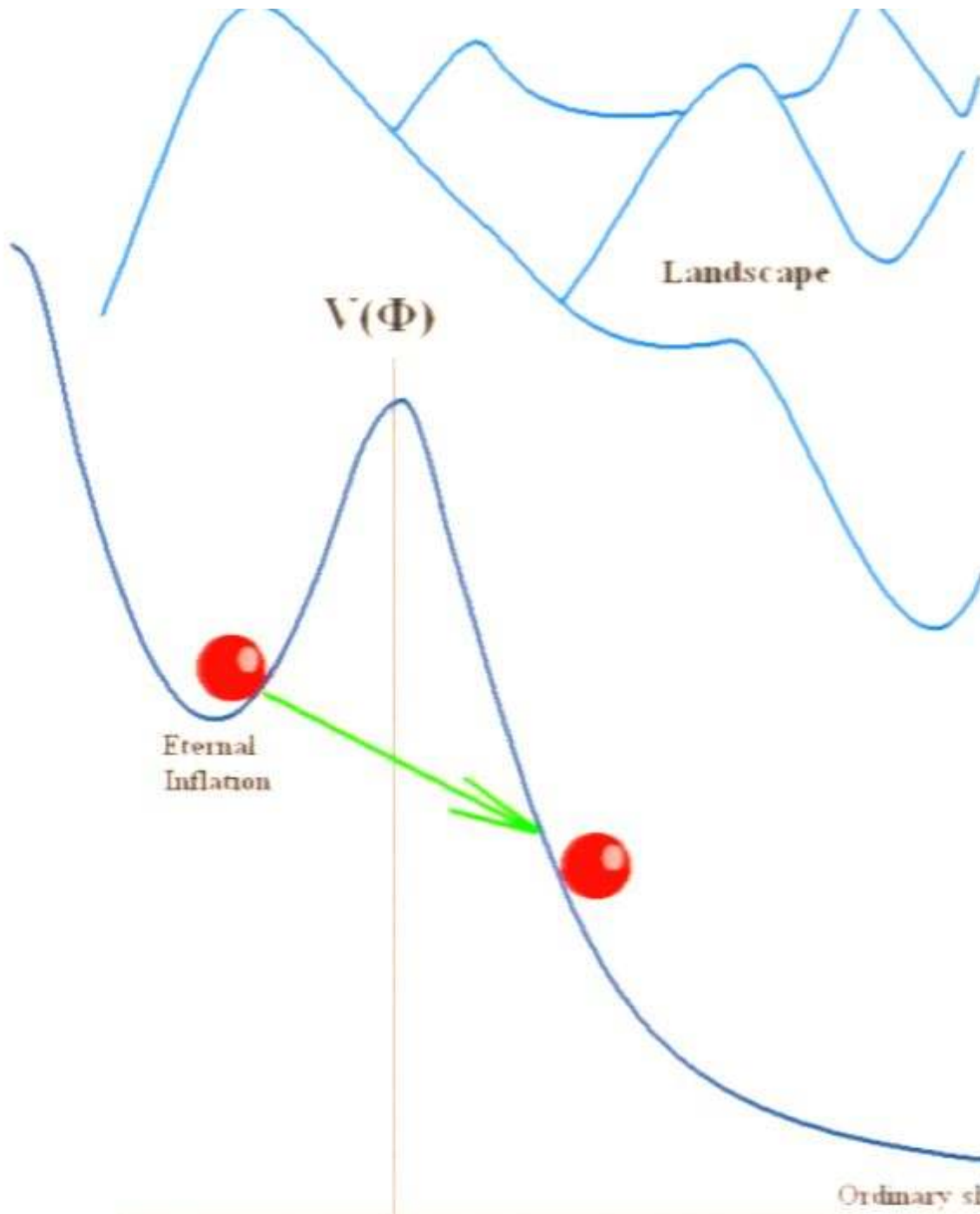


Title: Negative Curvature

Date: Jun 03, 2008 10:10 AM

URL: <http://pirsa.org/07060077>

Abstract: I will discuss the possibilities for a post-standard-cosmological-model phenomenology based on the assumption that our universe was born in a tunneling event from an earlier 'Ancestor' vacuum



Tunneling from
Eternal Inflation to
Ordinary Slow Roll
Inflation.

A Theoretical Prejudice

"Ordinary" inflation* stretched the universe far beyond the point where all fossils of an earlier epoch were completely obliterated.

The expansion factor could have been as large as

$$10^{1,000}$$

$$10^{1,000,000}$$

$$10^{10^{1,000,000}}$$

This prejudice is unjustified and is quite possible wrong.

In part it comes from mixing up the two kinds of inflation.*

* "Ordinary" inflation and "Slow Roll" inflation are synonymous in this talk. They are distinct from the earlier epoch of "Eternal" inflation.

- Just how much ordinary inflation did take place? Did it obliterate all evidence of an earlier epoch?
- Can we look back to when the universe may have nucleated from another point on the Landscape? If so, what will we see?
- Can we see into other bubbles?

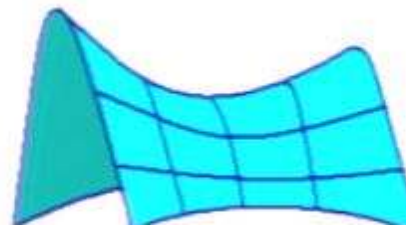
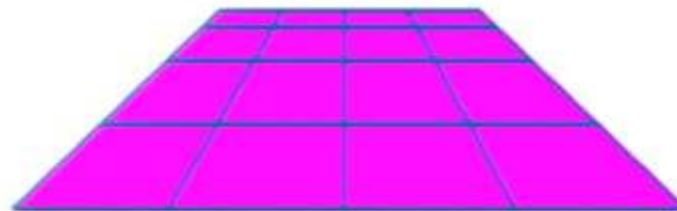
Quick Cosmology Lesson

FRW Cosmology

$$ds^2 = - dt^2 + a^2(t) \{ dR^2 + \sin^2 R (d\theta^2 + \sin^2 \theta d\phi^2) \}$$

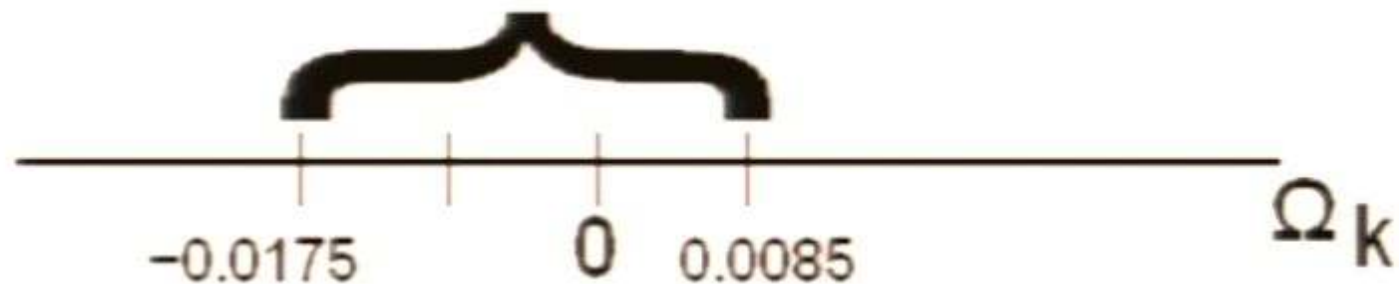
$$ds^2 = - dt^2 + a^2(t) \{ dR^2 + R^2 (d\theta^2 + \sin^2 \theta d\phi^2) \}$$

$$ds^2 = - dt^2 + a^2(t) \{ dR^2 + \sinh^2 R (d\theta^2 + \sin^2 \theta d\phi^2) \}$$



Data inconclusive

- Inflation flattens. Best fit: Curvature slightly negative but zero within 1-sigma error bars.



- Anomalous behavior of lowest l primordial fluctuations? Maybe.

What does theory say?

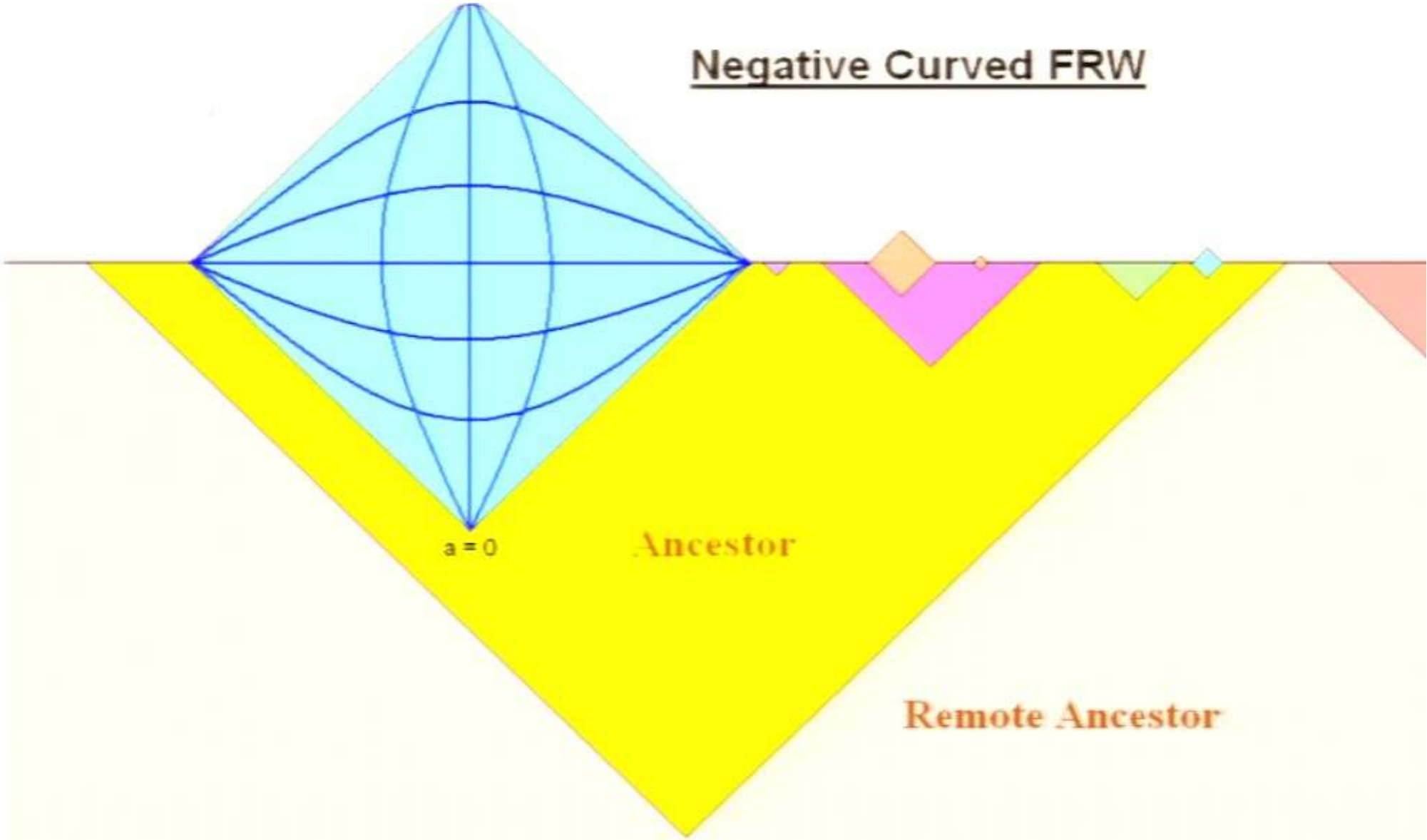
Tunneling on the Landscape

We are here.

Ancestor

Remote Ancestor

Negative Curved FRW

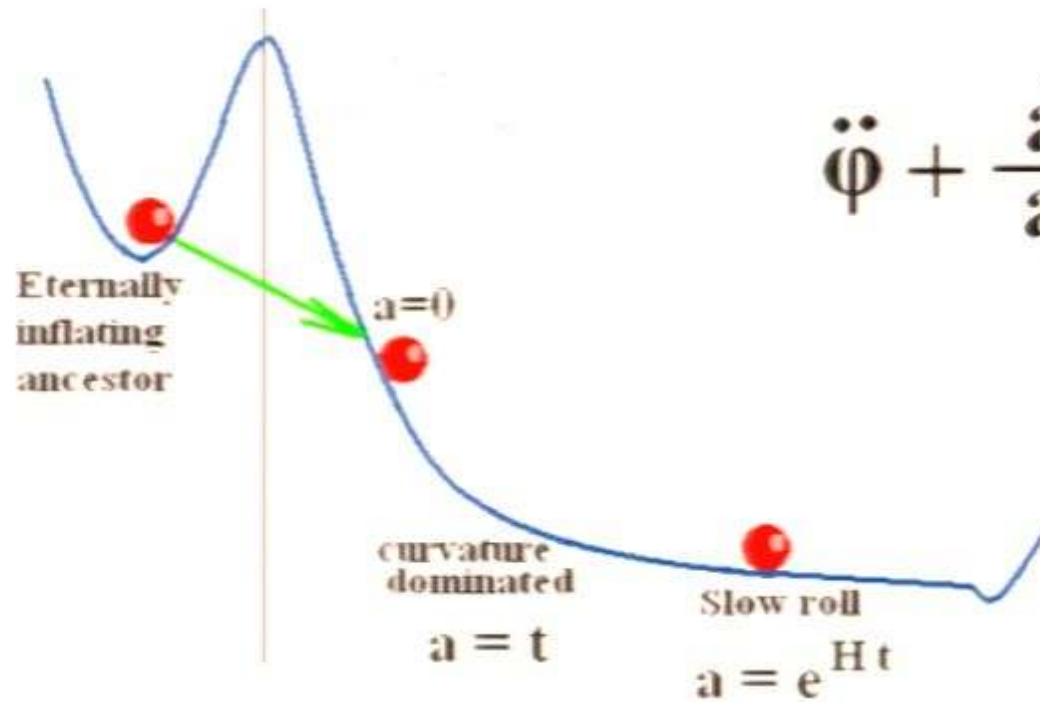


$a = 0$

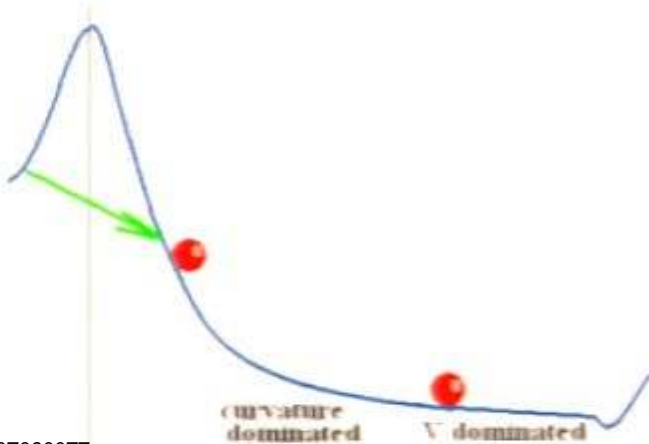
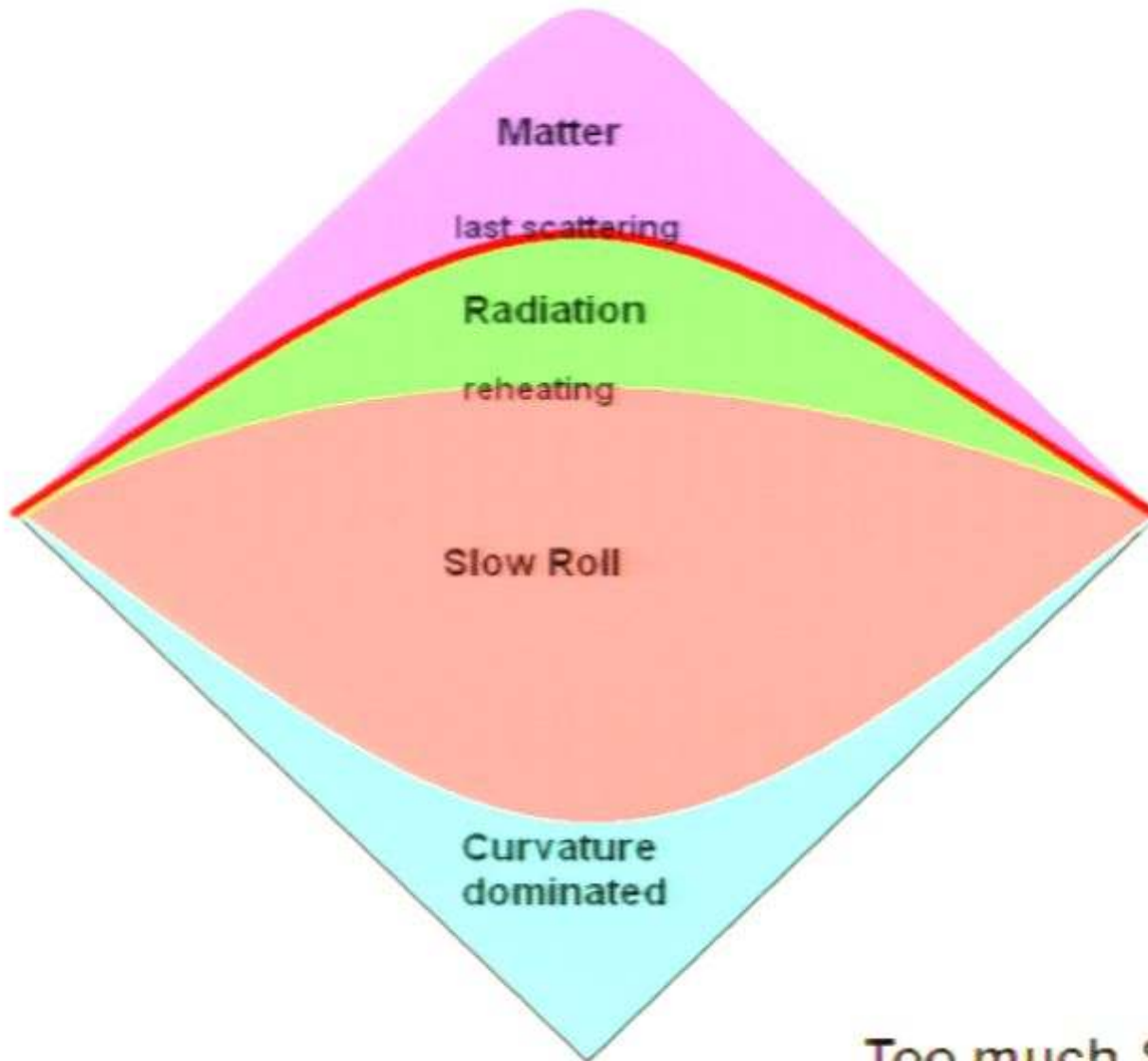
Ancestor

Remote Ancestor

$$\left(\frac{\dot{a}}{a}\right)^2 = V(\varphi) + \frac{\dot{\varphi}^2}{2} + \frac{1}{a^2}$$



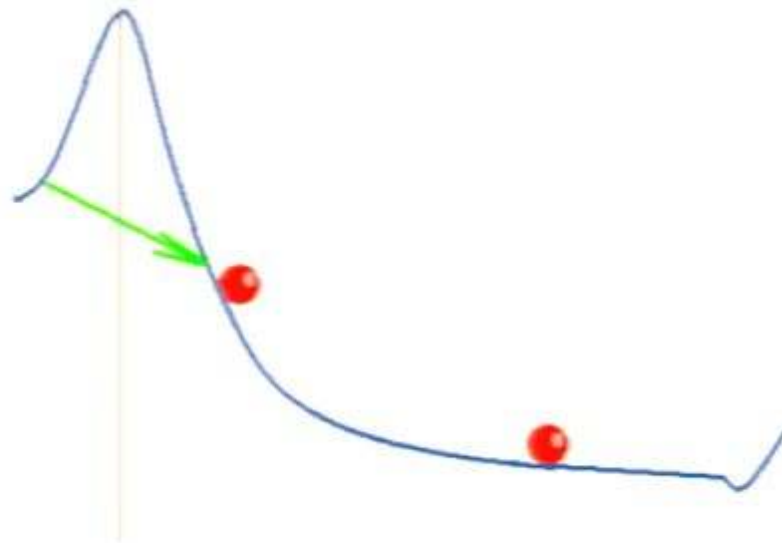
$$\ddot{\varphi} + \frac{\dot{a}}{a} \dot{\varphi} + V' = 0$$



Too much Slow Roll inflation would obliterate everything that came before.

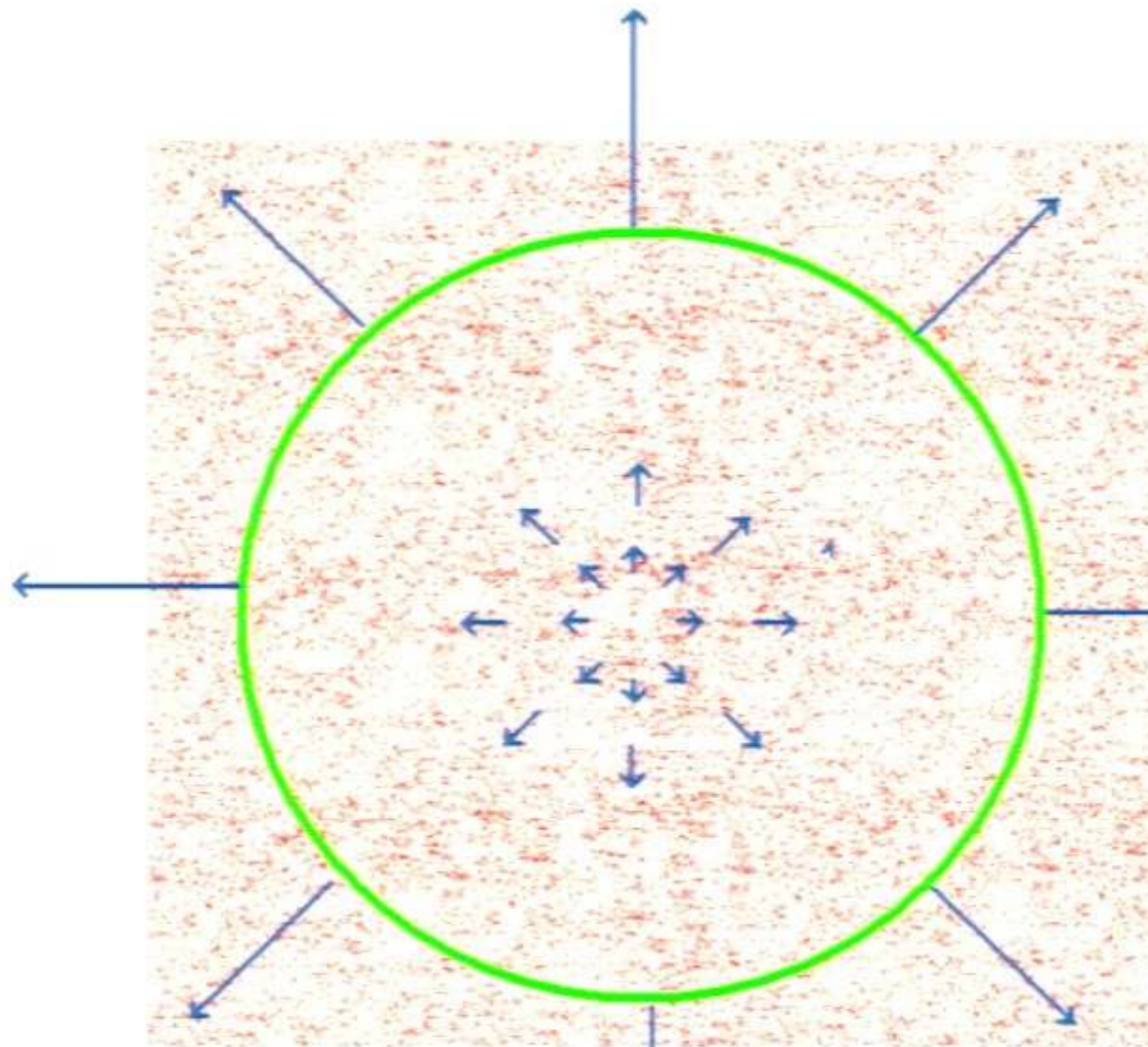
Why did slow roll inflation happen?

- Slow roll inflation is highly fine tuned.



- Best answer so far: Anthropic

Negative curvature means greater than the escape velocity.



Given $\delta\rho/\rho = 10^{-5}$
too much negative
curvature will
prevent structure
formation.

How to dilute
curvature?

A period of
slow roll Inflation

$$\left(\frac{\Omega_\Lambda}{\Omega_{\text{matter}}} \right)^{1.3} + \frac{\Omega_{\text{curvature}}}{\Omega_{\text{matter}}} < \left(\frac{\delta\rho}{\rho} \right)_{\text{dc}}^3 \frac{\rho}{\rho_{\text{today}}}$$

At decoupling

$$\frac{\Omega_{\text{curvature}}}{\Omega_{\text{matter}}} < \left(\frac{\delta\rho}{\rho} \right)_{\text{dc}}^3 \frac{\rho_{\text{dc}}}{\rho_{\text{today}}}$$

Or in terms of e-foldings

$$N_{\text{observation}} > 50$$

$$N_{\text{structure anthropic}} > 47.5$$

B Freivogel,
M Kleban,
M Rodriguez Martinez,
L S

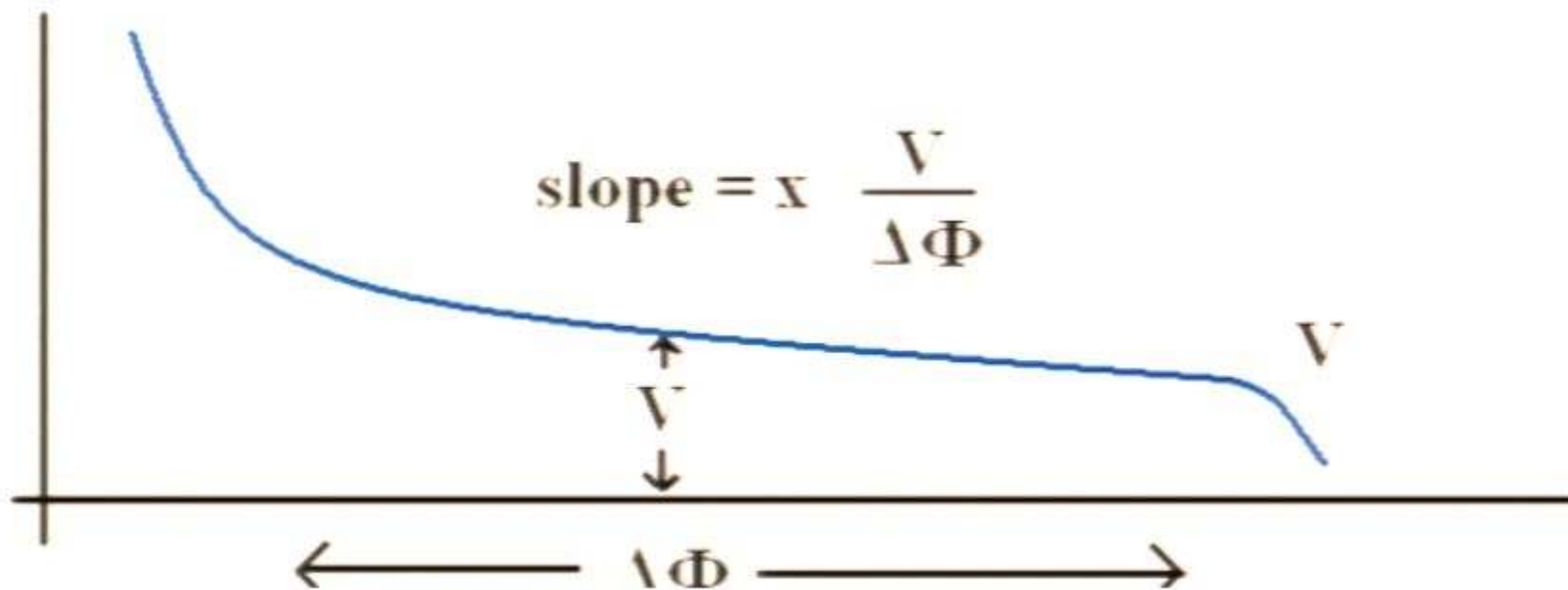
Measure Problem

Measures that

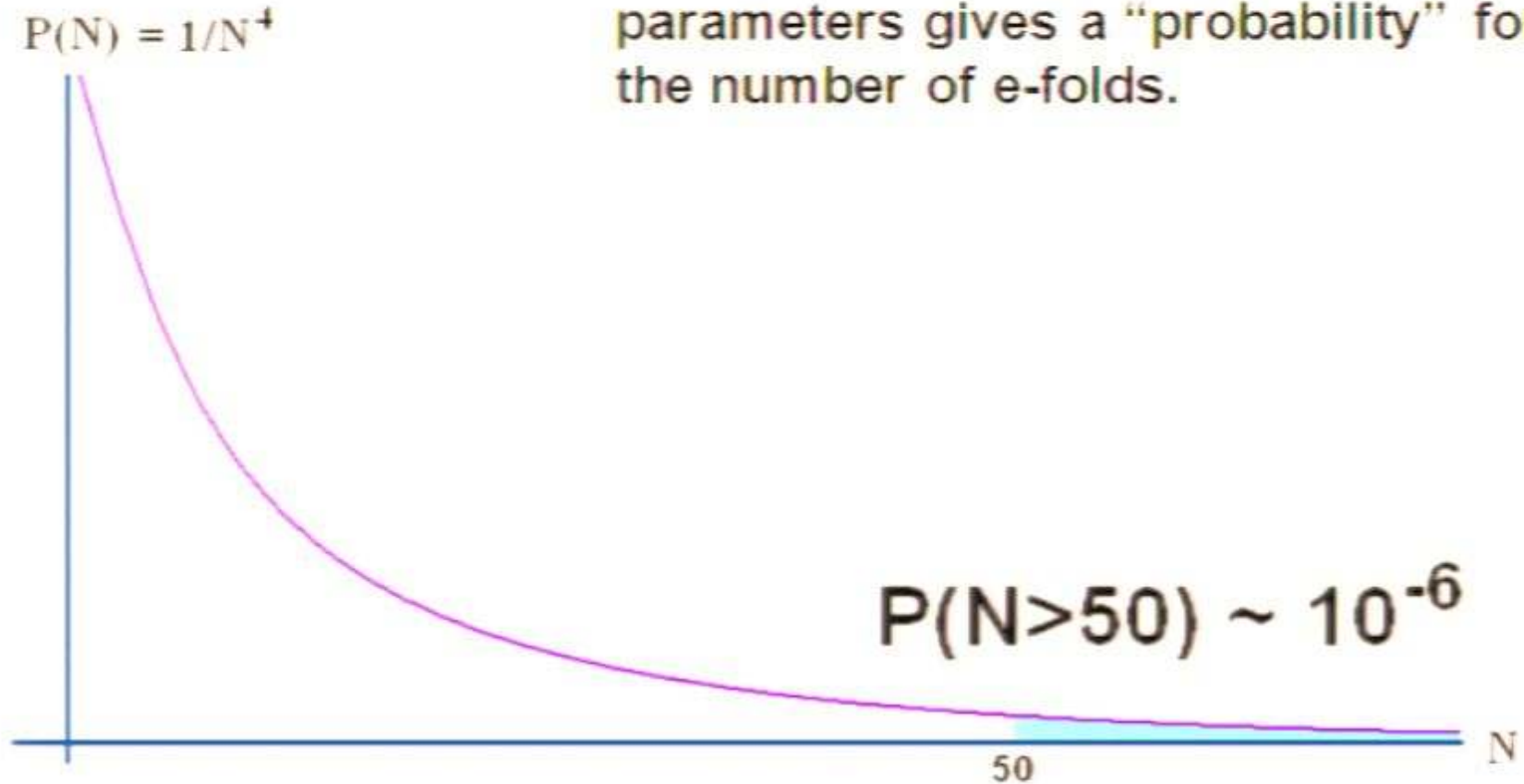
- violently favor large number of e-foldings (typically very bizarre consequences).
- that are more or less neutral with respect to N .
(e.g., **Bousso, Harnik, Kribs, Perez**, hep-th/0702115, and more recently, **Guth and Vilenkin**, arXiv:0805.2173)

A very simplified 3-parameter model of
Landscape statistics
(slope, width, height)

Freivogel,
Kleban,
Martinez,
L.S.

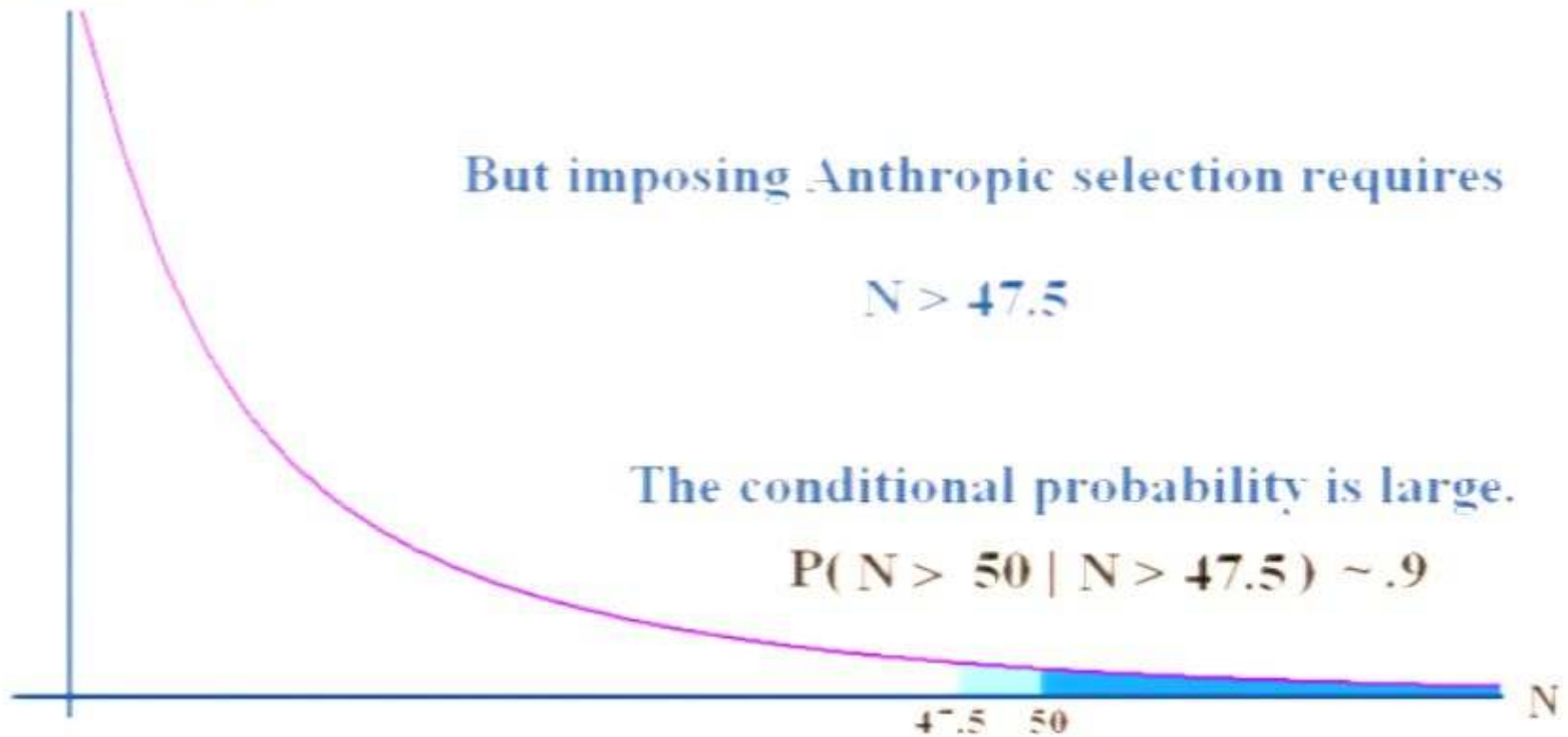


Fixing N and integrating over the 3 parameters gives a “probability” for the number of e-folds.



Inflation is fine tuned to about one part in a million.

$$P(N) = 1/N^4$$



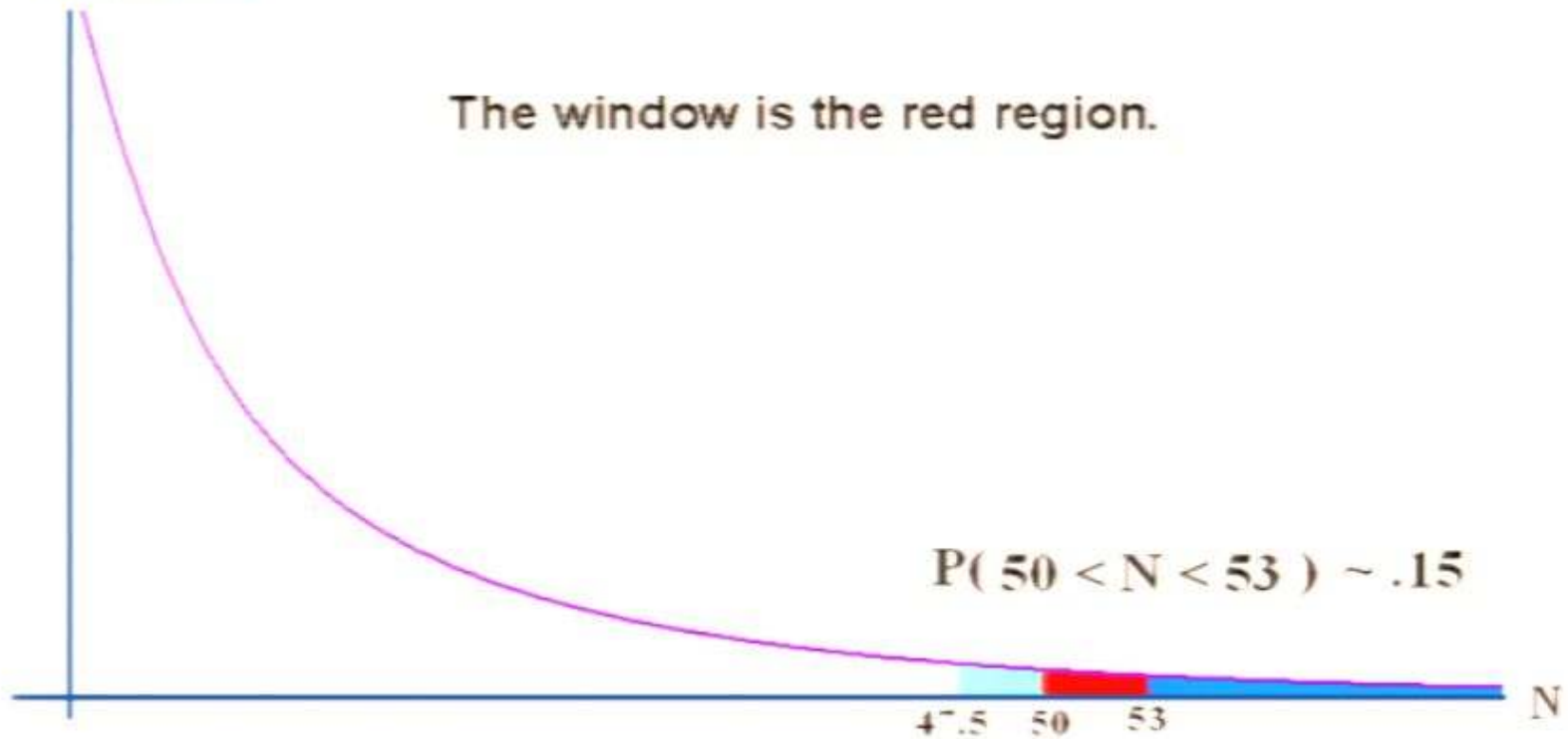
This is the only known explanation for inflation.

Note: $P(N > 100 \mid N > 50) \sim .1$

Now consider the probability that N is in the window in which we can see back to the onset of inflation. This means $N < 53$.

$$P(N) = 1/N^4$$

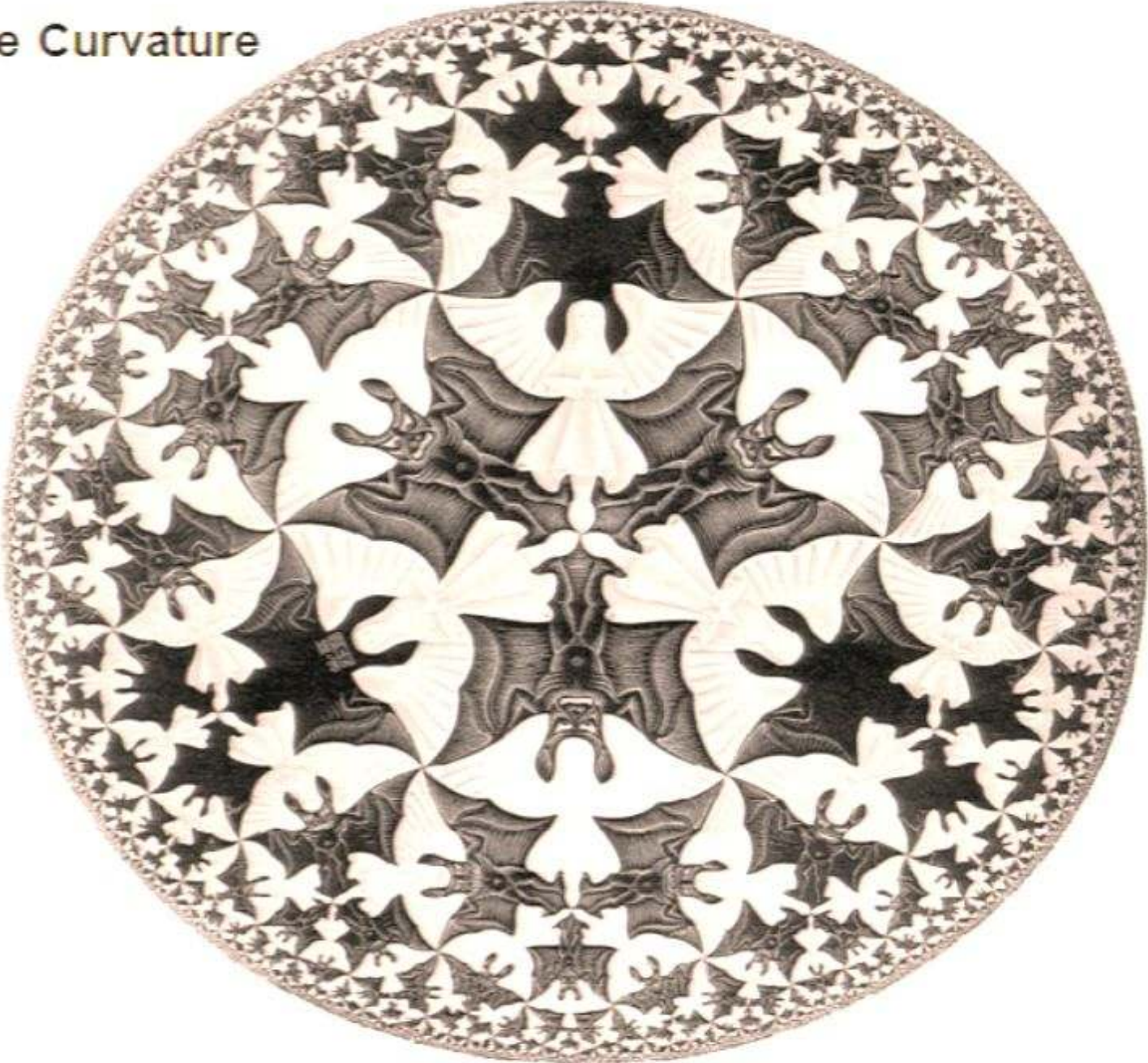
The window is the red region.

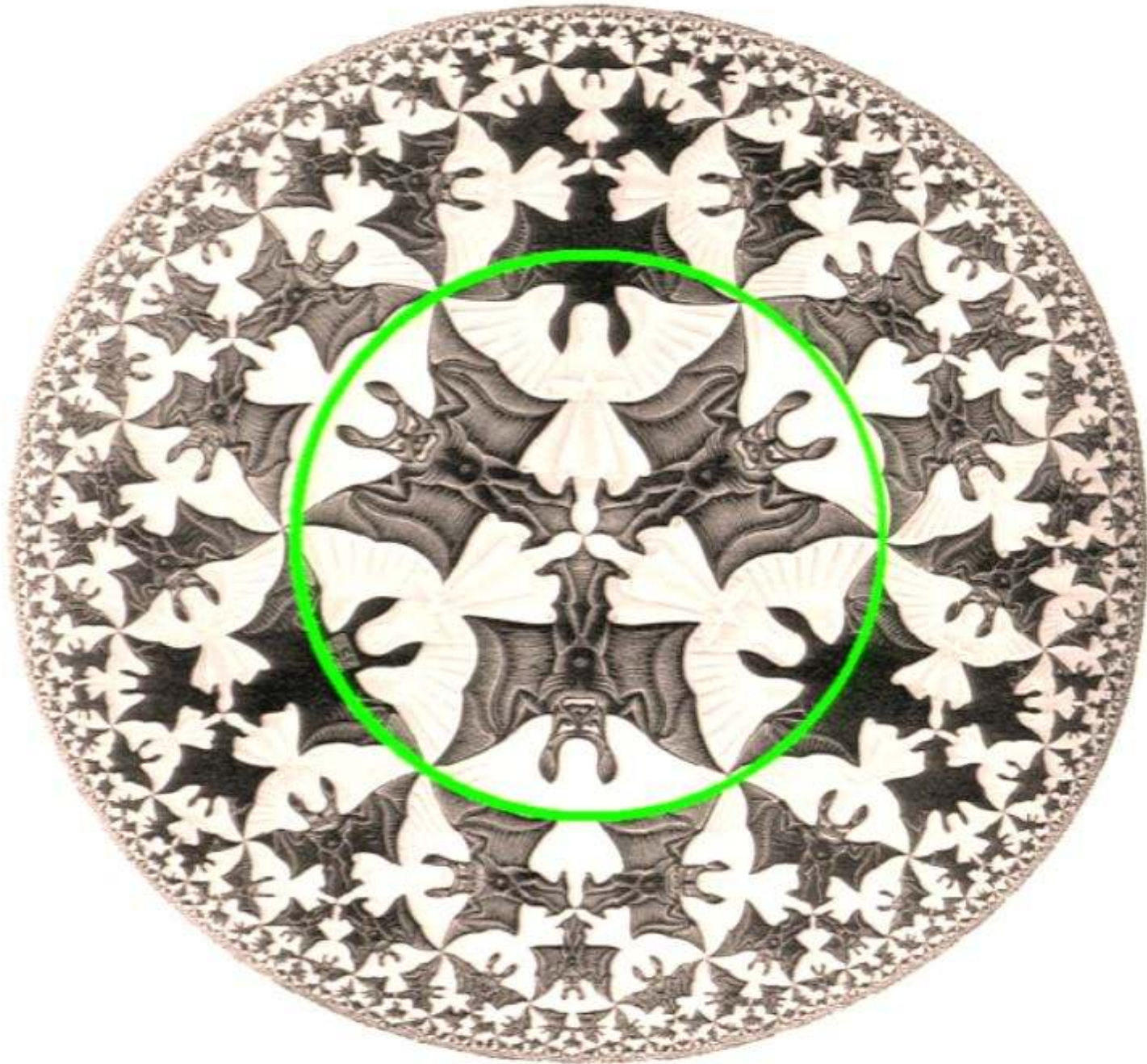


Fossils of a Tunneling Event

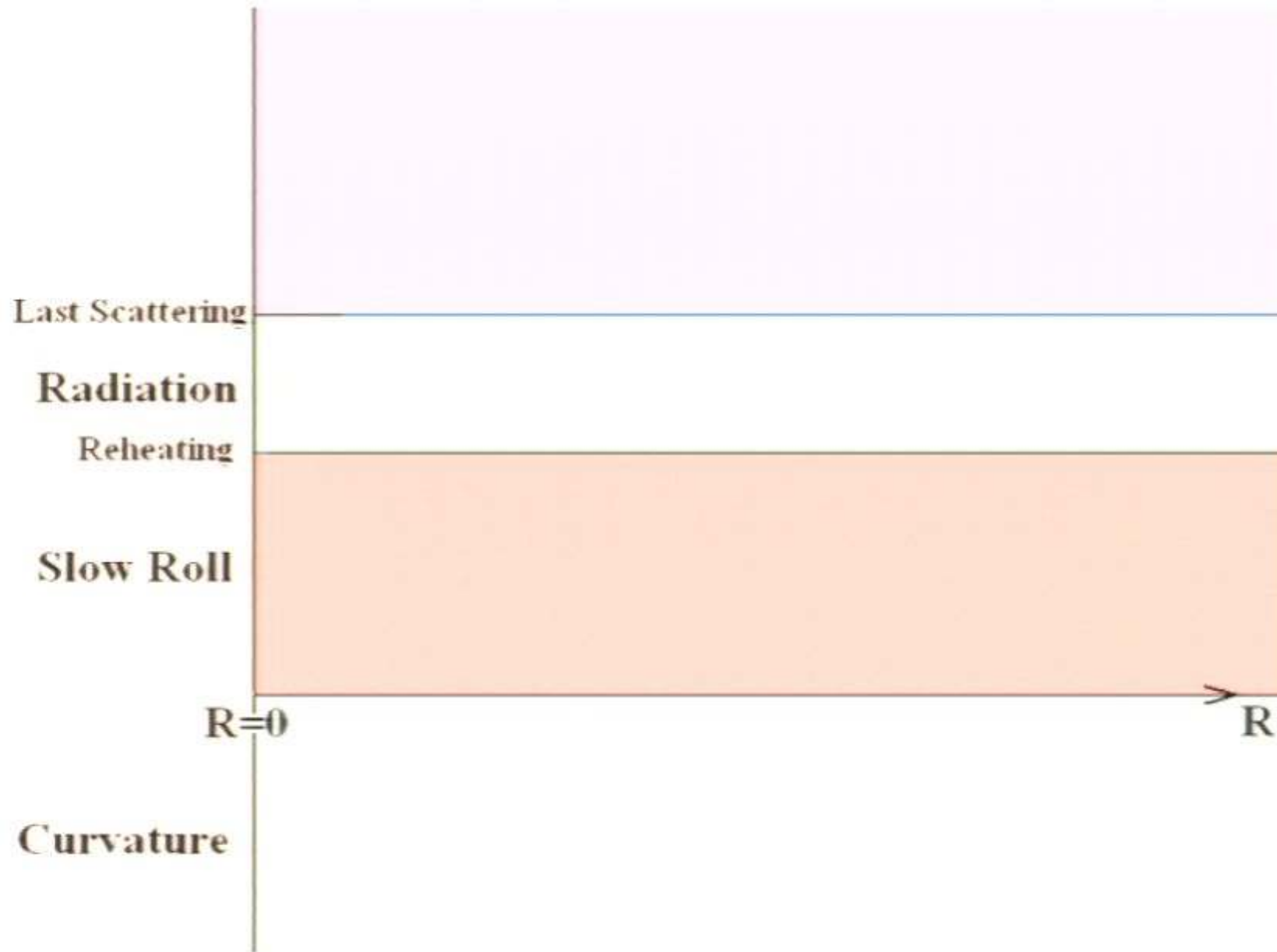
Fossil #1

Negative Curvature

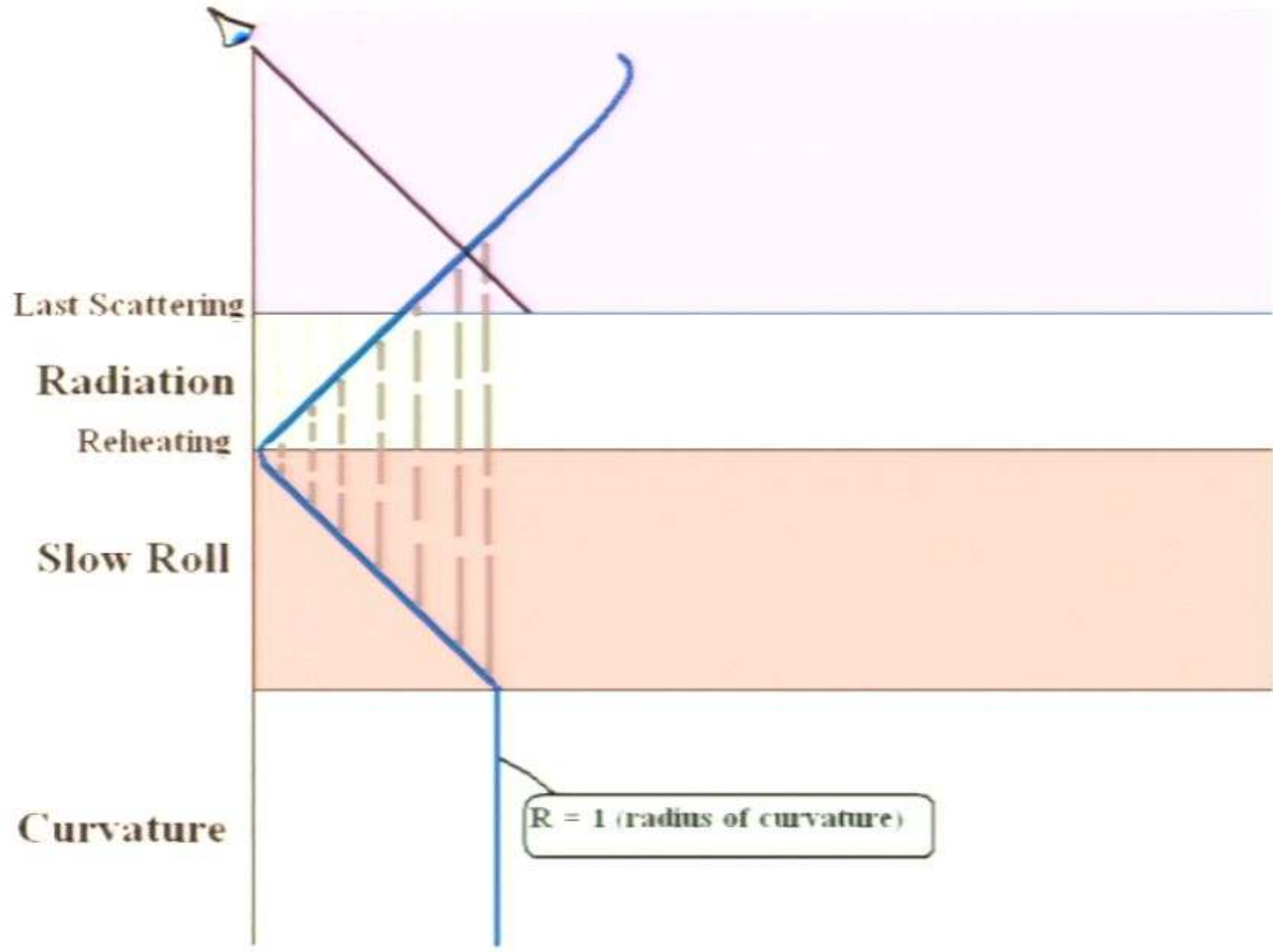




R = 1

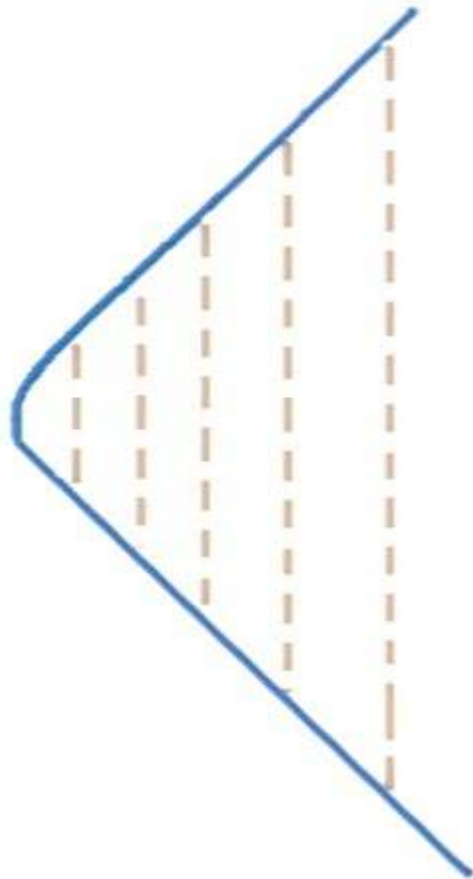


$R =$ Co-moving radial distance



Fossil 2

Very low I tensor modes



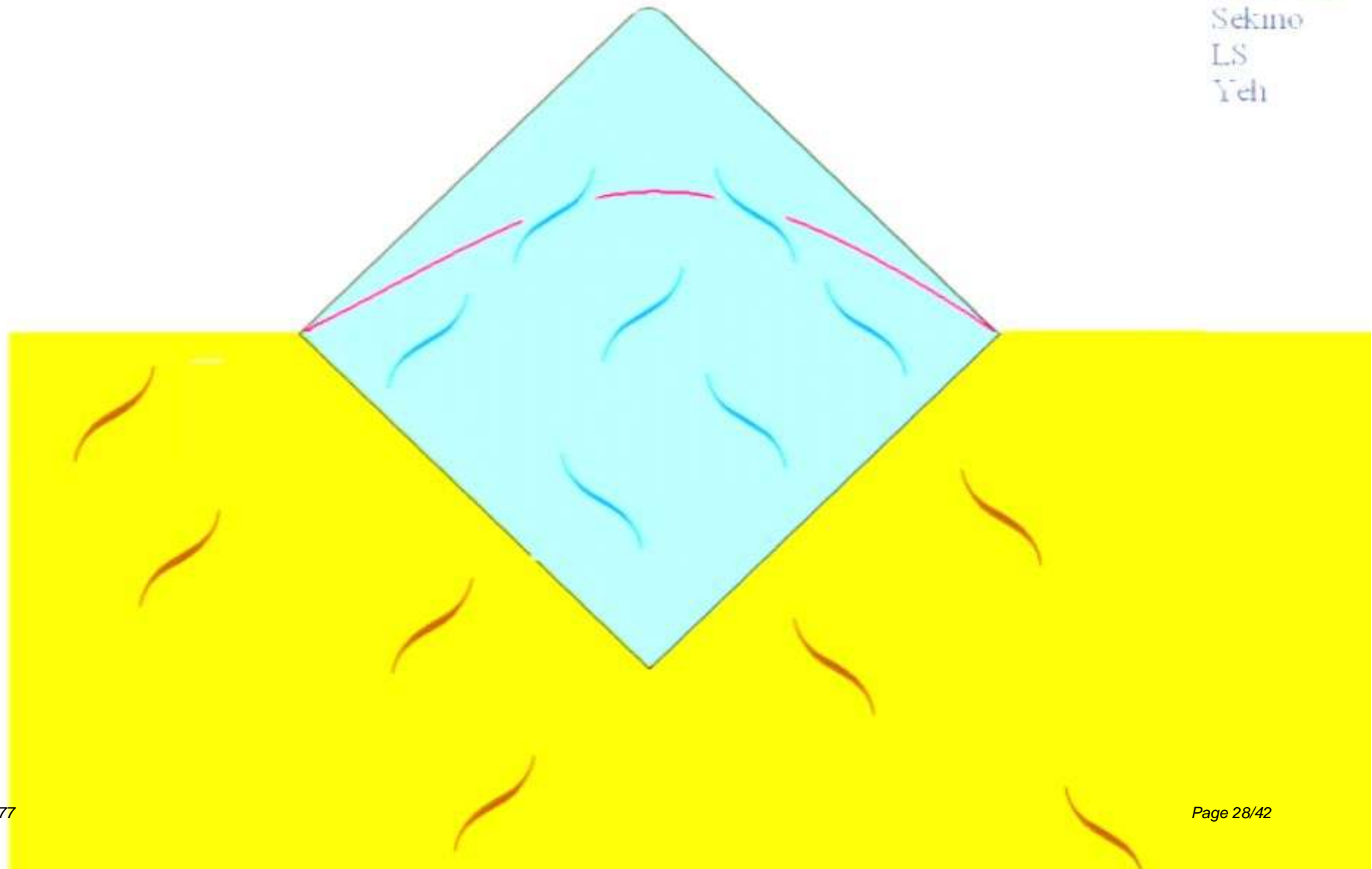
Gravity waves (Tensor modes) are also produced during inflation but their amplitude may be (?) too small to detect.

$$h \sim H_{\text{SR}} < 10^{-7}$$

But there is a mechanism to create strong large-scale tensor modes.

Gravity waves created
in the ancestor are
inherited in the FRW.

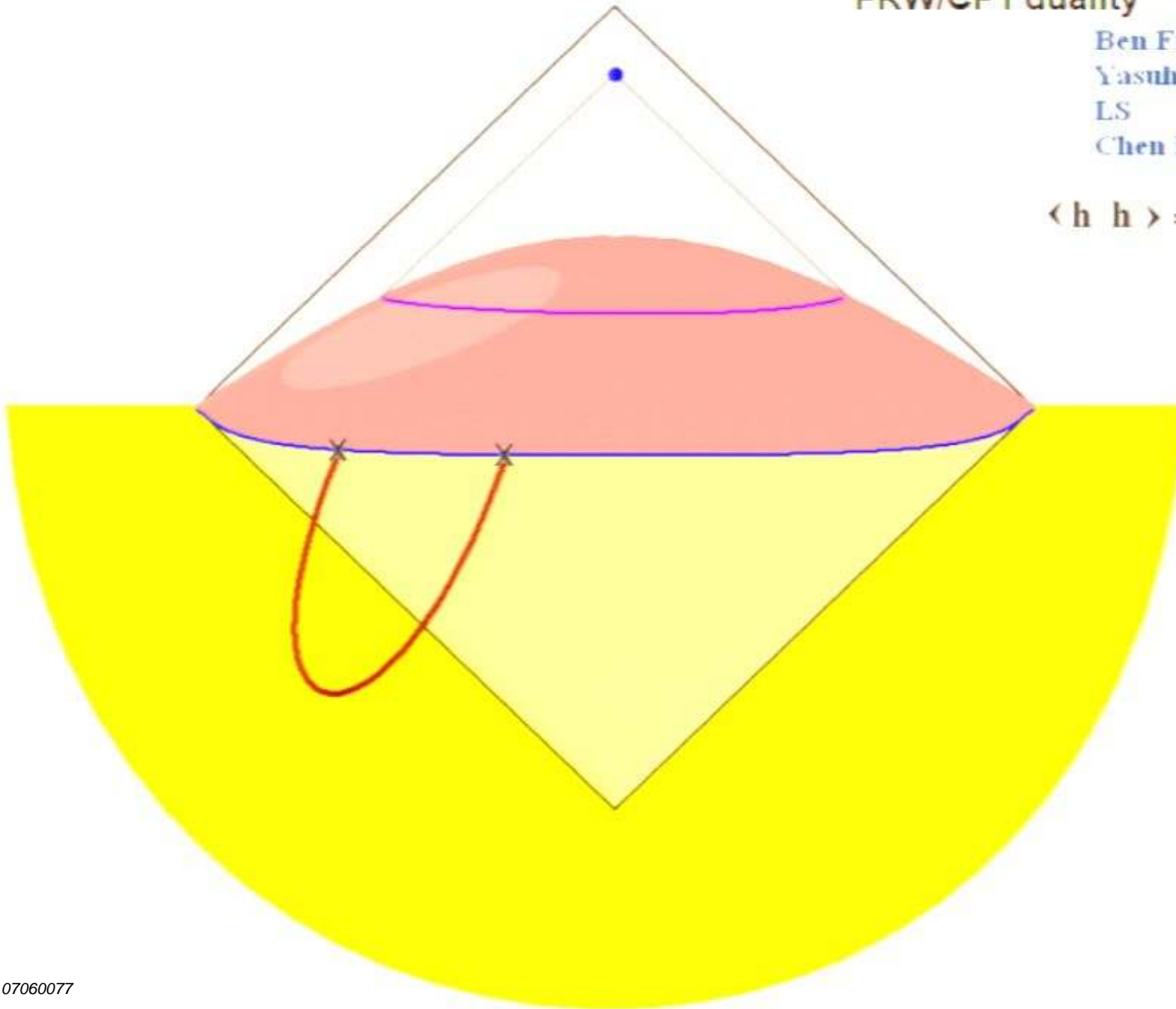
Freivogel
Sekino
LS
Yeh

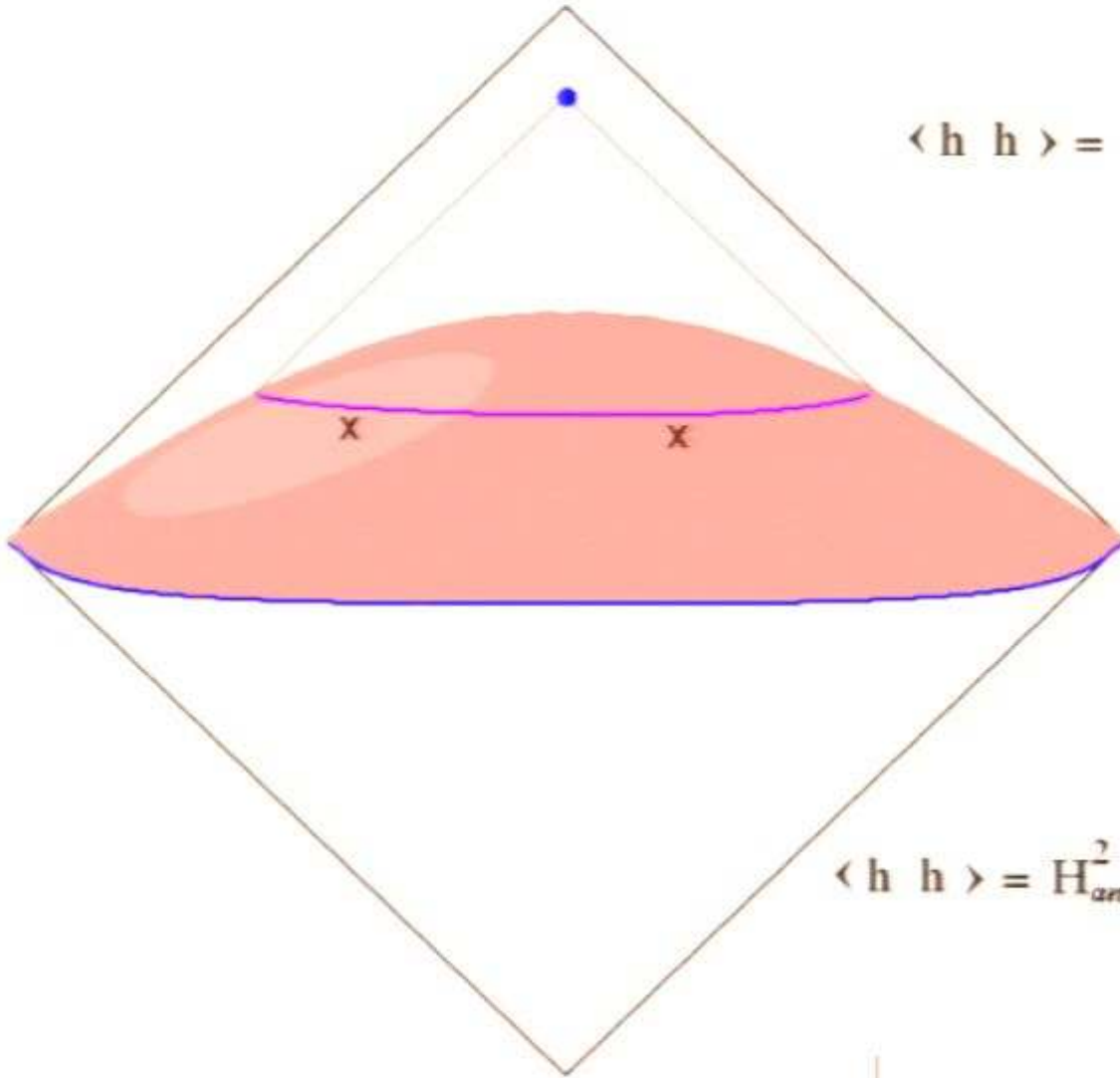


FRW/CFT duality

Ben Freivogel
Yasuhiro Sekino
LS
Chen Pin Yeh

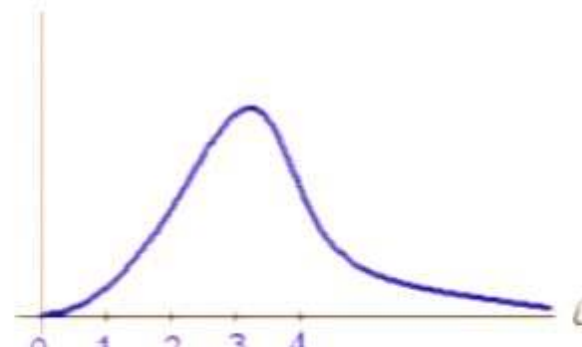
$$\langle h \ h \rangle = \ell^2 H_{\text{ancestors}}^2$$

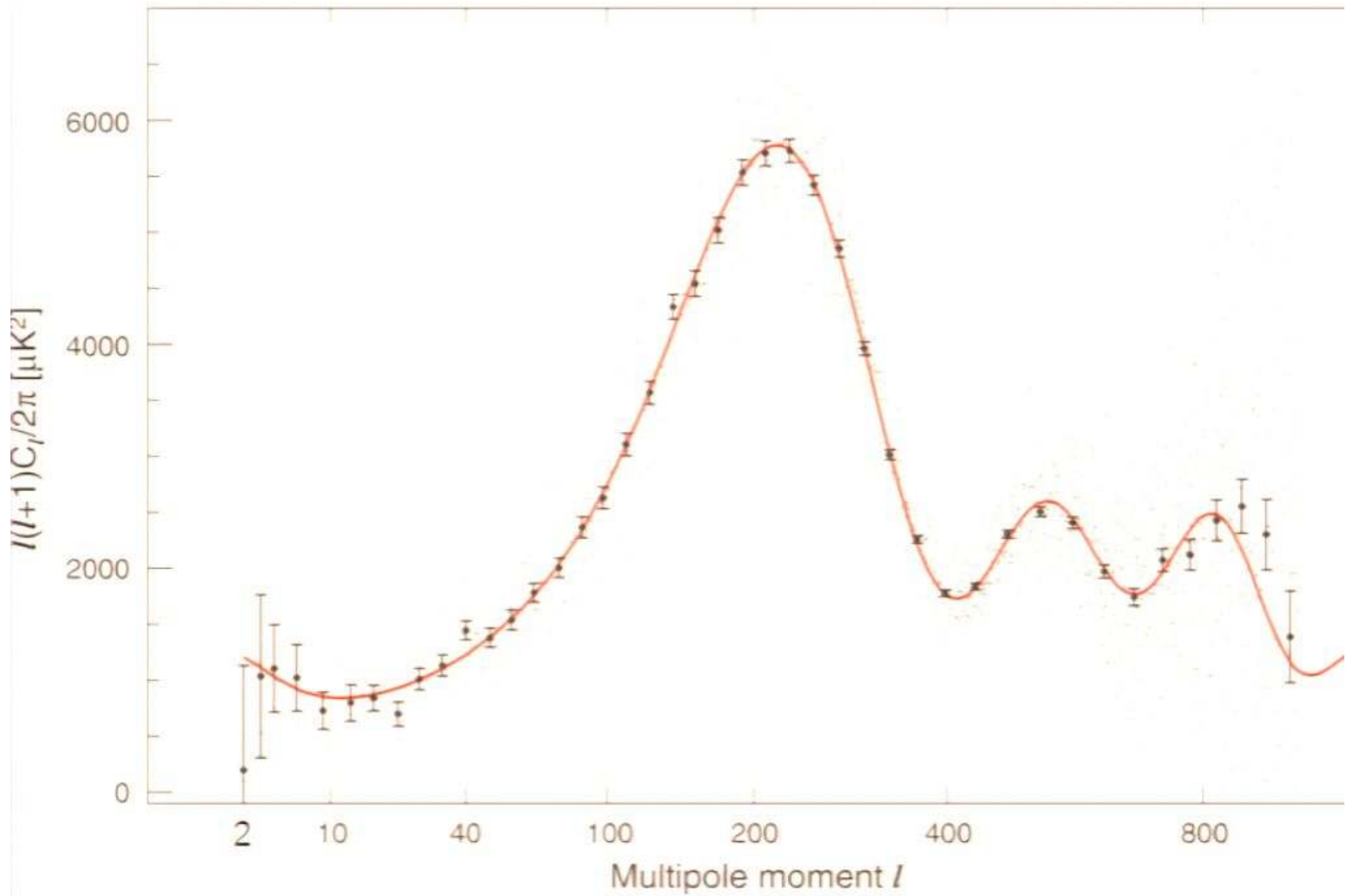


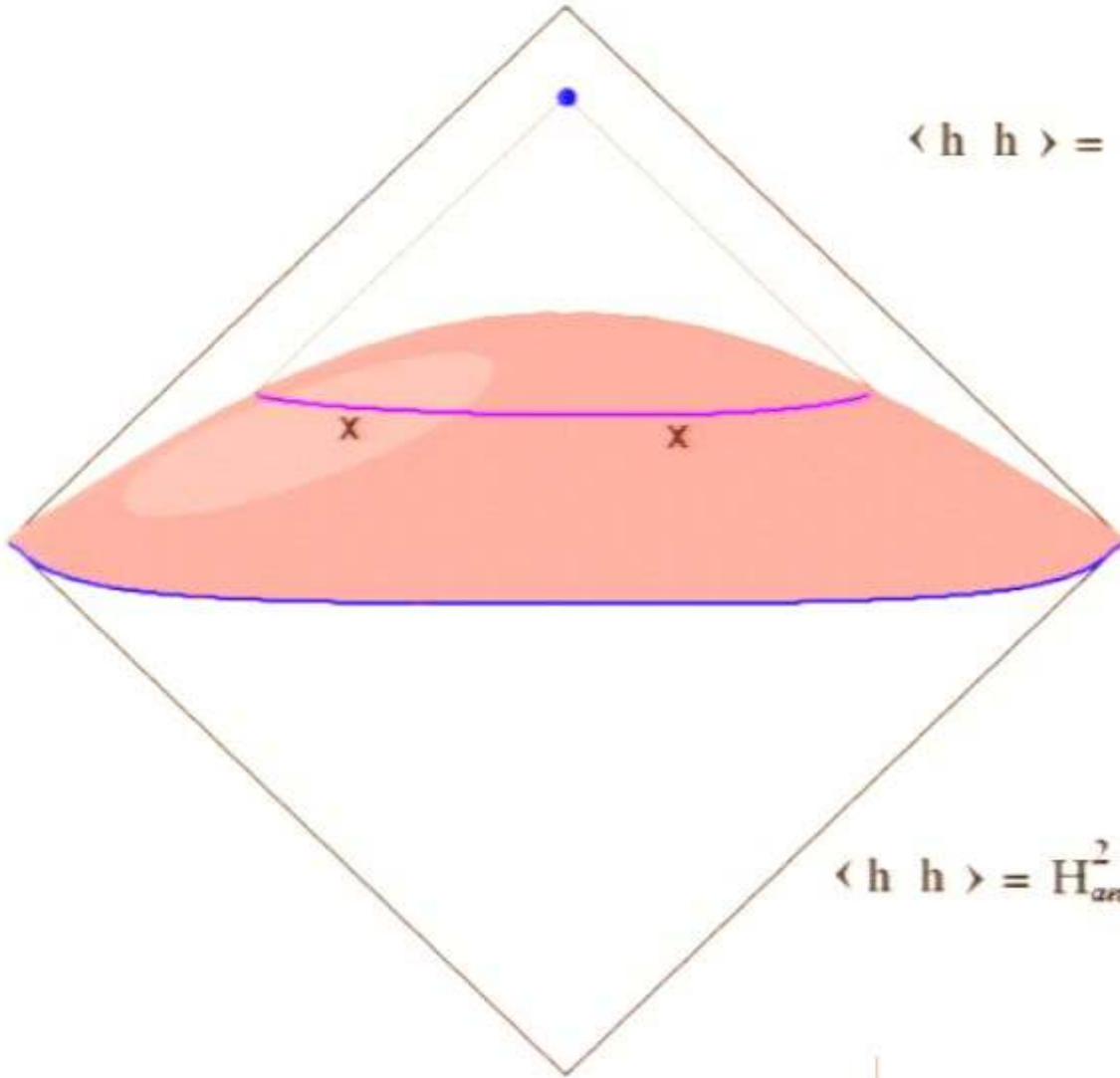


$$\langle h \ h \rangle = H_{\text{ancestor}}^2 \ell^2 \quad (R \geq 1)$$

$$\langle h \ h \rangle = H_{\text{ancestor}}^2 \ell^2 R^\ell \quad (R < 1)$$

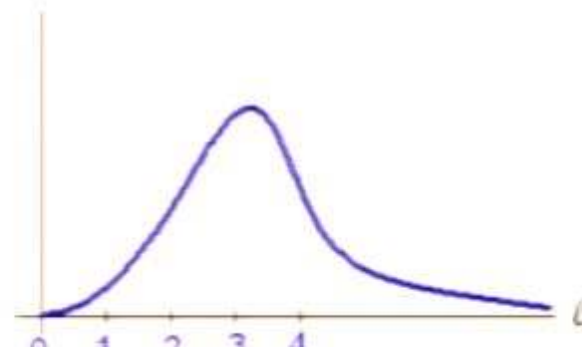


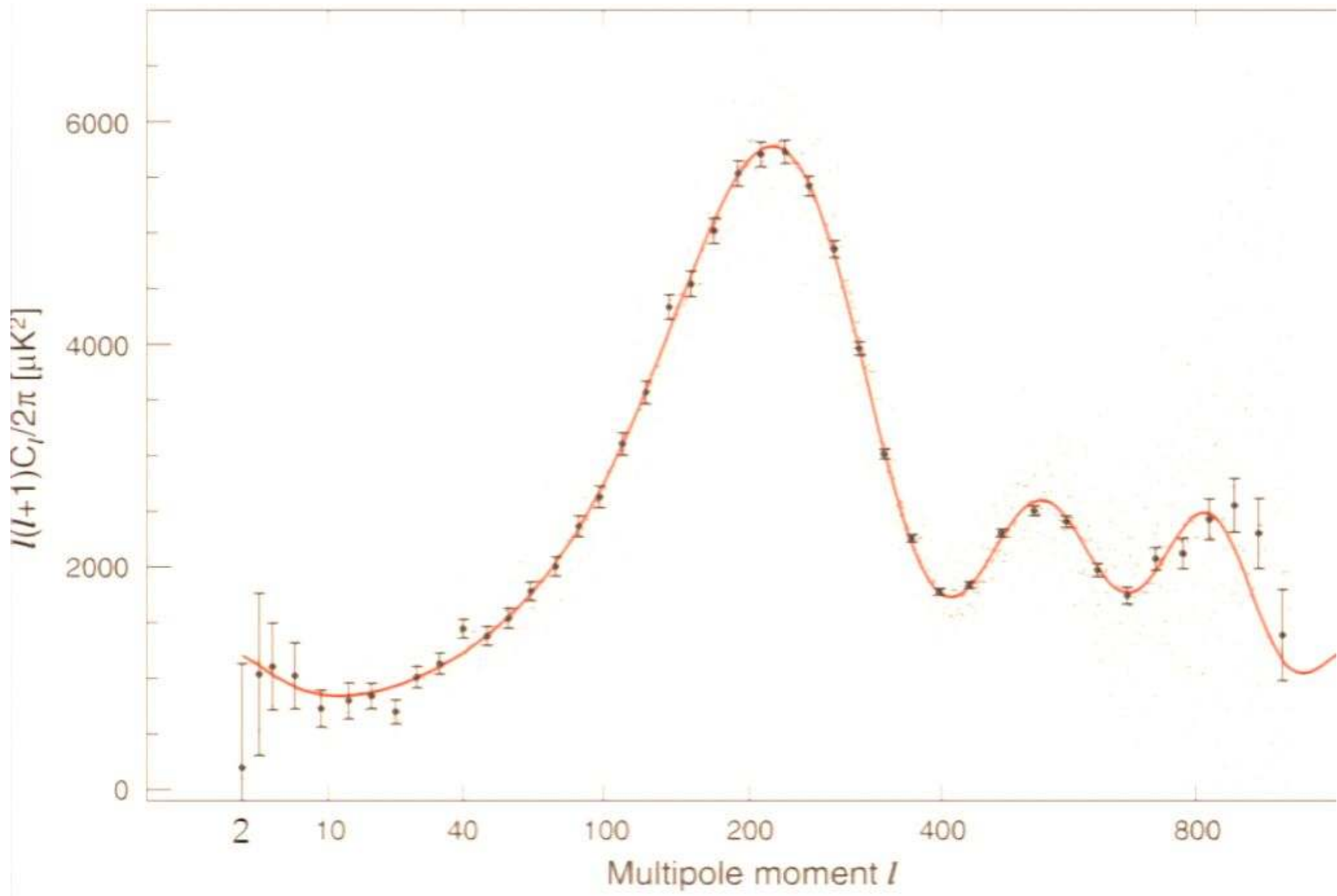




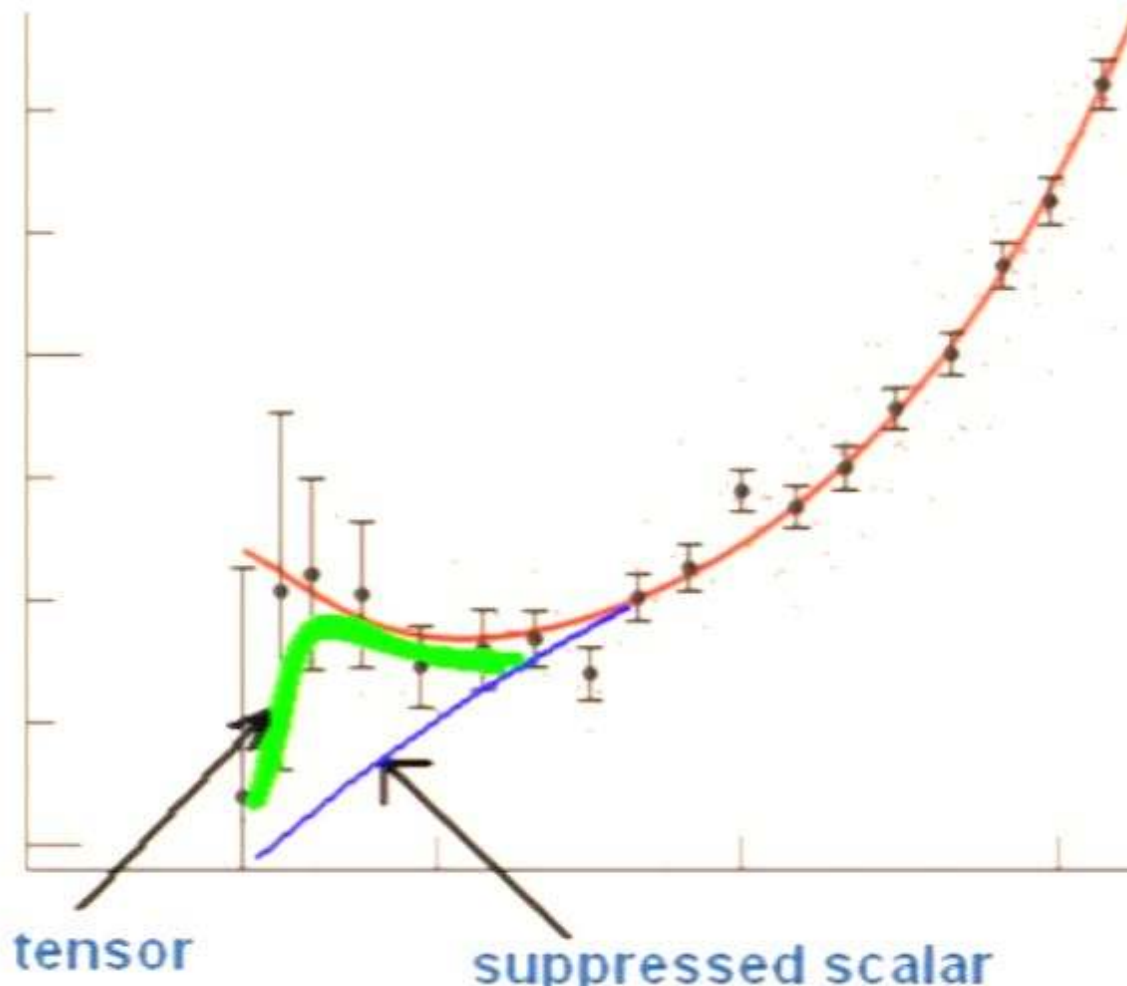
$$\langle h \ h \rangle = H_{\text{ancestor}}^2 \ell^2 \quad (R \geq 1)$$

$$\langle h \ h \rangle = H_{\text{ancestor}}^2 \ell^2 R^\ell \quad (R < 1)$$



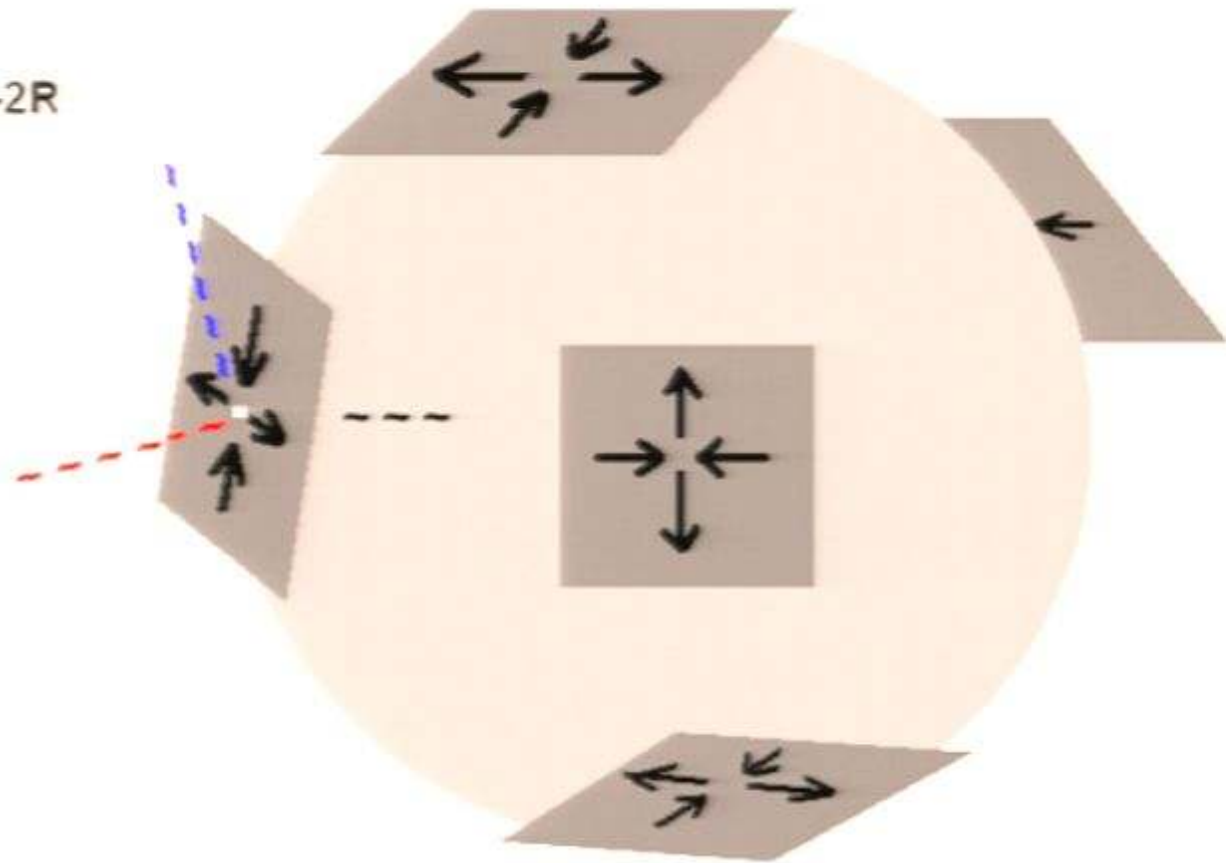


could low l tensor modes add to a suppressed low l scalar spectrum to produce observed data?

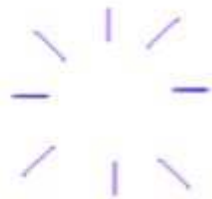


Polarization

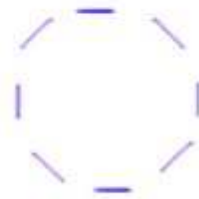
$$h_{ij} \sim H_{\text{ancestor}} e^{-2R}$$



$$\varepsilon_{ab} \hat{c}_a \mathbf{P}_{bc} = \mathbf{0}$$



Gradient modes



**G-waves and
density
fluctuations**

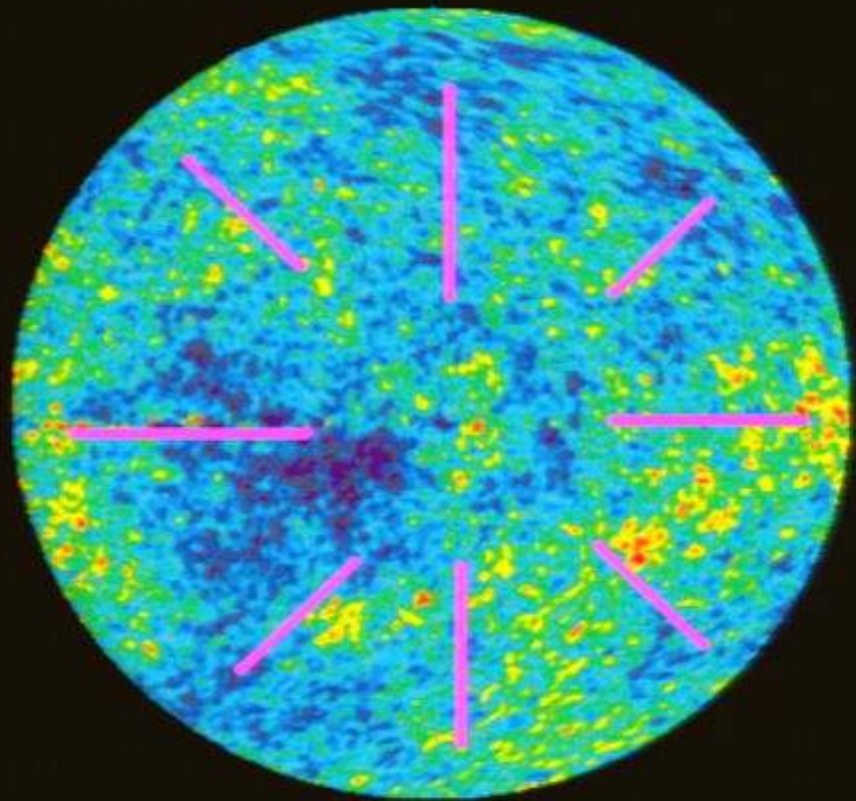
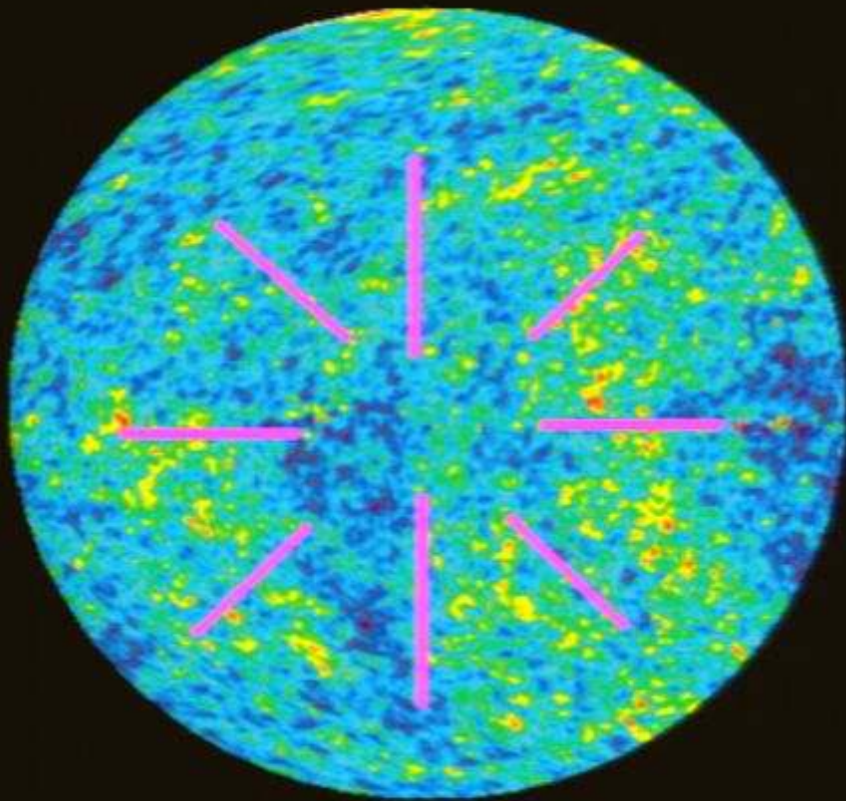
$$\hat{c}_b \mathbf{P}_{bc} = \mathbf{0}$$

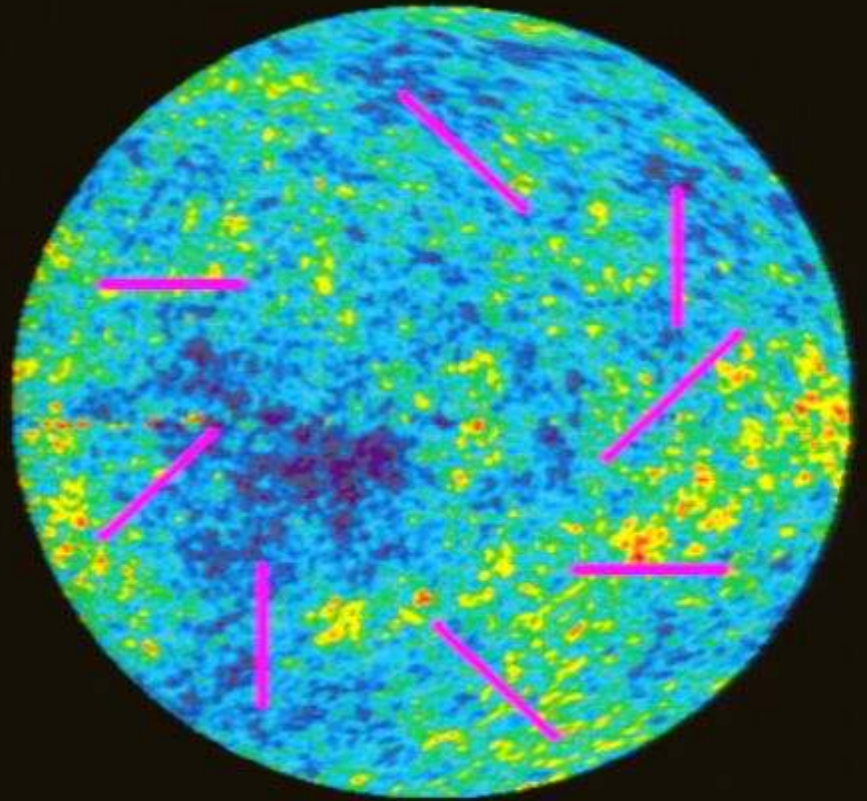
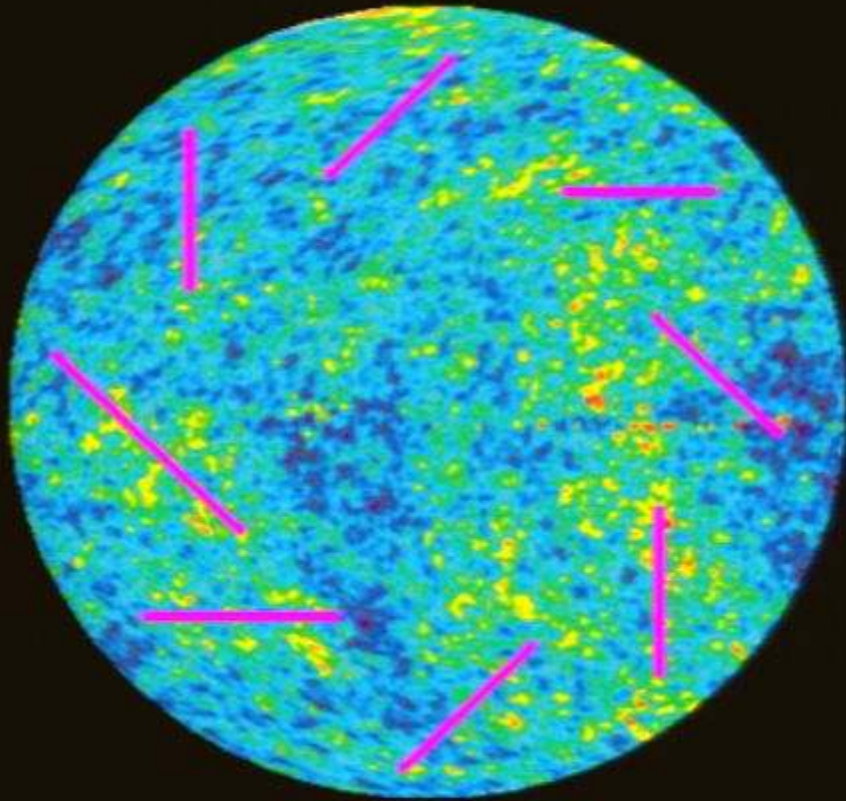


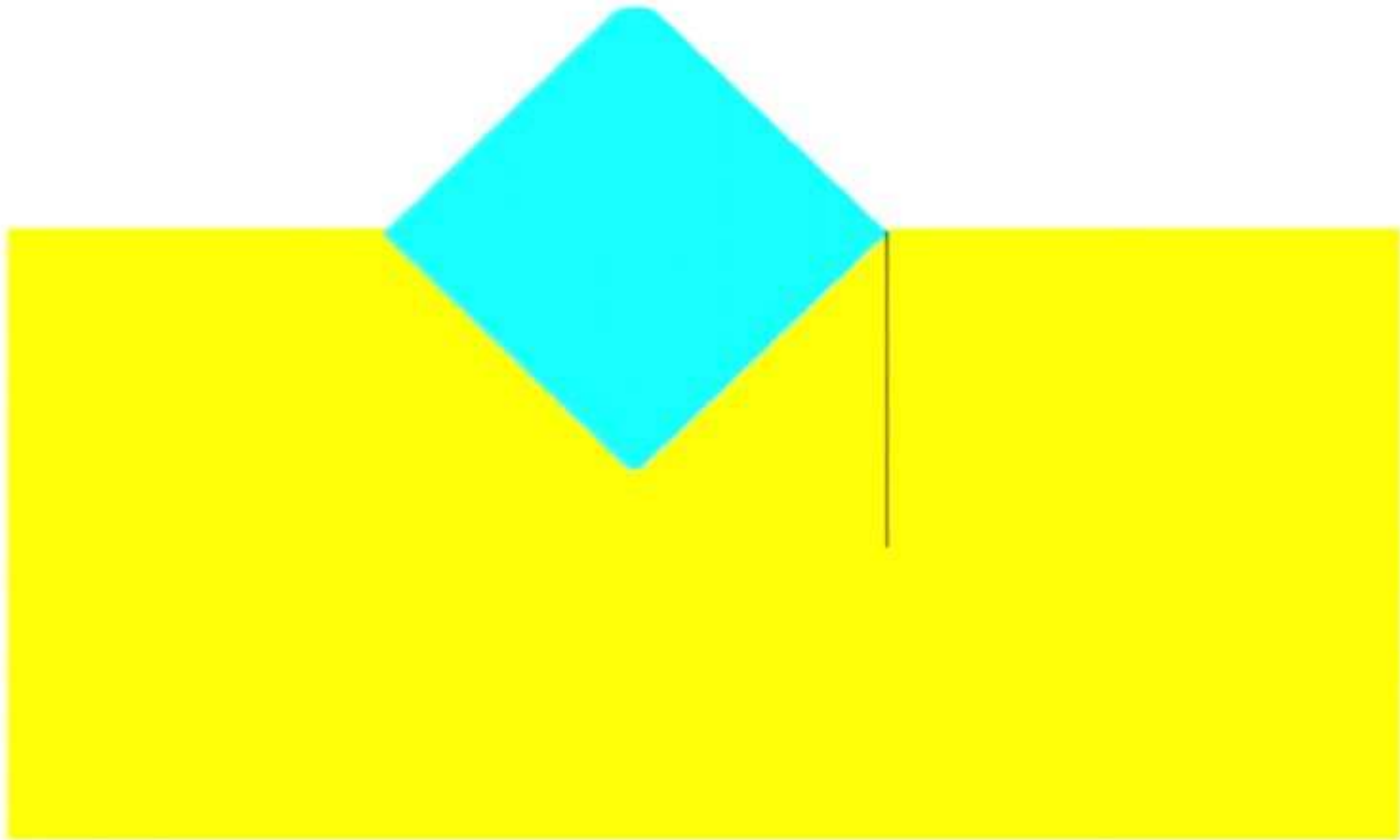
Curl modes

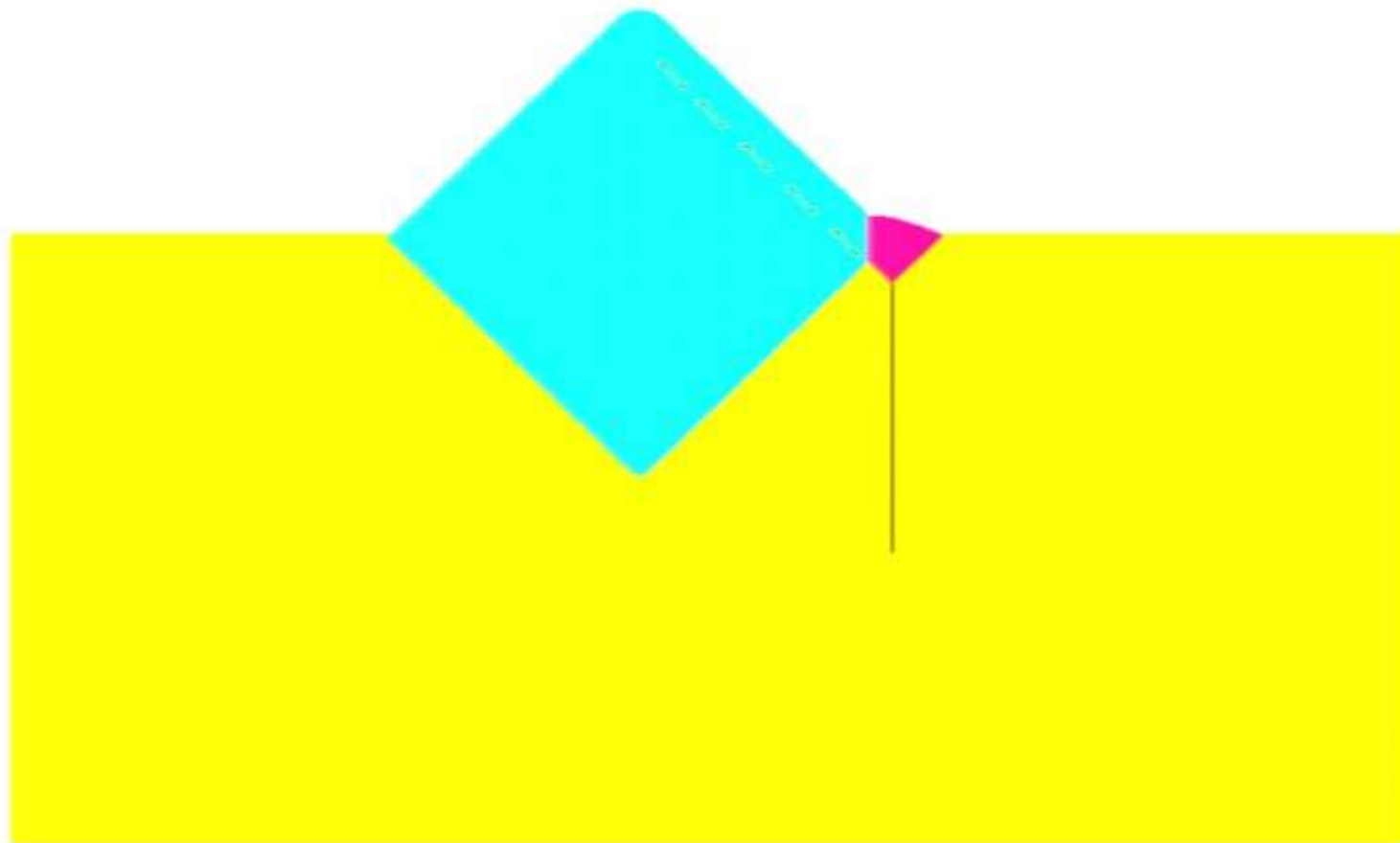


Only G-waves

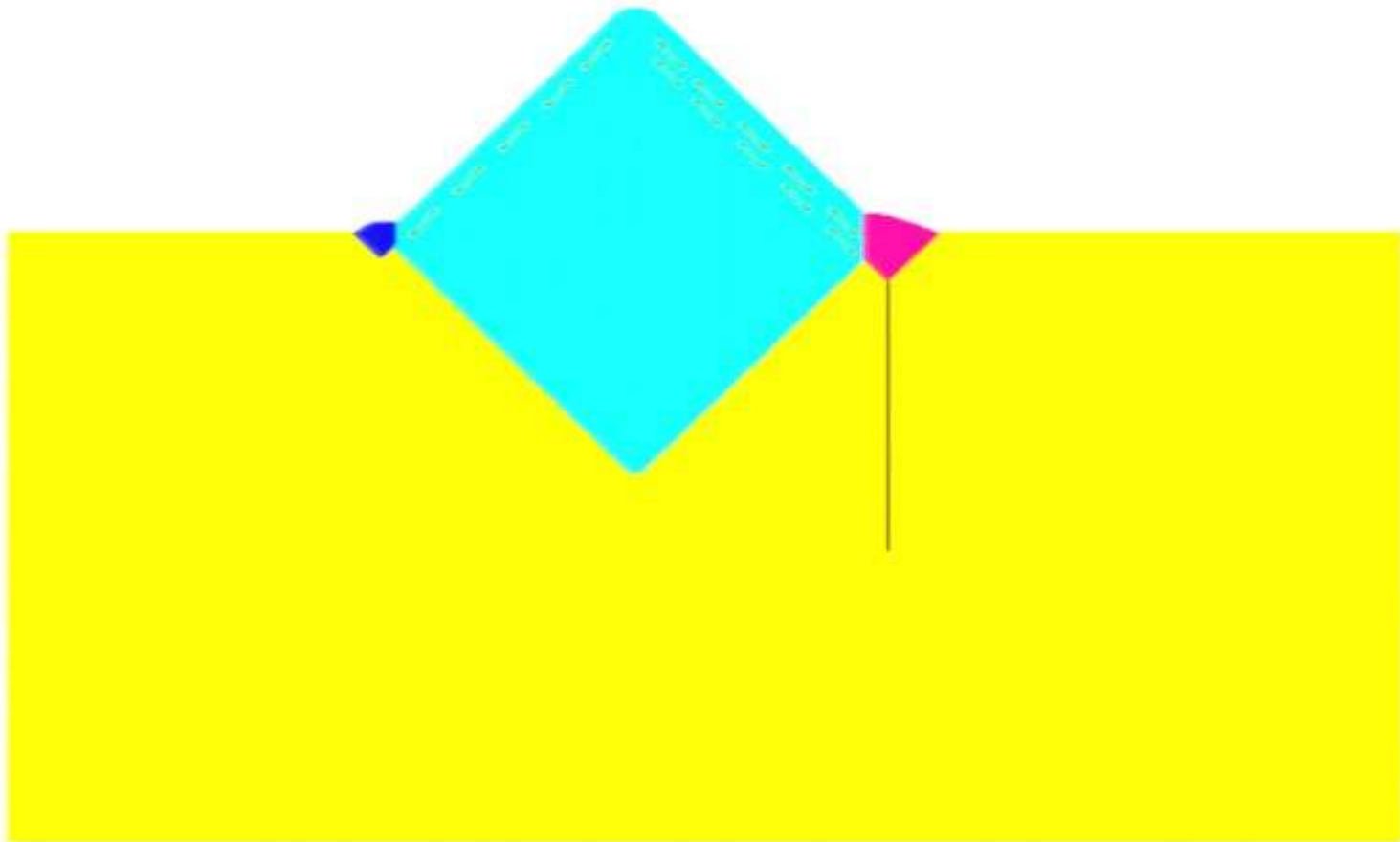


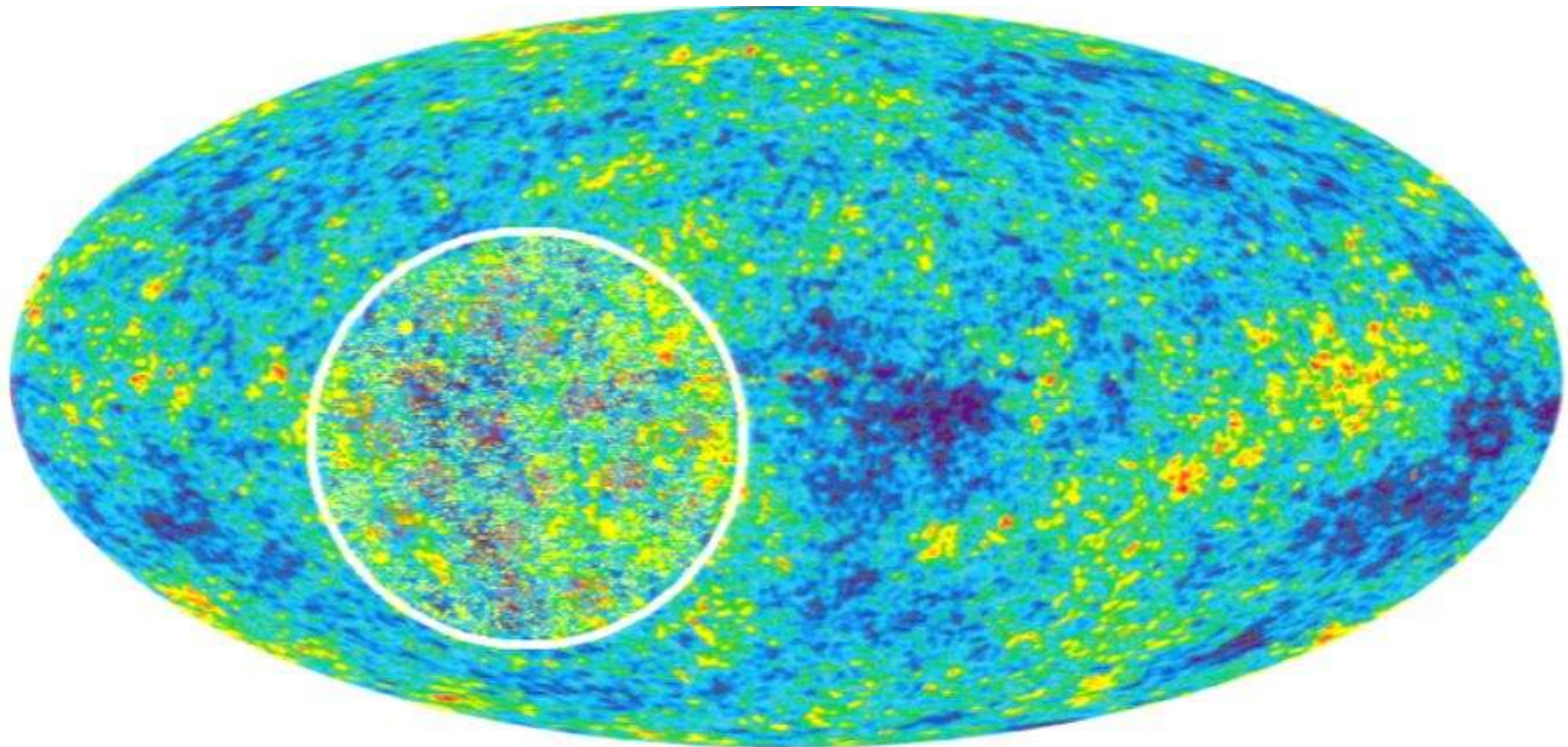






Guth. Weinberg. Vilenkin. Garriga. Freivogel. Bousso. Shenker.
Sekino. Kleban. Bjorken.





Rings bounding regions of modified temperature. Non-gaussian statistics? See for example Chang, Kleban, Levi arXiv:0712.2261

But, as with other fossils too much slow roll will dilute the signal to unobservability.