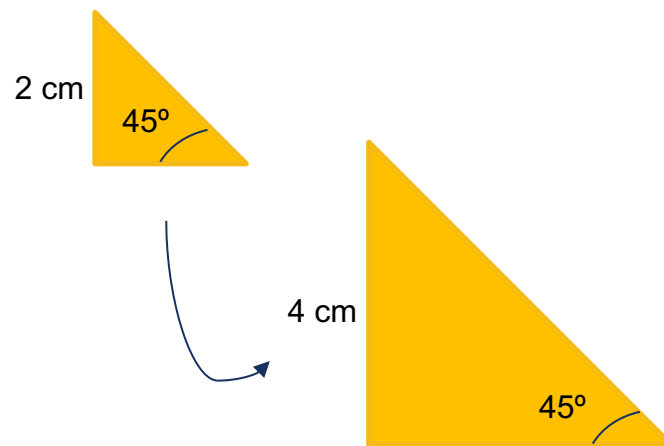
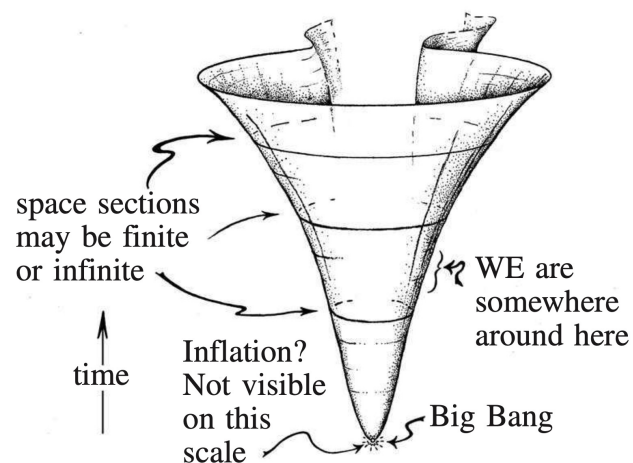
What are the dynamics of the very early and very late Universe?

- Current dominant theory: Λ CDM
- Goal: to search for ring-like anomalies in the CMB
- Context: Conformal Cyclic Cosmology (CCC) by Sir Roger Penrose



Brief introduction to Conformal Cyclic Cosmology

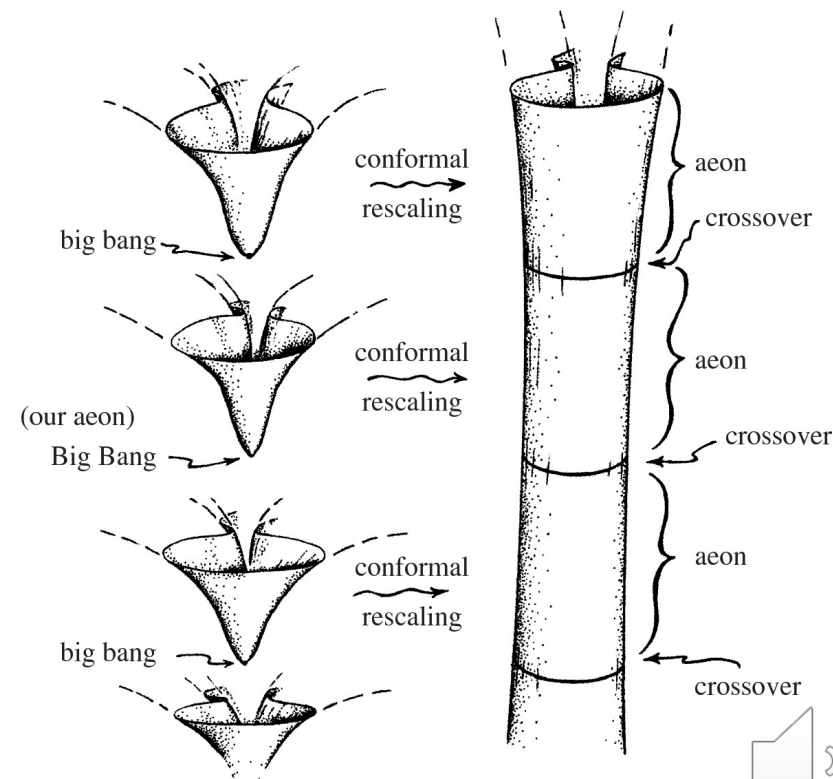
Λ CDM



Conformal geometry preserves angles while losing the notion of scale

- What happened **before** the Big Bang?
- What will happen **after** the infinite expansion?

CCC



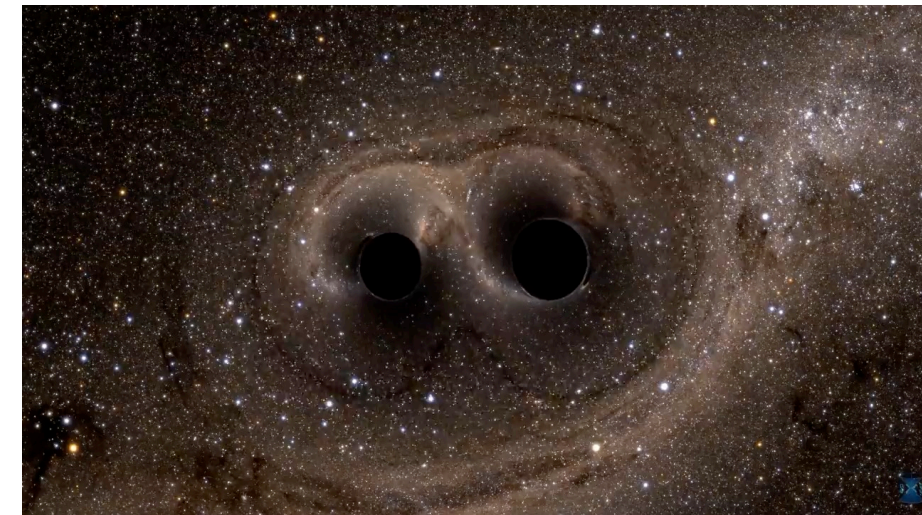
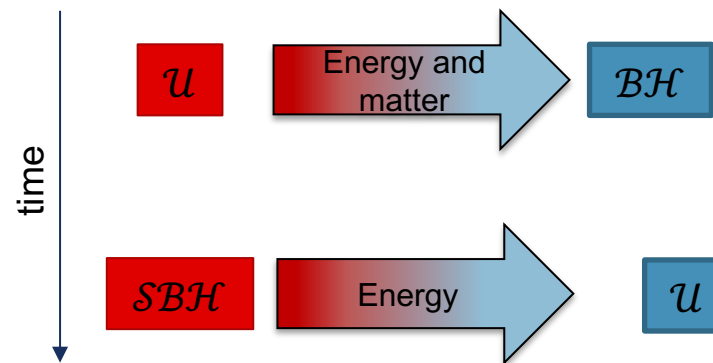
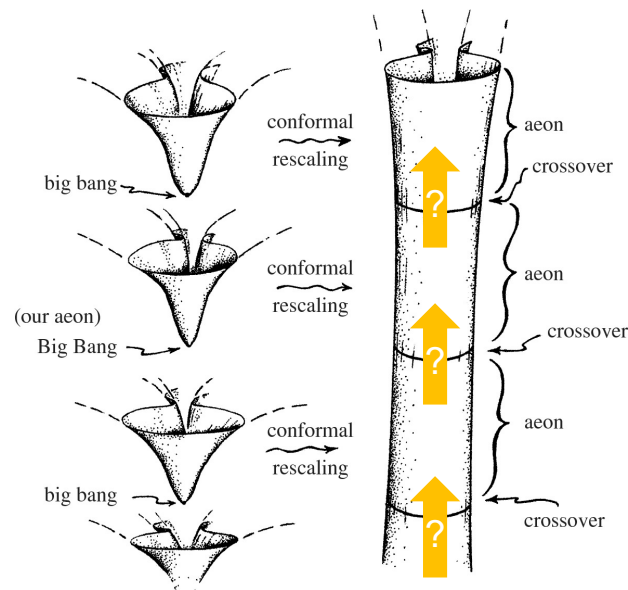
Early Universe

1. Big Bang $\rightarrow$ very high temperature and velocity!
2. Massless particles (General Relativity)

Late Universe

1. Supermassive black holes $\rightarrow$ swallow most of the mass
2. Massless particles (mass fade out assumption)

Scale invariant!



Observational implications

1. Supermassive black hole mergers
2. Hawking evaporation

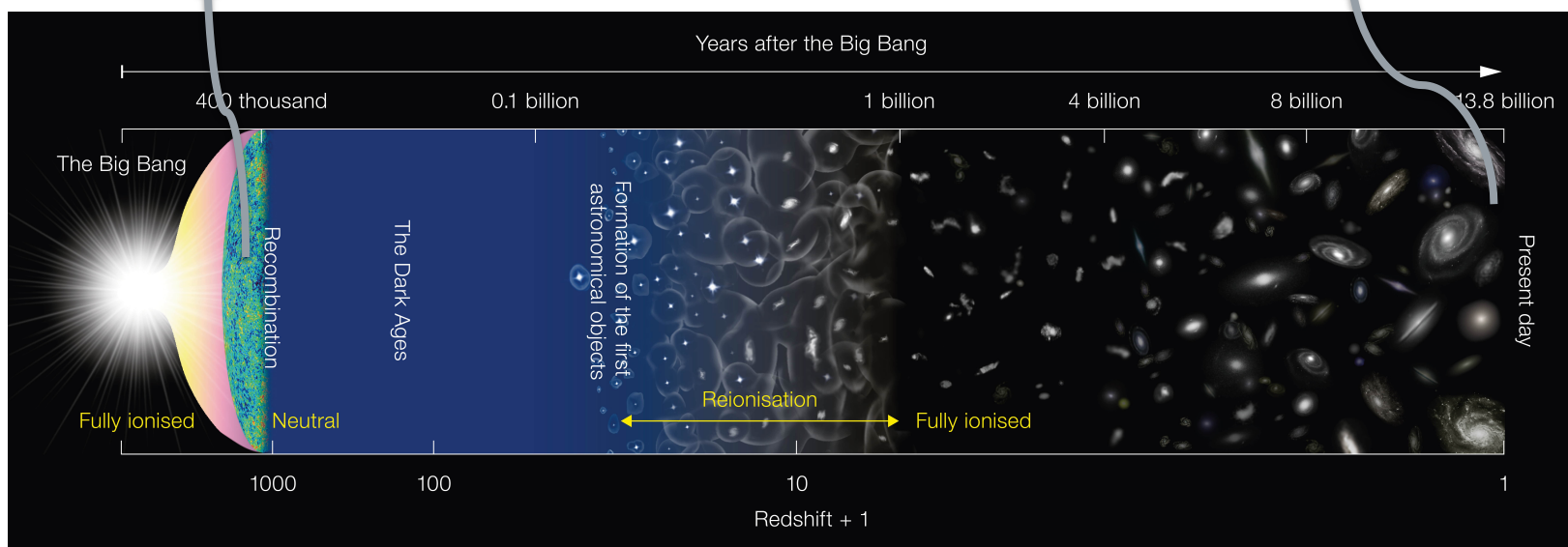


CCC is cyclic. Can we measure observables from the previous aeon in the current one?

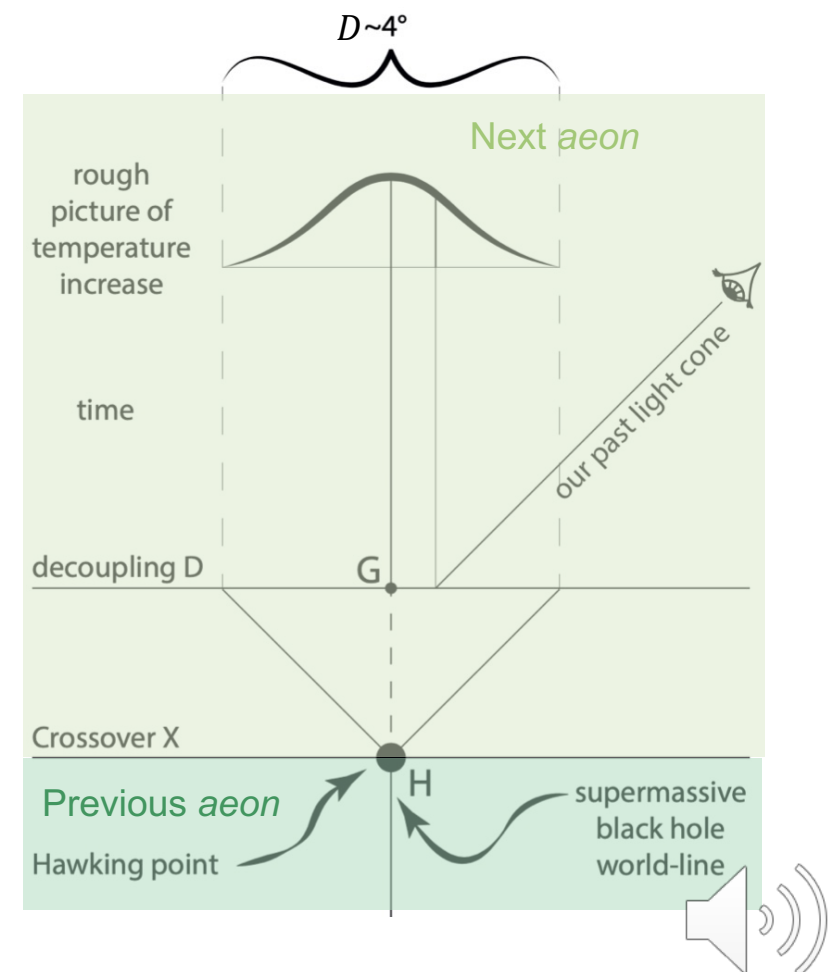
What are Hawking points?

Cosmic Microwave Background (CMB)

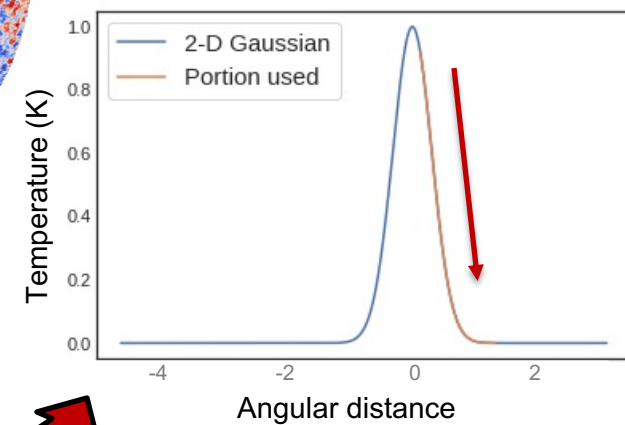
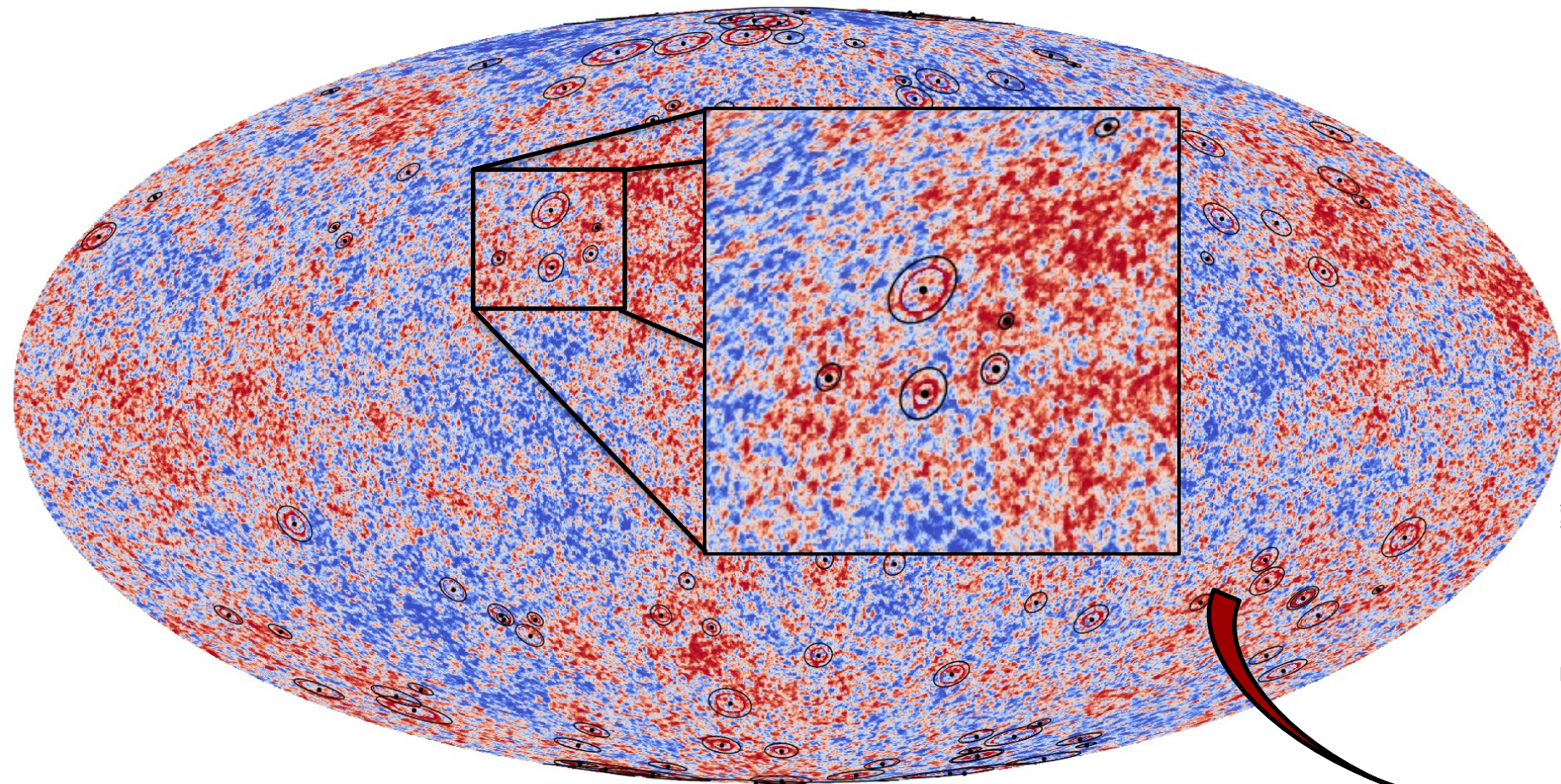
Cosmic Gravitational wave Background (CGB)



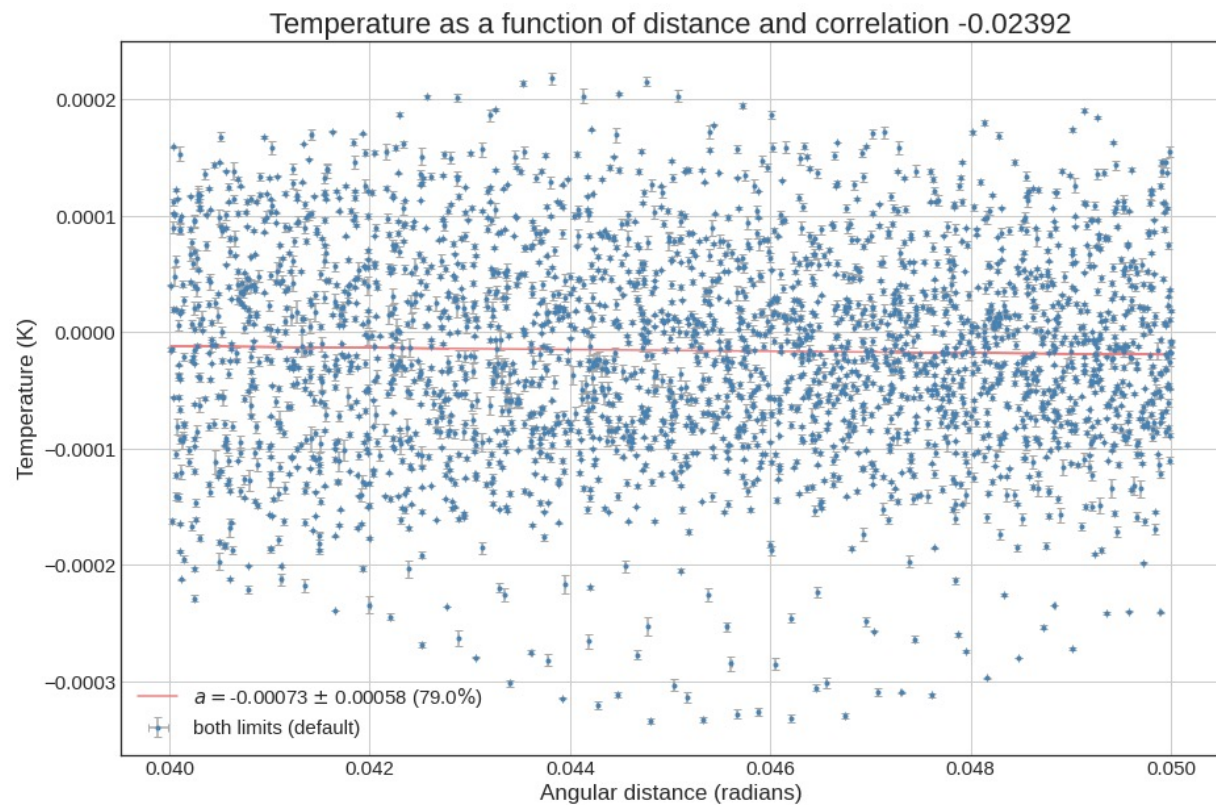
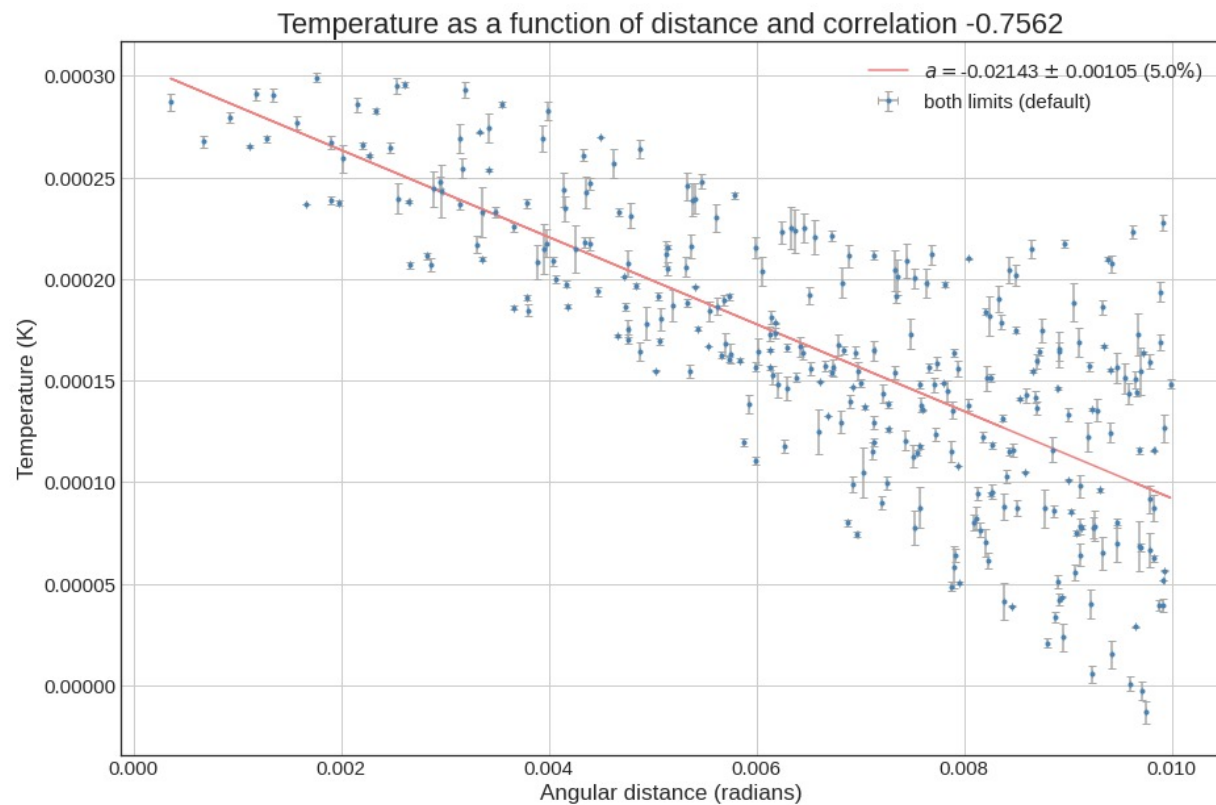
**HPs are ring-like structures in the CMB and CGB.
How big? Upper threshold $r_{out} < 0.035$ rad in the CMB.**



110 artificial HPs in simulated CMB



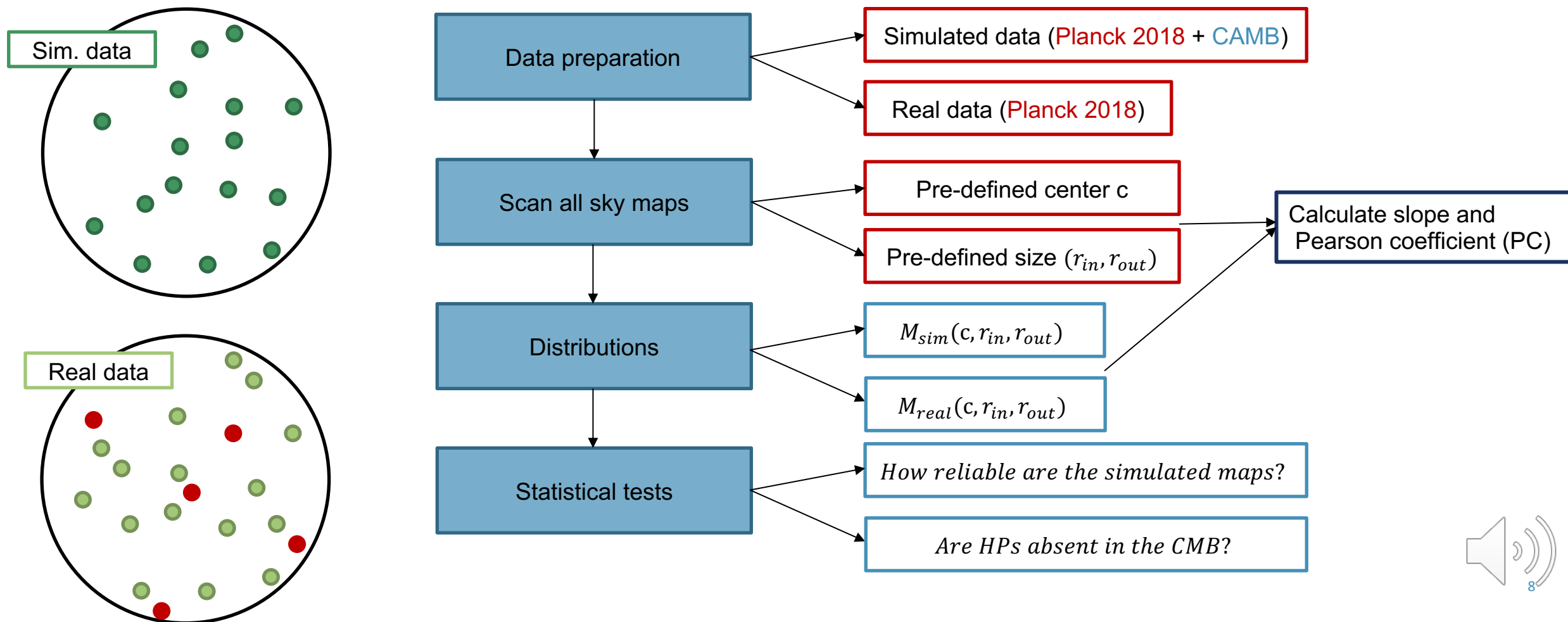
A HPC and a NHPC from real CMB map (Planck 2018)



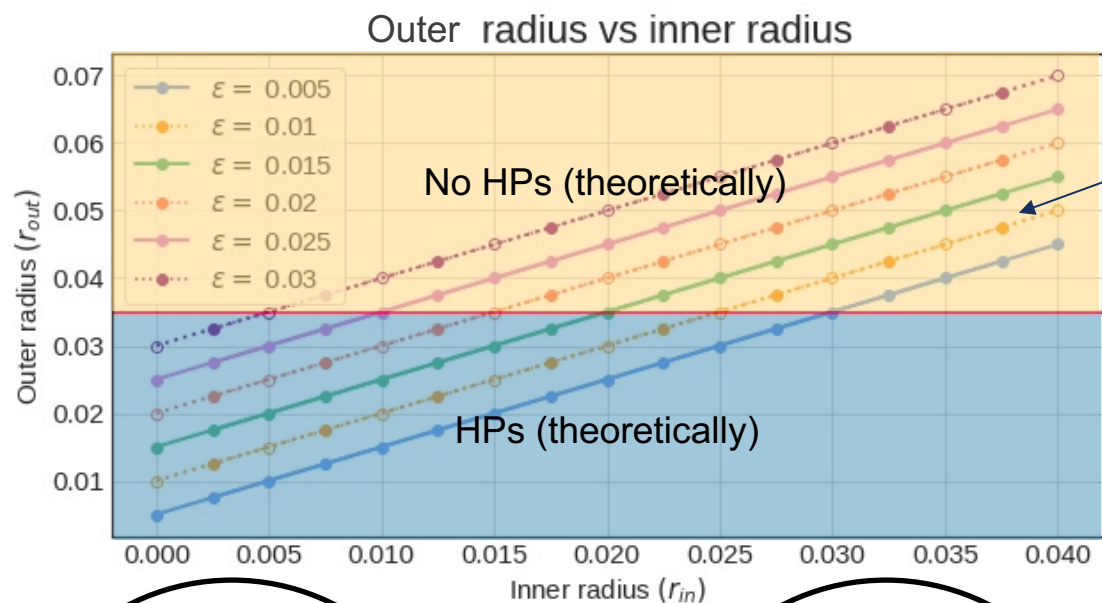
HPs are very negative. How much? We don't know



How do we measure HPs?

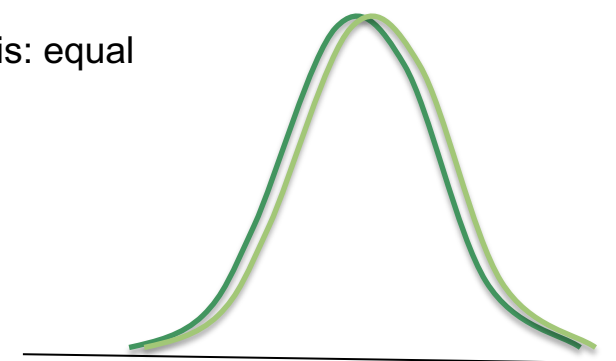


How reliable are the simulated maps?

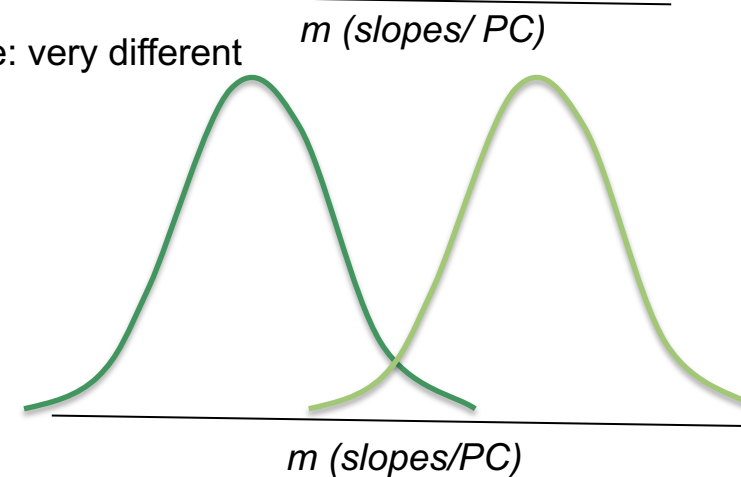


Test reliability of the simulations (region $r_{out} \geq 0.035$)

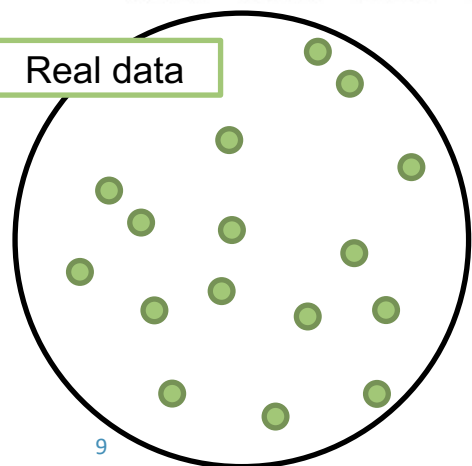
Null hypothesis: equal



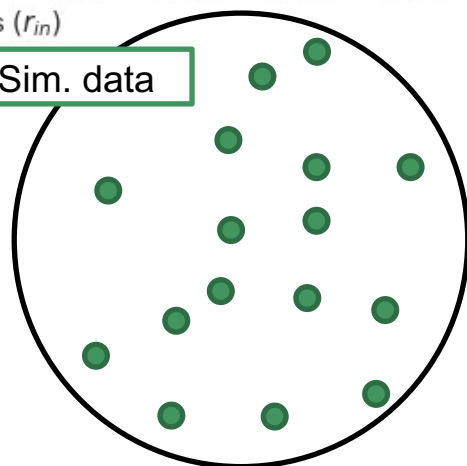
Alternative: very different



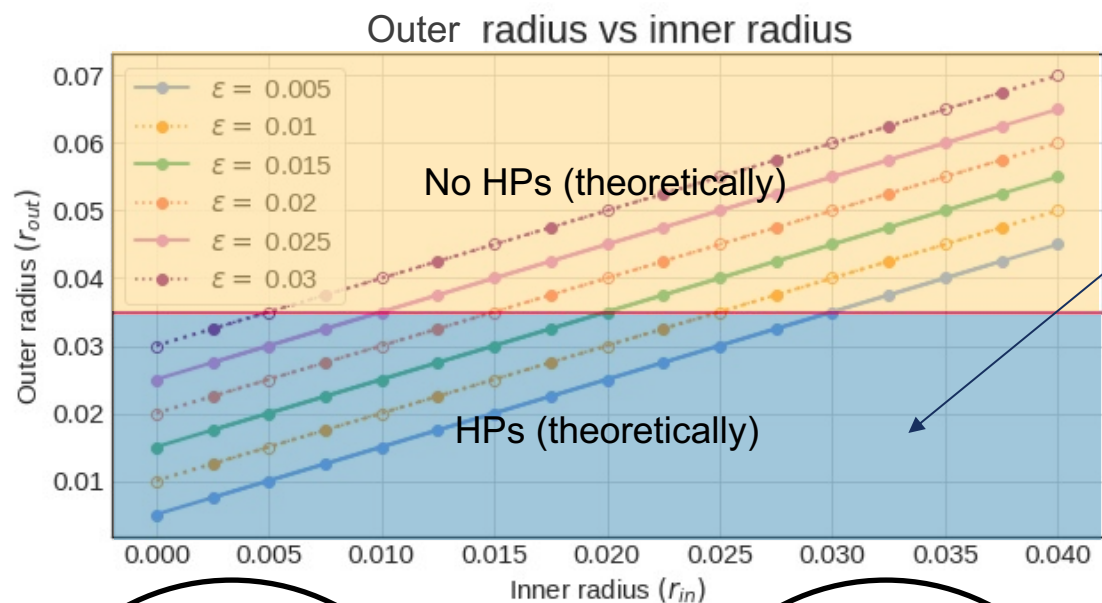
Real data



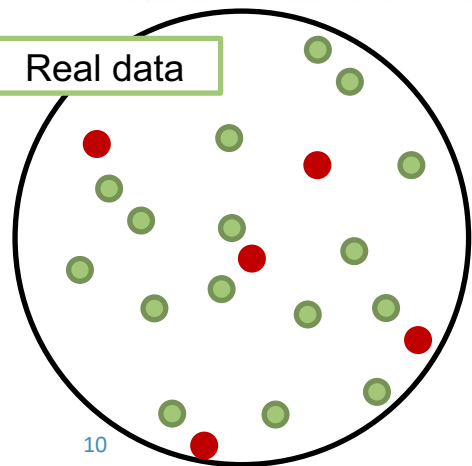
Sim. data



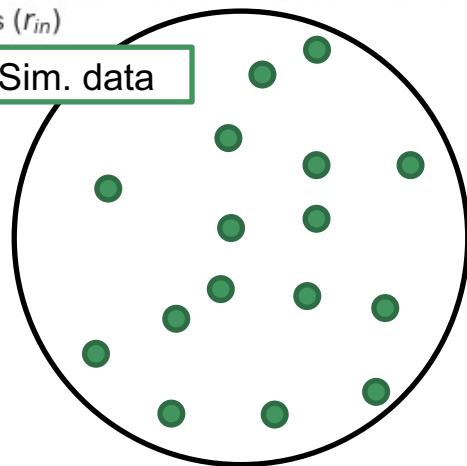
Are HPs absent in the CMB?



Real data

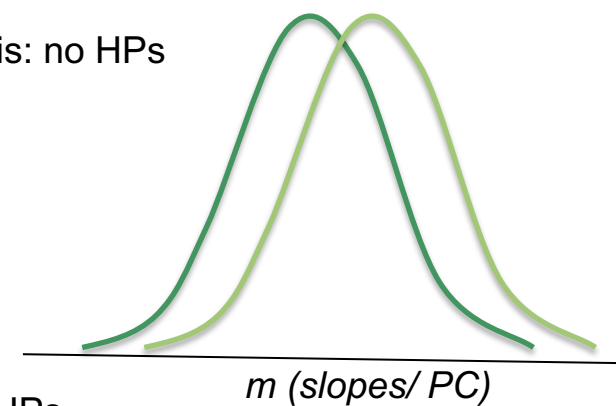


Sim. data

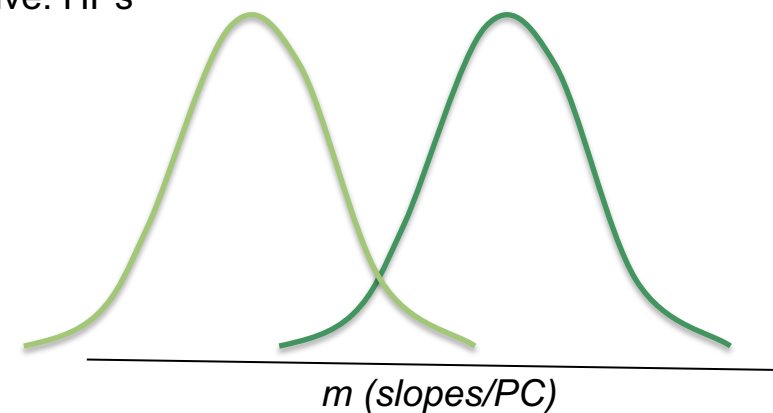


Test absence of HPs (region $r_{out} < 0.035$)

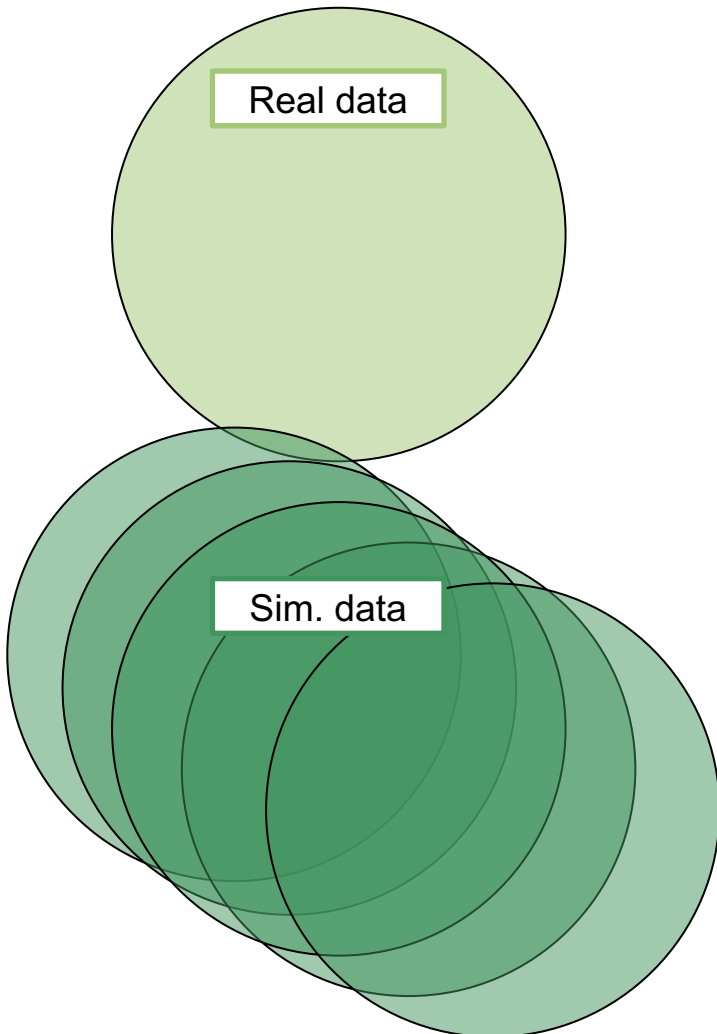
Null hypothesis: no HPs



Alternative: HPs



Results with Kolmogorov-Smirnov test



$$P_{KS} \longrightarrow \mu(P_{KS}) \pm \varepsilon(P_{KS}) \text{ at 95\% CI}$$

Set $\alpha = 0.01$ for KS test

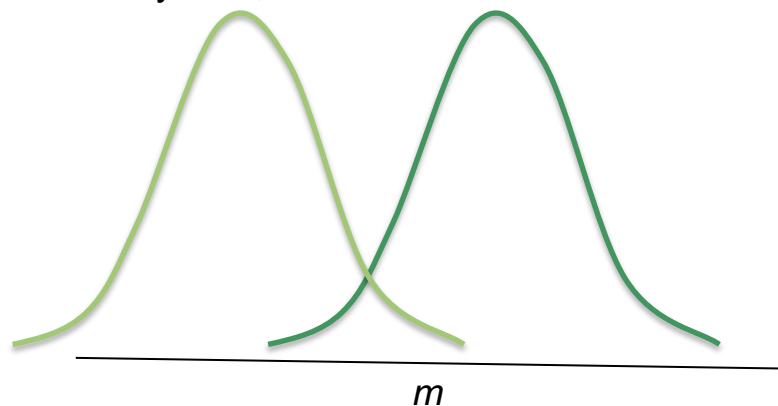
	Reliability (region $r_{out} \geq 0.035$)	Absence (region $r_{out} < 0.035$)
$\mu(P_{KS}) \pm \varepsilon(P_{KS})$	Obtain $\mu(P_{KS}) < 0.1$	Obtain $\min(\mu(P_{KS})) = 0.19$
Null	Reject	Accept

Mismatch between Sim and Real data



Are HPs anomalies in the CMB?

We consider many HPs, ...

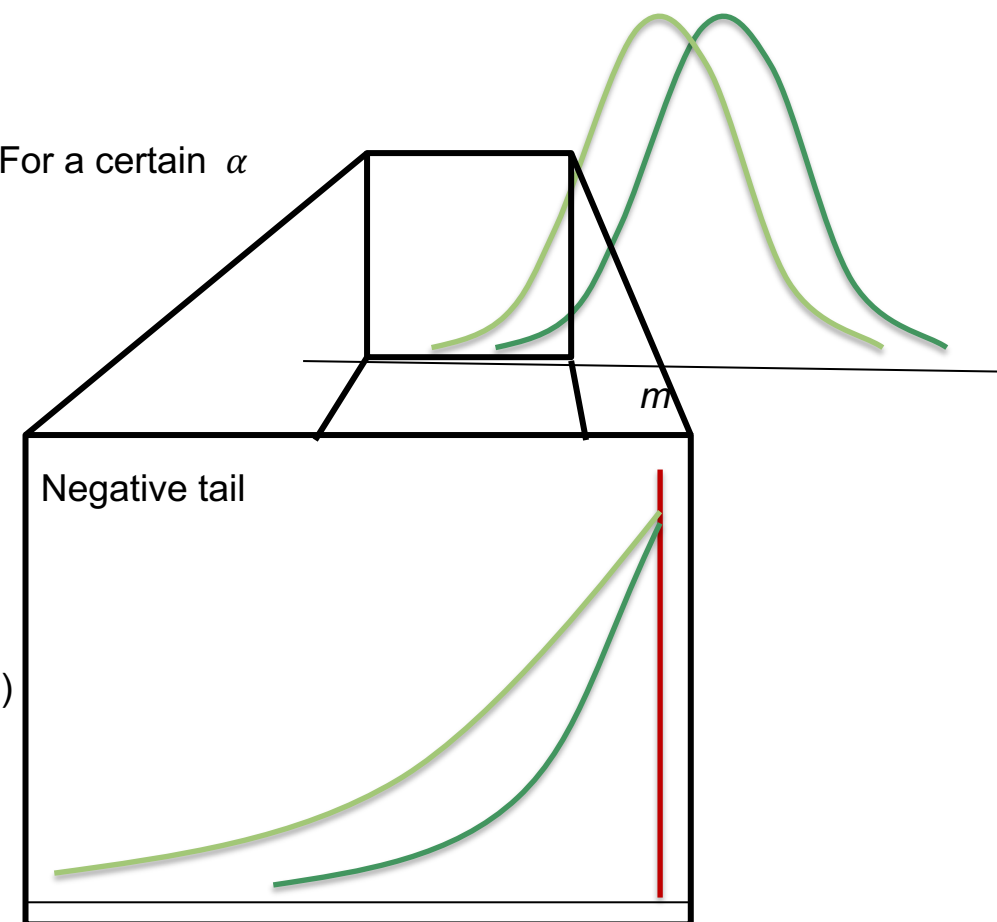


- If m_{real} inside lower tail: “Hawking point candidate” (HPC)
- If m_{real} outside lower tail: “No Hawking point candidate” (NHPC)

$$Rate = \frac{\text{number of HPC}}{\text{total number of locations}} (\%)$$

... but what if they are anomalies?

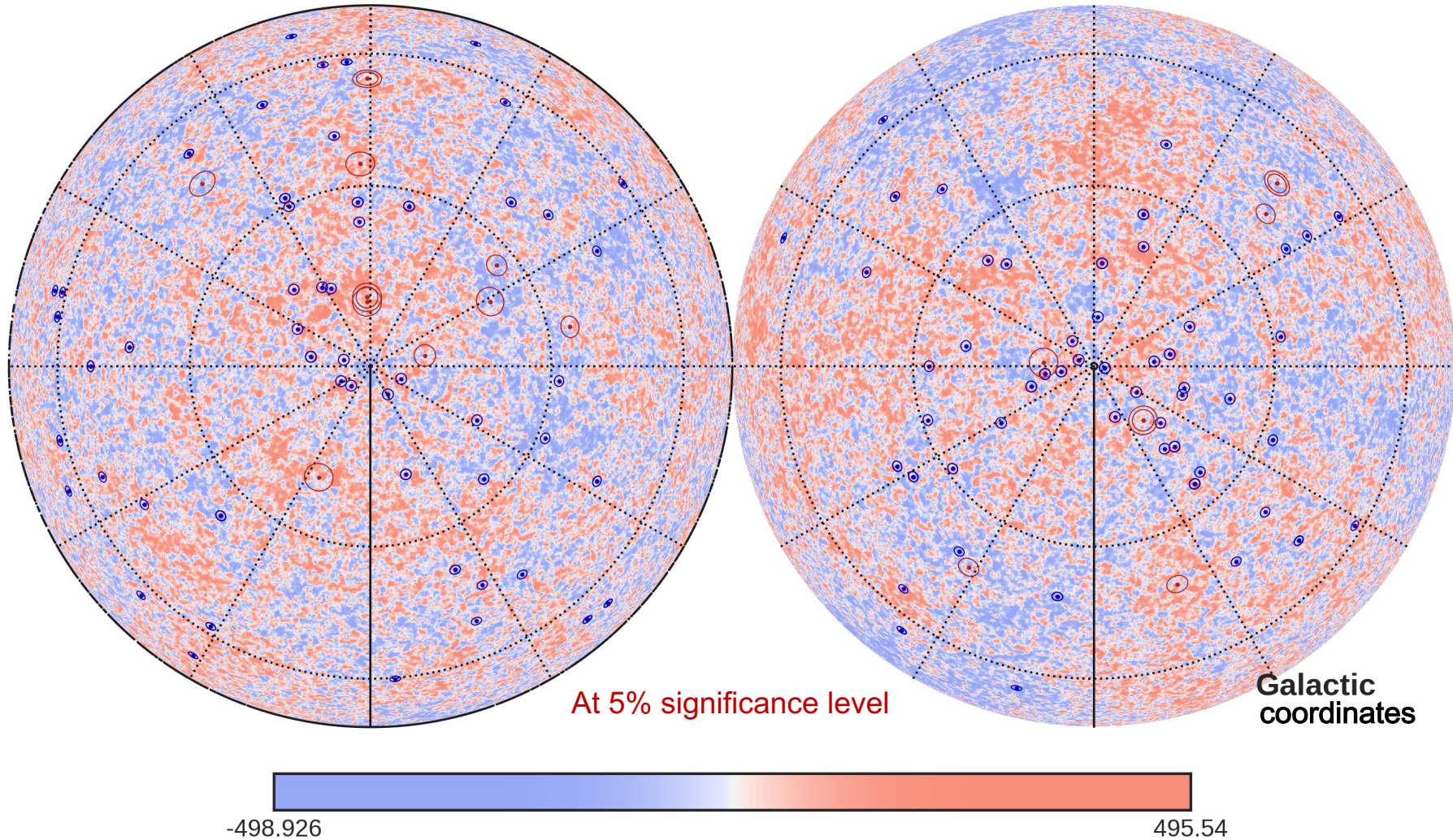
For a certain α



Annulus in red: interesting locations from An, D. et al. 2020 Monthly Notices of the Royal Astronomical Society.

Annulus in blue: our special locations

Interesting locations for Pearson coefficients r for Commander-Ruler



Conclusions:

- Mismatch between real data and simulated data
- HPs seem to be very rare.
- Good performance with artificial data set (see [arXiv:2105.03990](https://arxiv.org/abs/2105.03990))

Future work:

- Understand the mismatch between real and simulated data
- Understand the imprint mechanism in the CMB and the CGB
- Apply methodology to CGB



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