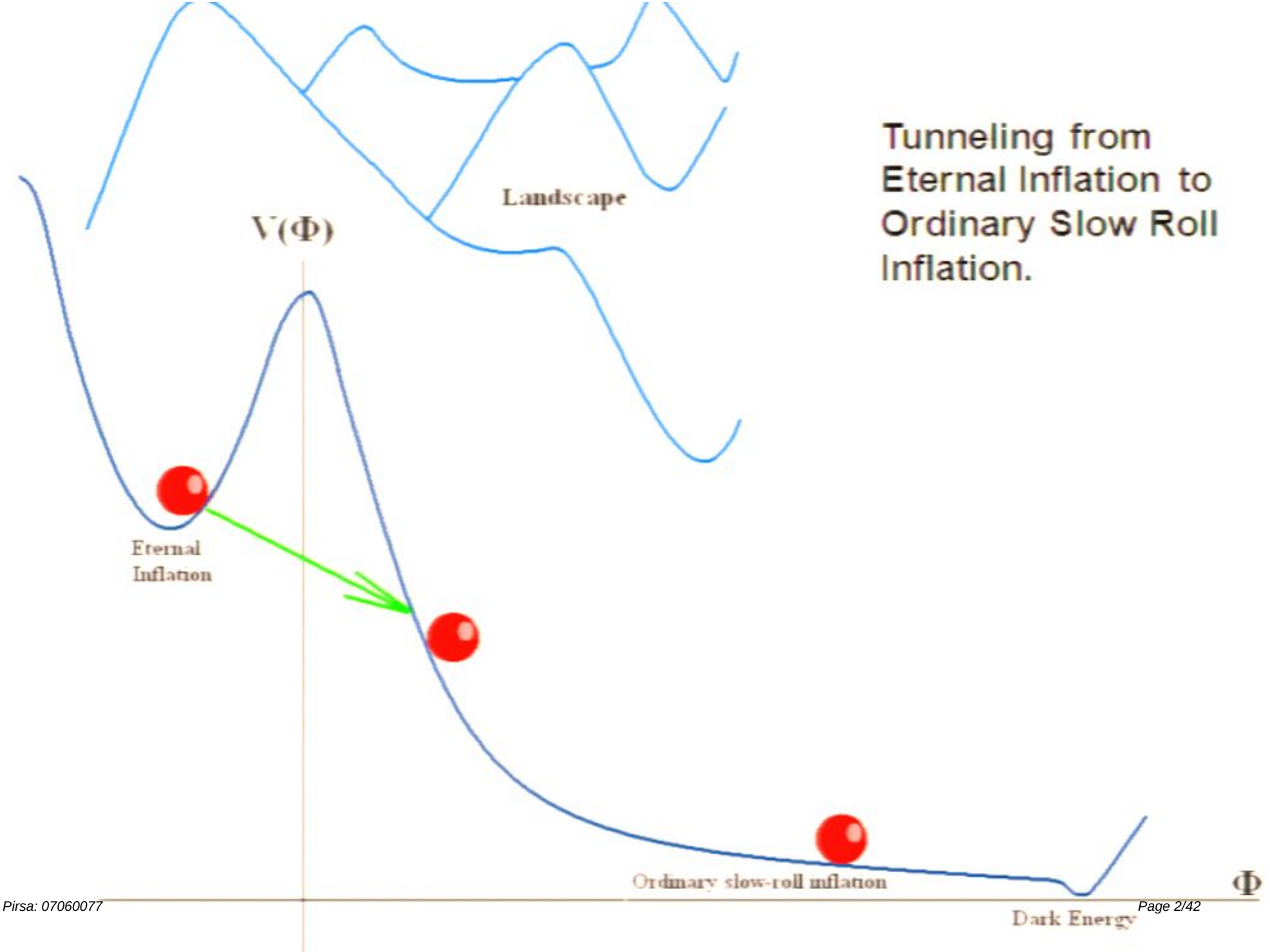
Title: Negative Curvature

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 synonomous 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?

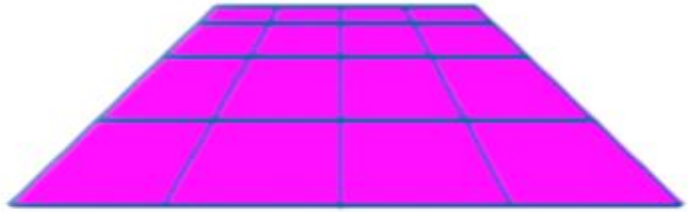
Quick Cosmology Lesson

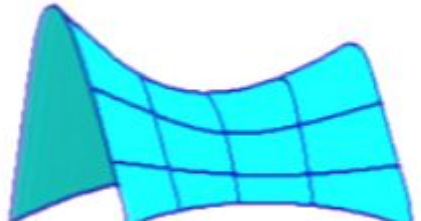
FRW Cosmology

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

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

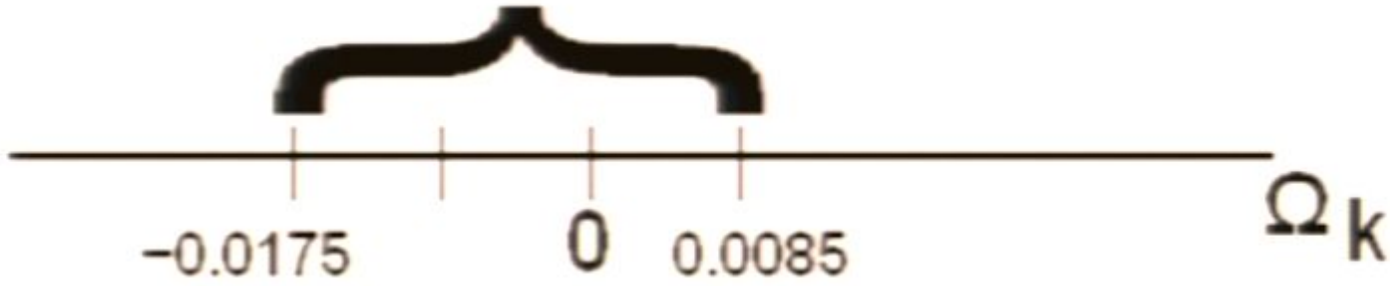
$$ds^2 = - dt^2 + a^2(t) \{ dR^2 + \sinh^2 R \ (d\theta^2 + \sin^2\theta \ d\varphi^2) \}$$





Data inconclusive

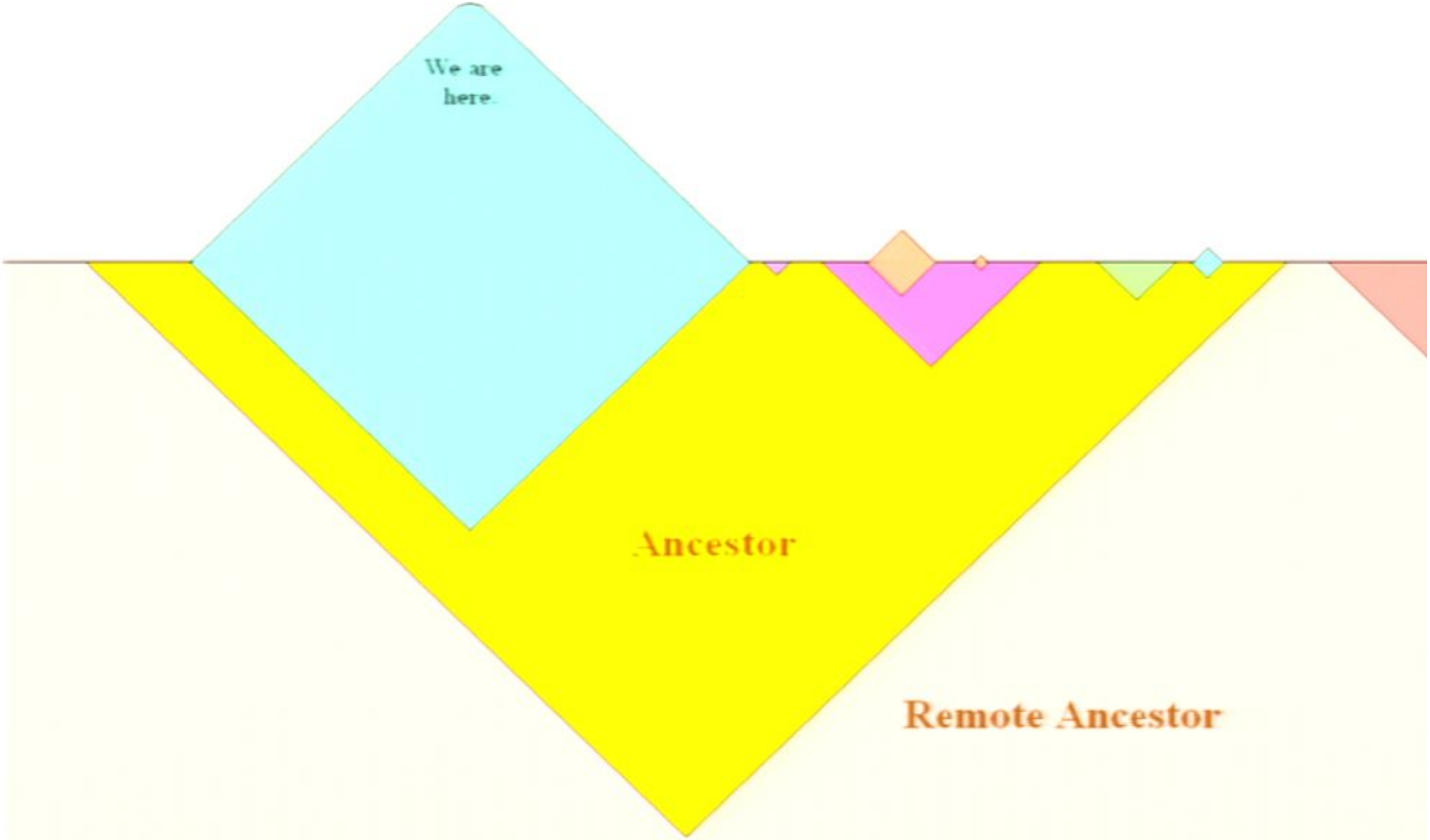
- Inflation flattens. Best fit: Curvature slightly negative but zero within 1-sigma error bars.

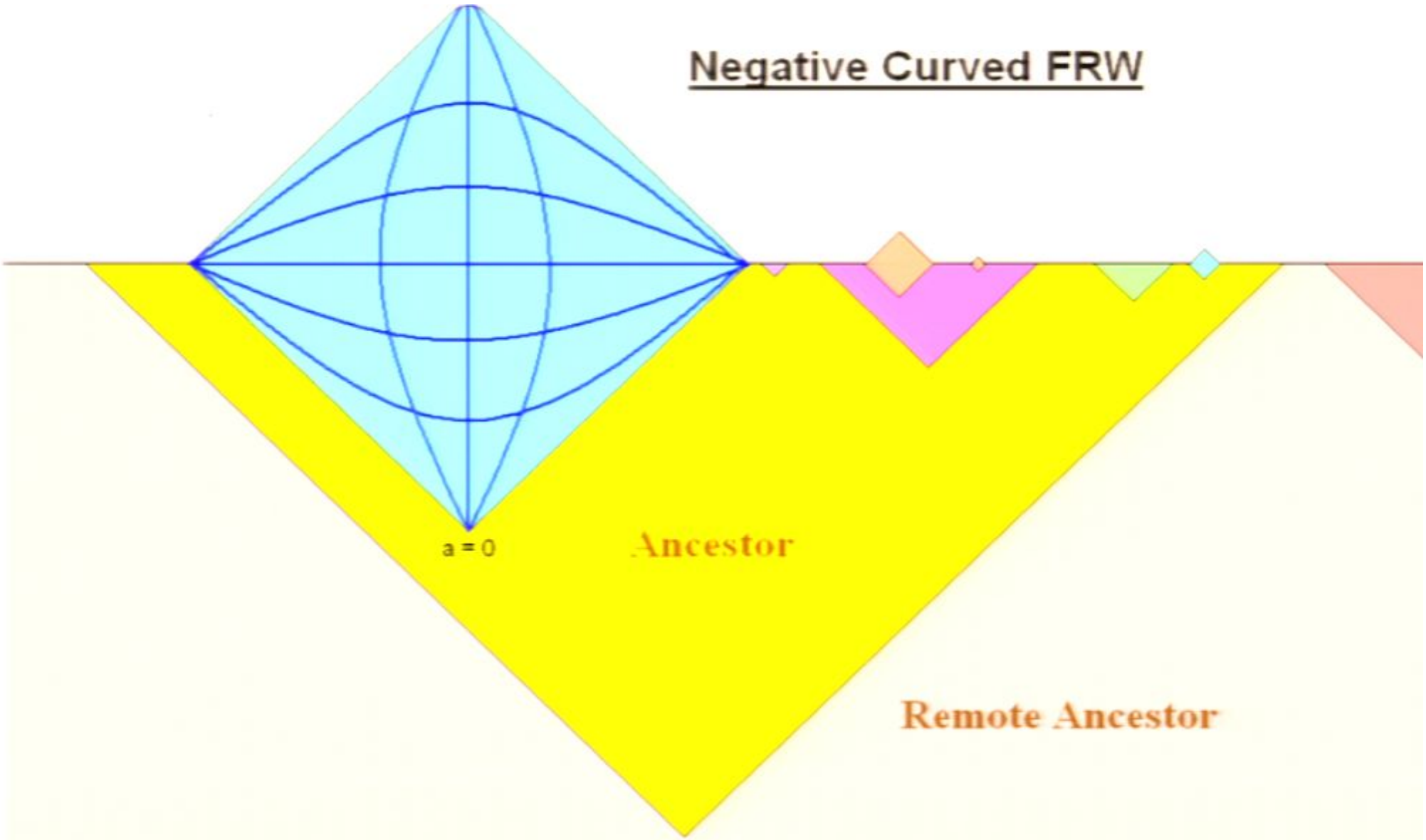


- Anomalous behavior of lowest **l** primordial fluctuations? Maybe.

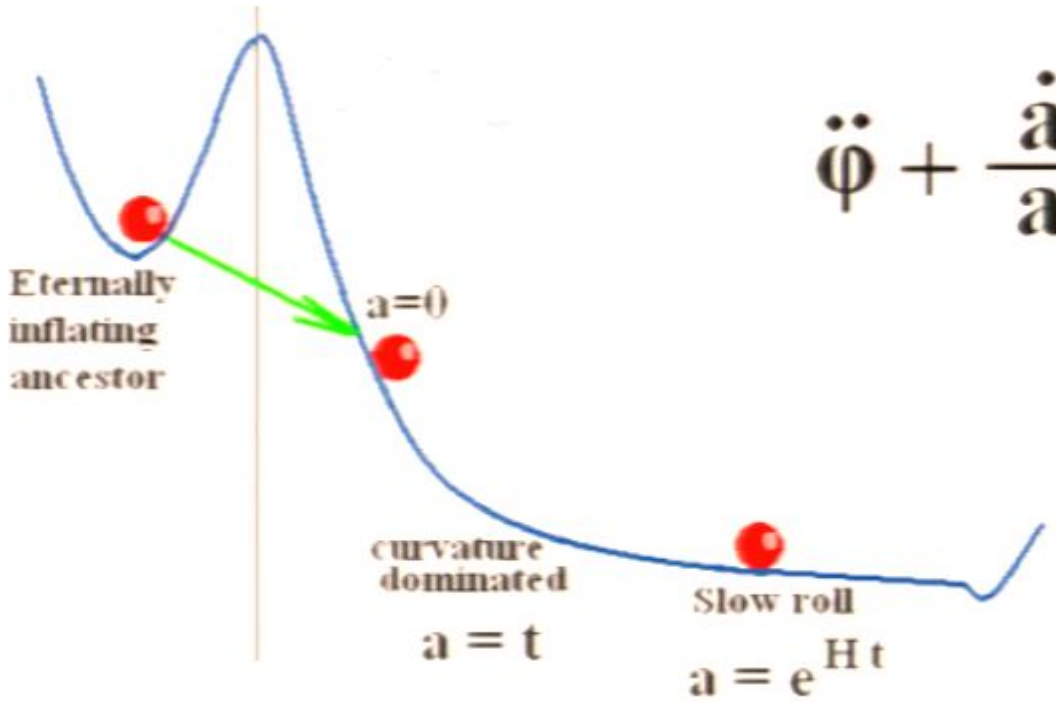
What does theory say?

Tunneling on the Landscape

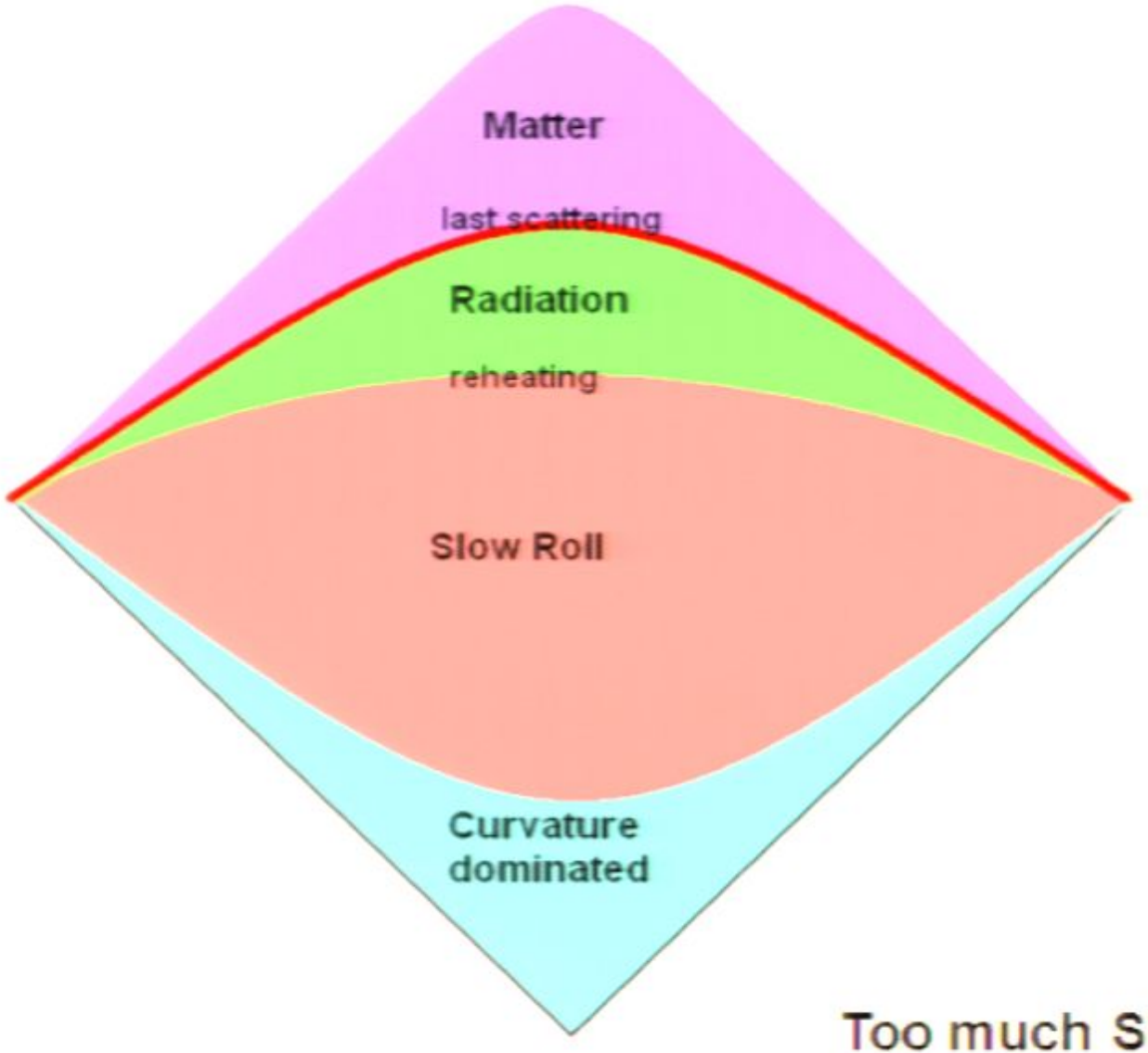

We are
here.
Ancestor
Remote Ancestor

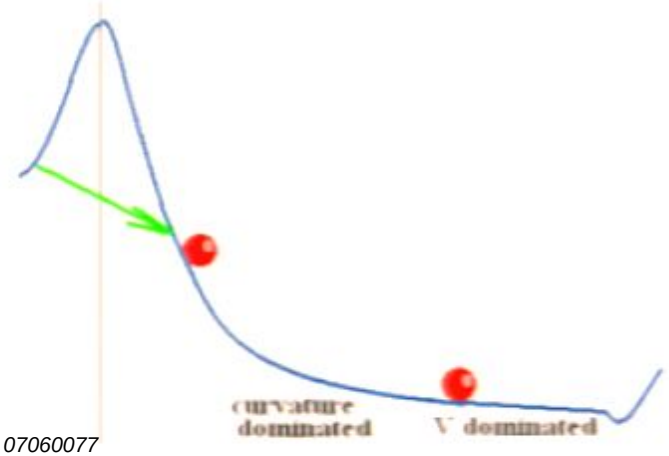

Negative Curved FRW
a = 0
Ancestor
Remote Ancestor

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



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

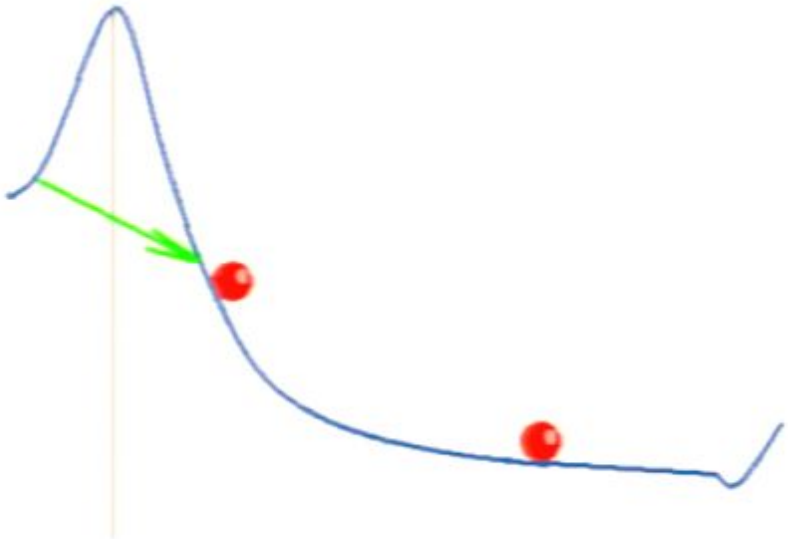




Too much Slow Roll inflation would obliterate everything that came before.

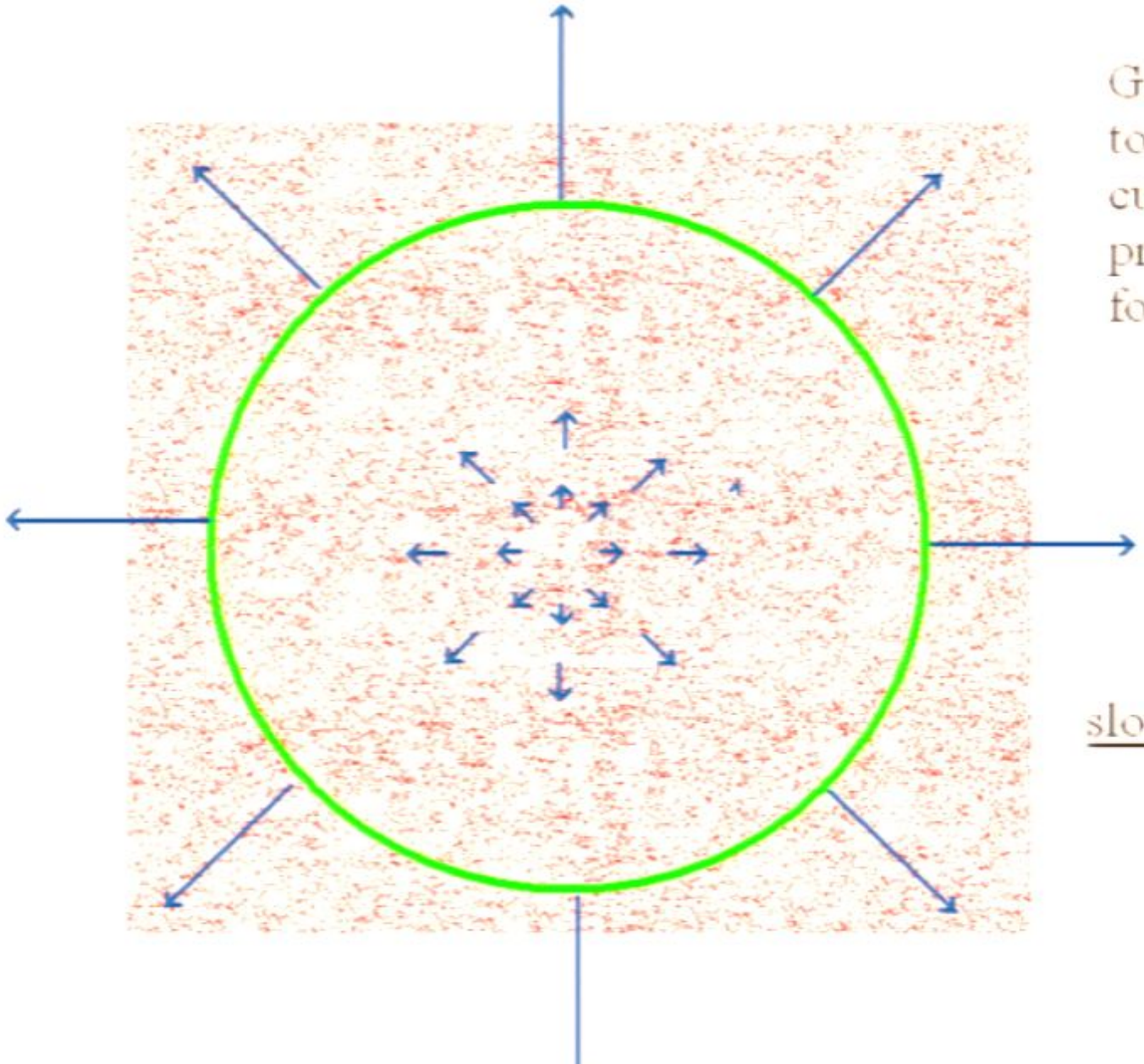
Why did slow roll inflation happen?

- 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

$$\left(\frac{\Omega_\Lambda}{\Omega_{matter}} \right)^{1/3} + \frac{\Omega_{curvature}}{\Omega_{matter}} < \left(\frac{\delta\rho}{\rho} \right)^{3}_{dc} \frac{\rho}{\rho_{today}}$$

At decoupling

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

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

Or in terms of e-foldings

$$N_{observation} > 50$$

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

Measure Problem

Measures that

- violently favor large number of e-foldings (typically very bizarre consequences).

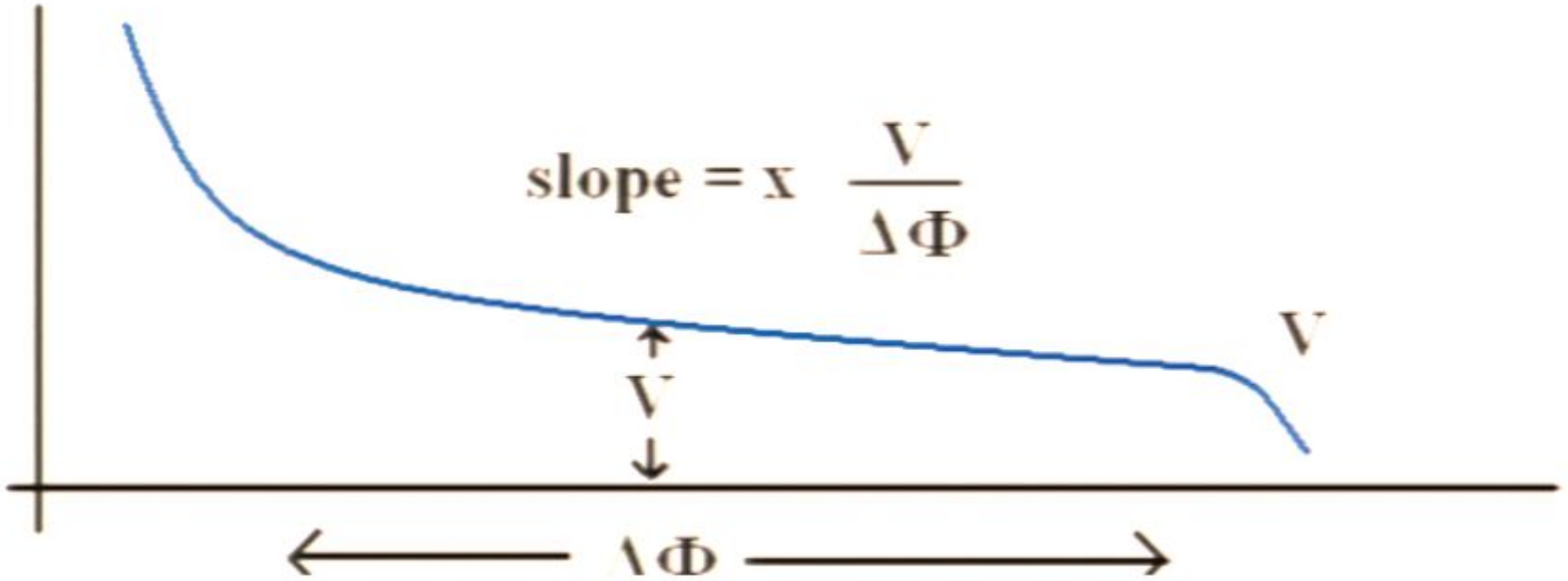
- that are more or less neutral with respect to N.

  (e.g., Bousso, Harnik, Kribs, Perez, hep-th/0702115, and more recently, Guth and Vilenkin, arXiv:0805.2173)

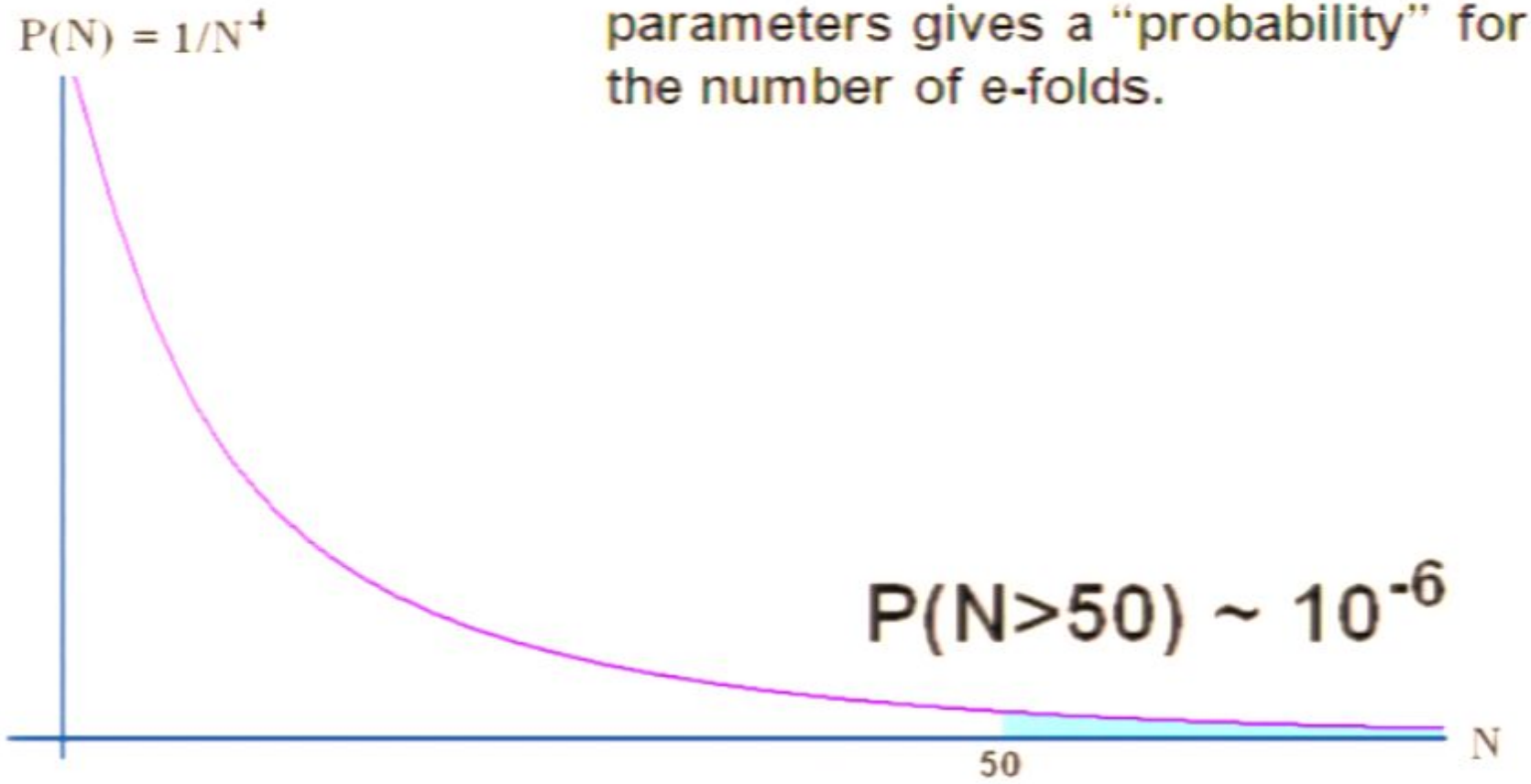
A very simplified 3-parameter model of Landscape statistics

(slope, width, height)

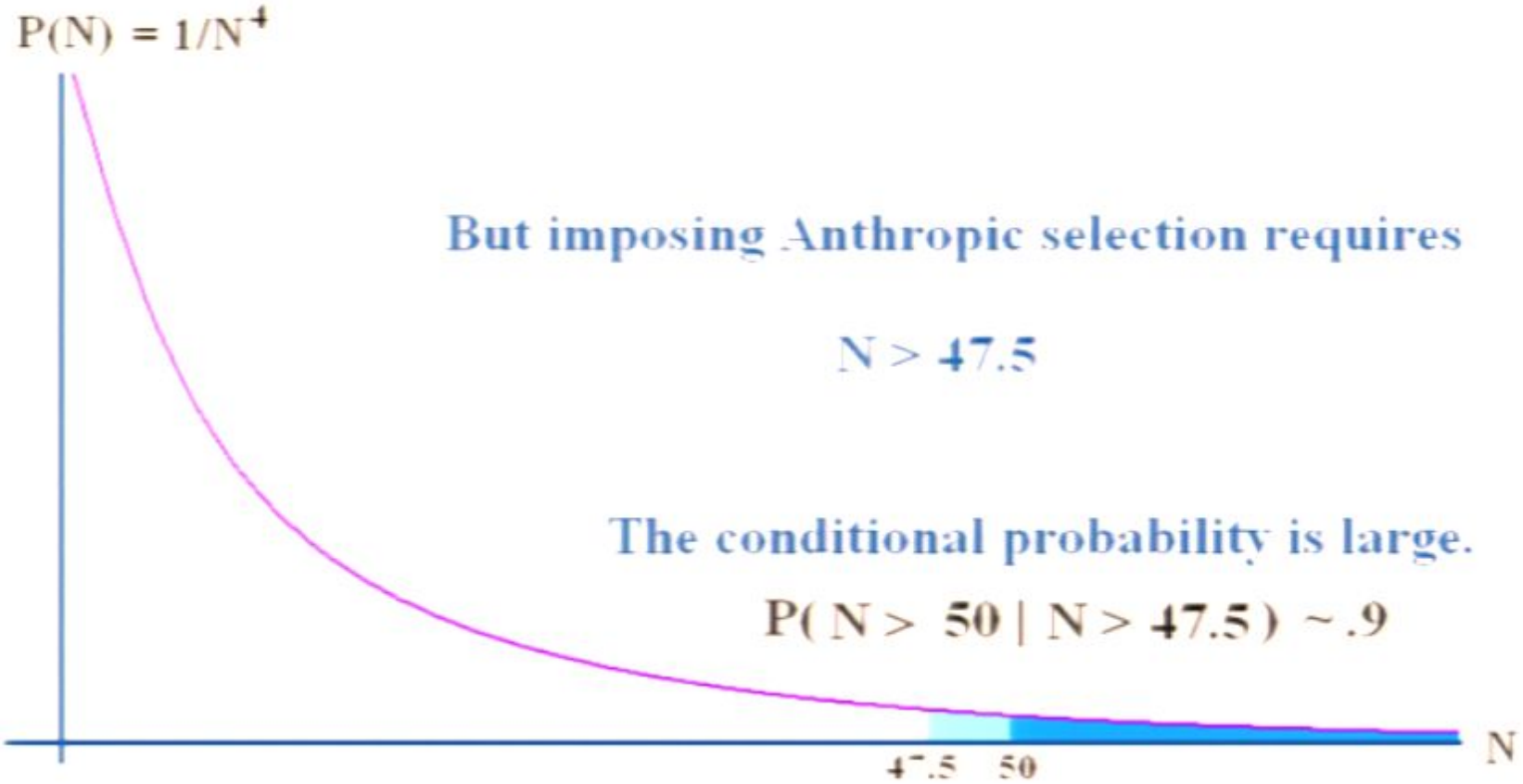
Freivogel,
Kleban,
Martinez,
L.S.



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



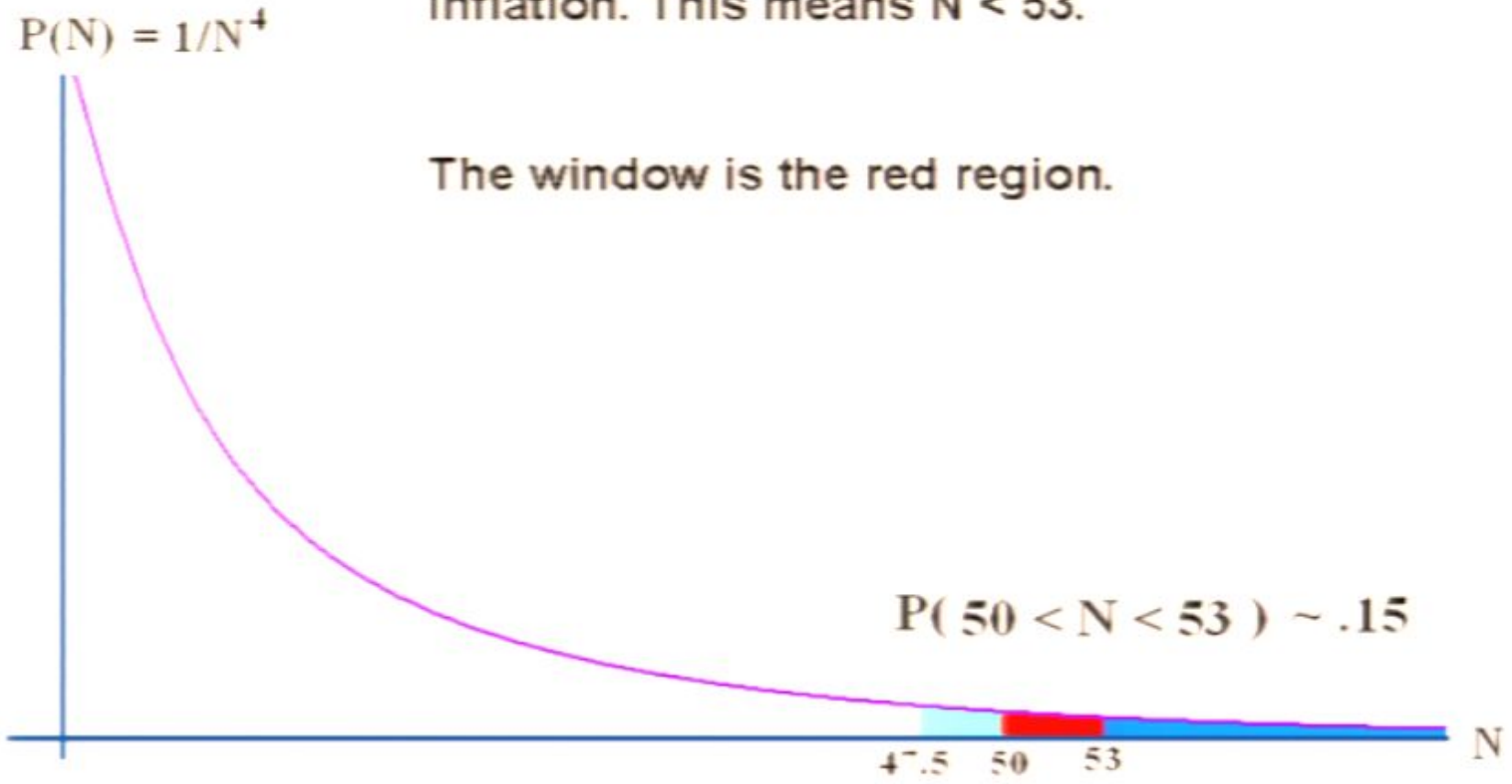
Inflation is fine tuned to about one part in a million.



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.

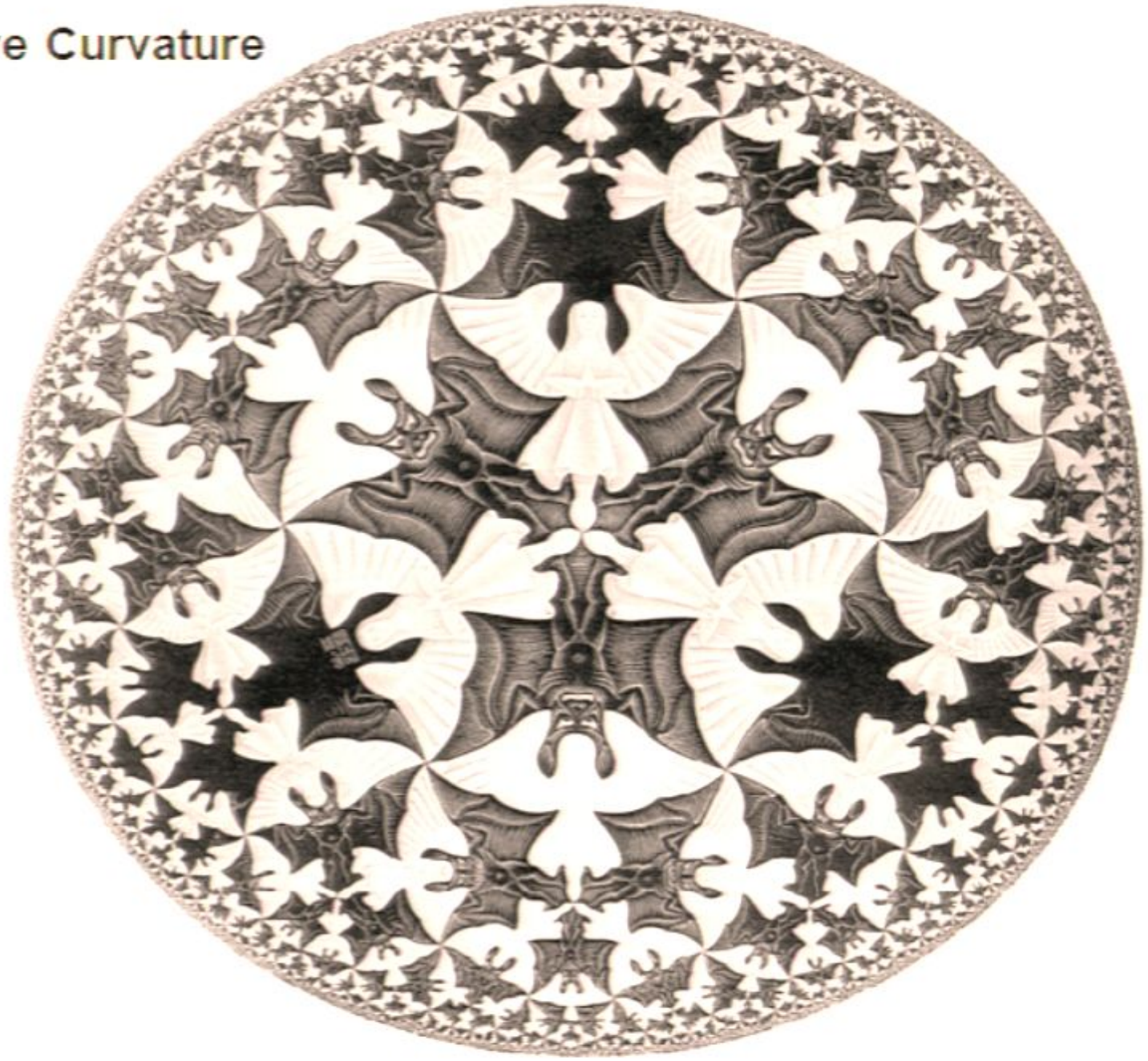


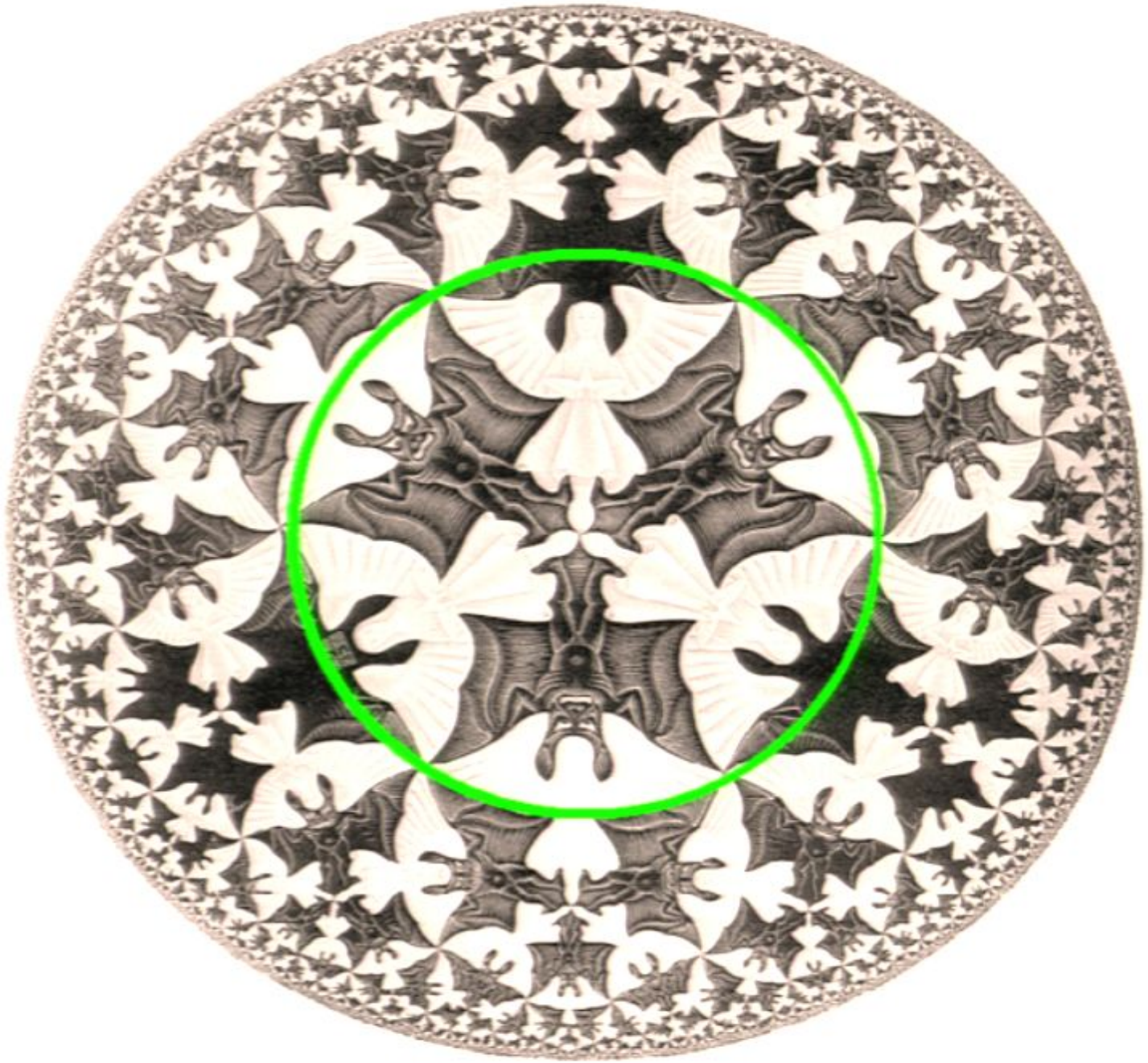
The window is the red region.

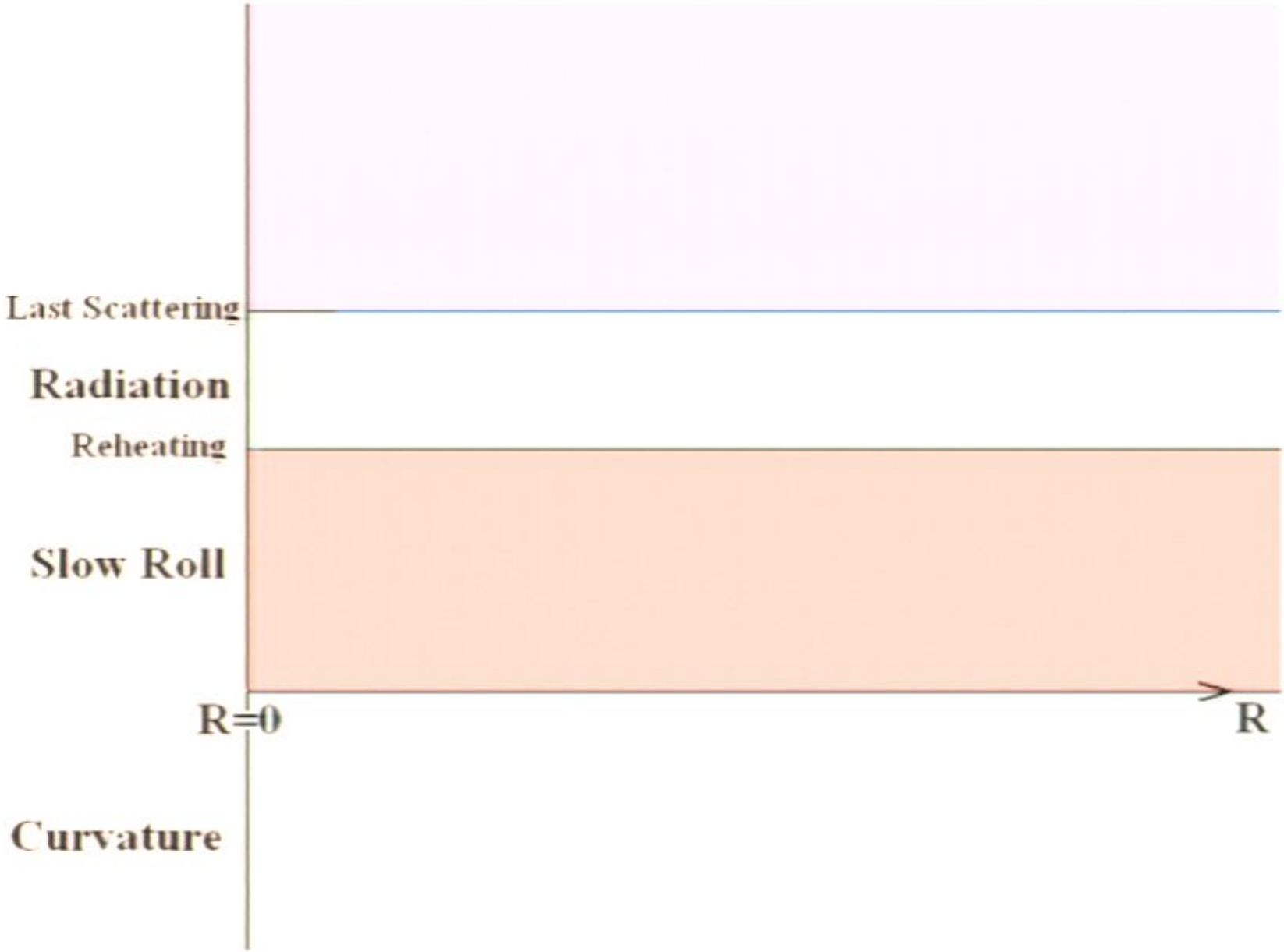
Fossils of a Tunneling Event

Fossil #1

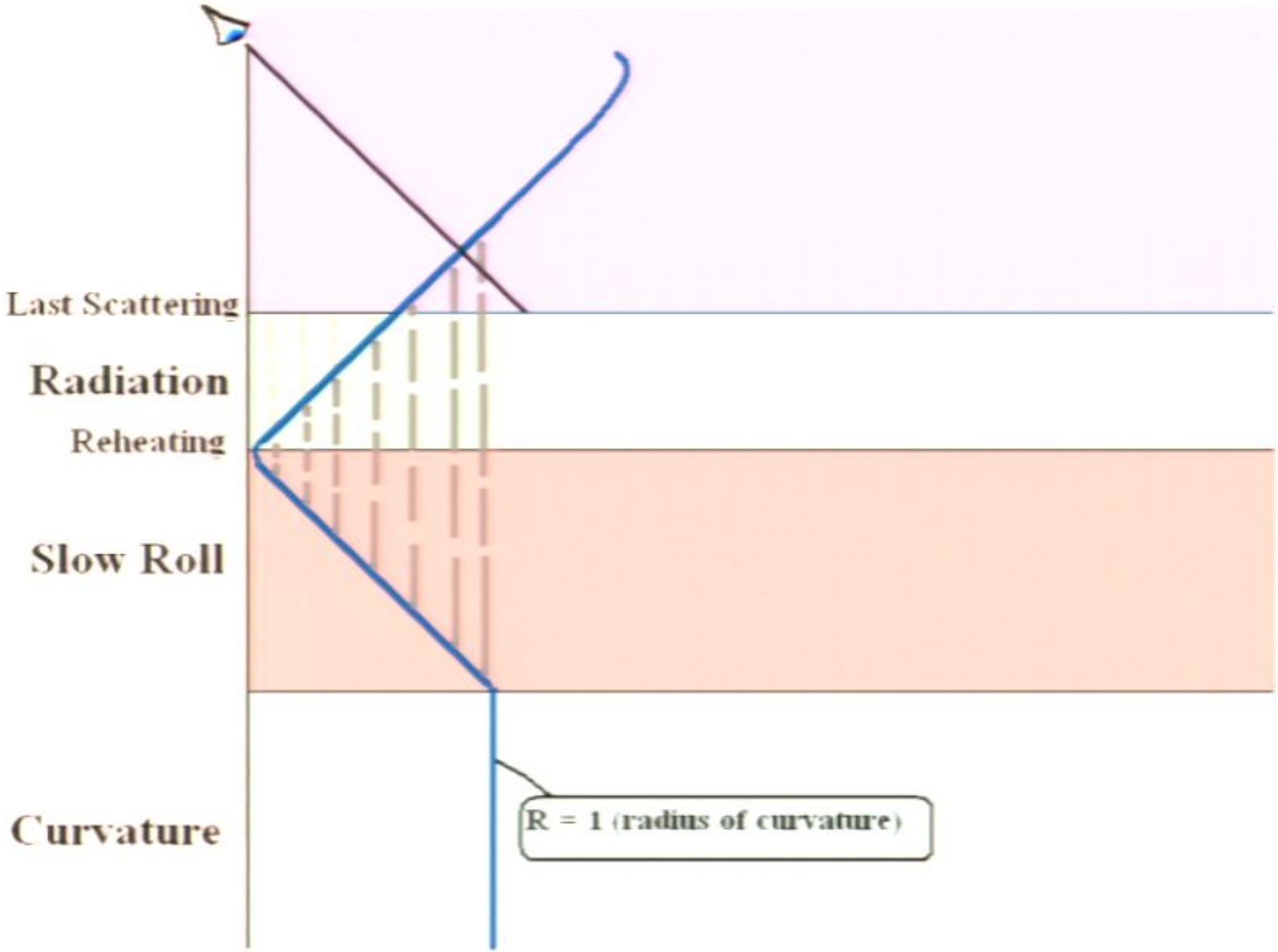
Negative Curvature




R = 1

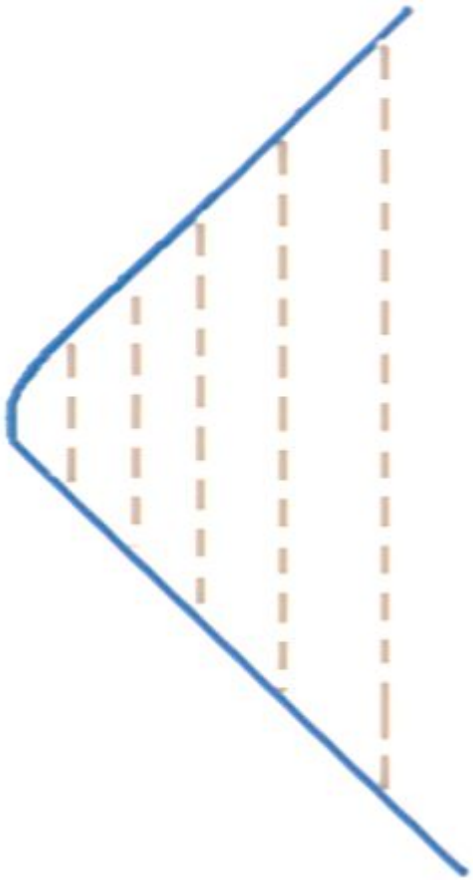


R = Co-moving radial distance


Last Scattering
Radiation
Reheating
Slow Roll
Curvature
R = 1 (radius of curvature)

Fossil 2

Very low l tensor modes



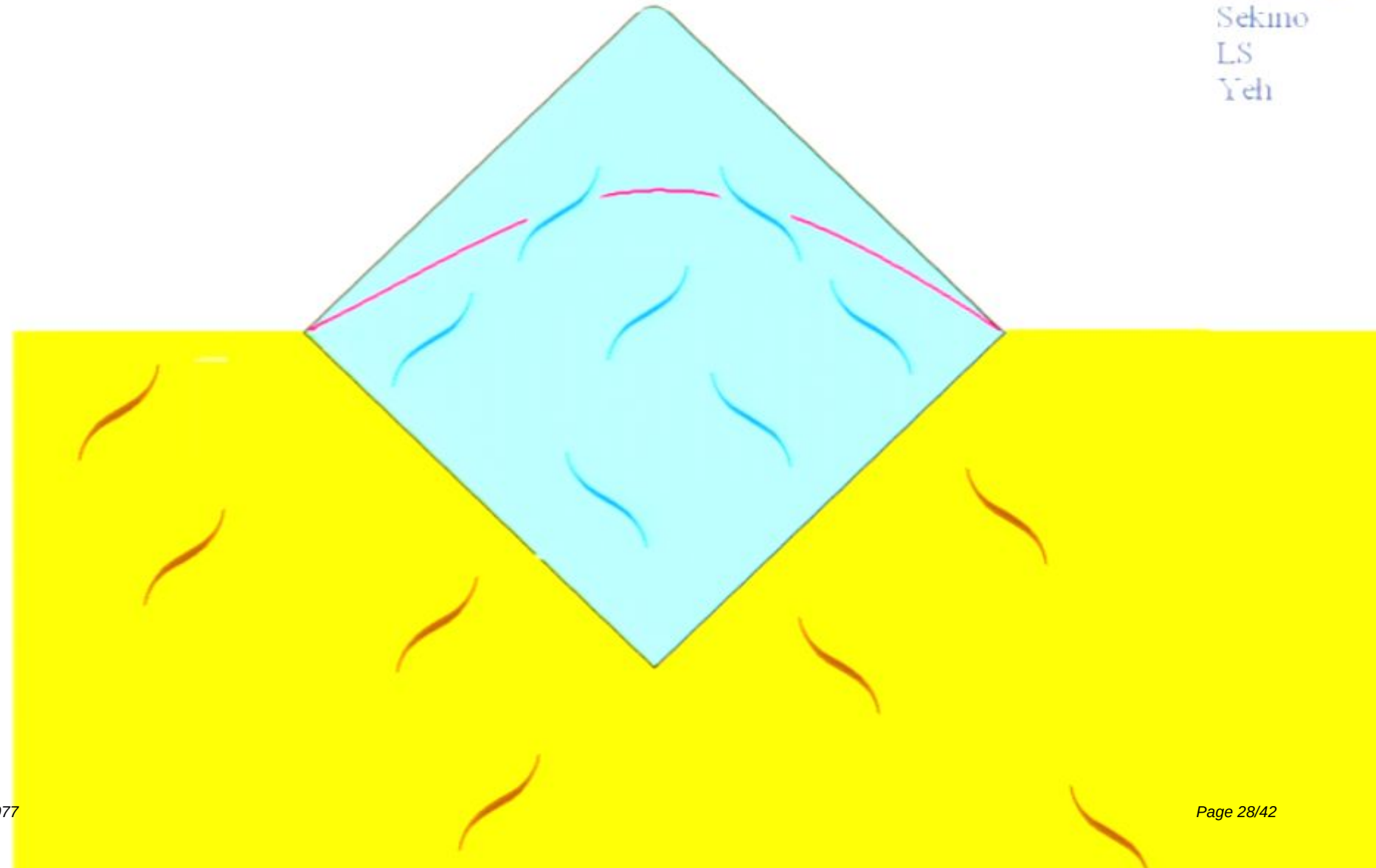
Gravity waves (Tensor modes) are also produced during inflation but their amplitude may be (?) too small to detect.

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

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

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

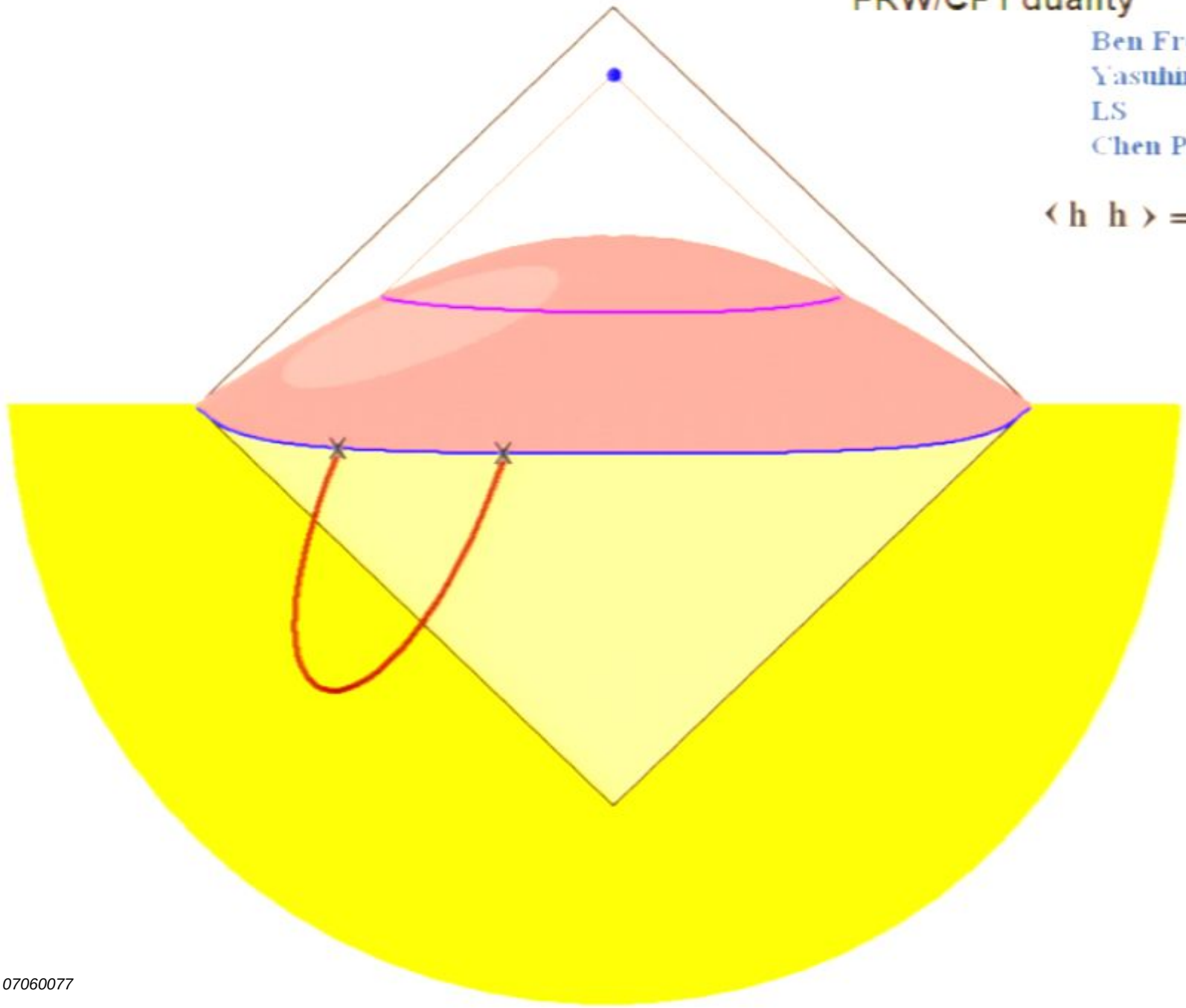
Frenvogel
Sekino
LS
Yeh

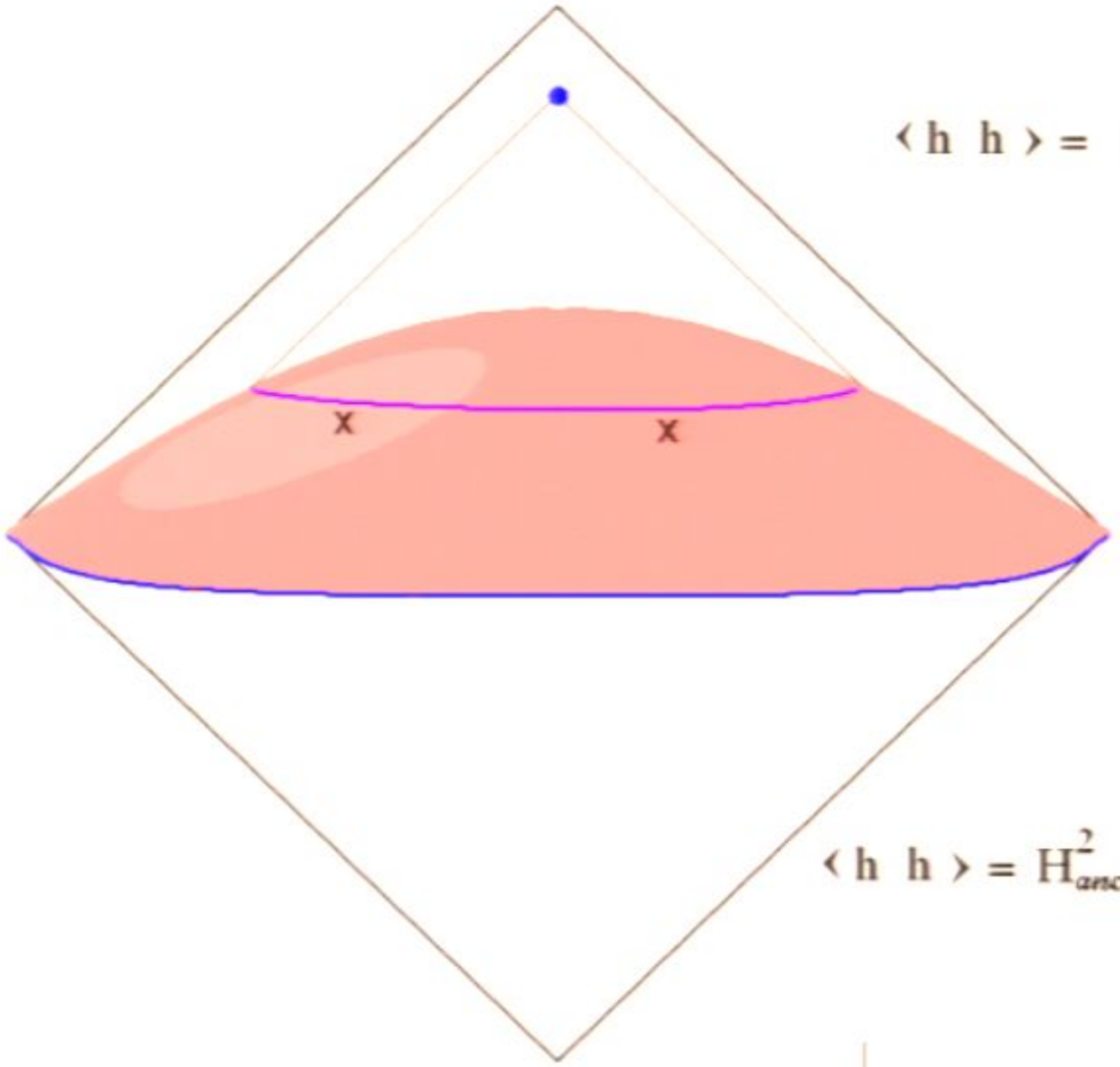


FRW/CFT duality

Ben Freivogel
Yasuhiro Sekino
LS
Chen Pin Yeh

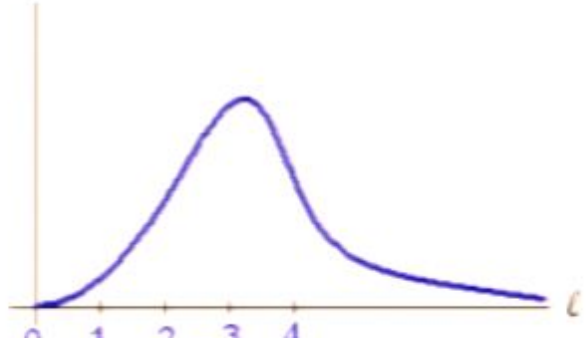
$$\langle h \; h \rangle = \ell^2 \; H^2_{ancestor}$$

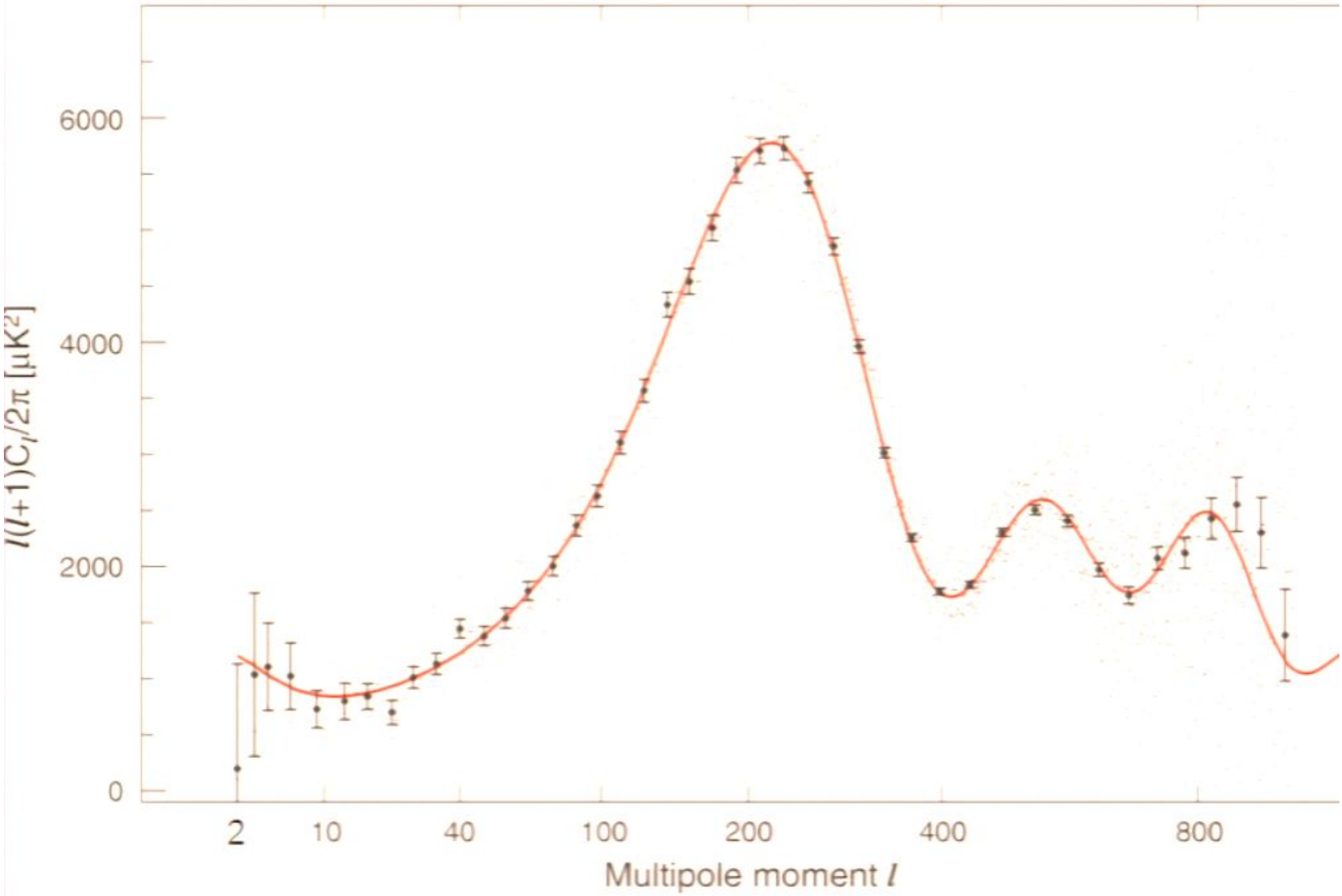


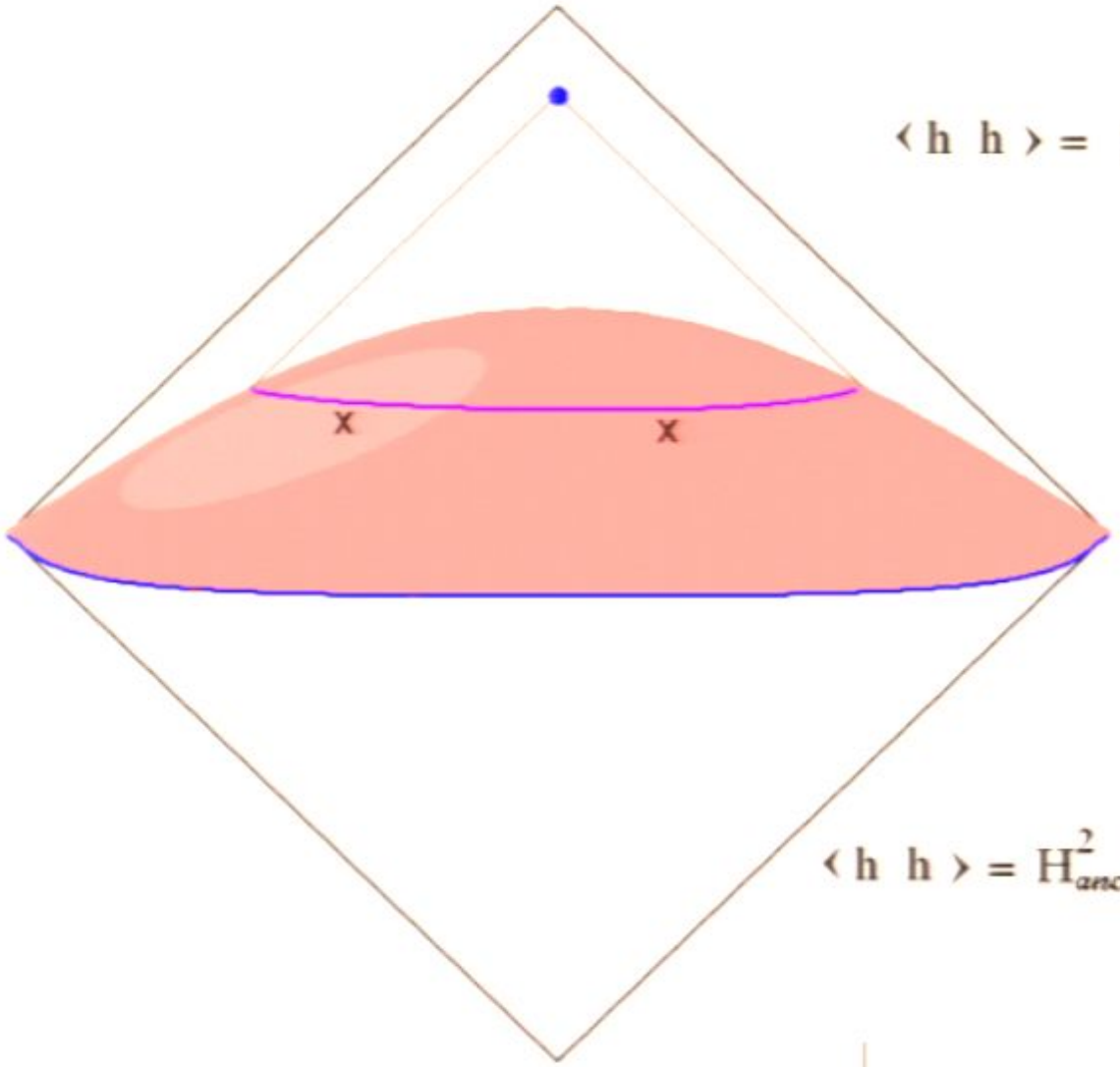


$$\langle h\ h \rangle = H^2_{ancestor}\, \ell^2 \qquad (R \geq 1)$$

$$\langle h\ h \rangle = H^2_{ancestor}\, \ell^2\ R^{\ell} \qquad (R < 1)$$




6000
4000
2000
0
$l(l+1)C_l/2\pi$ [μK^2]
2
10
40
100
200
400
800
Multipole moment l



$$\langle h\ h \rangle = H^2_{ancestor}\, \ell^2 \qquad (R \geq 1)$$

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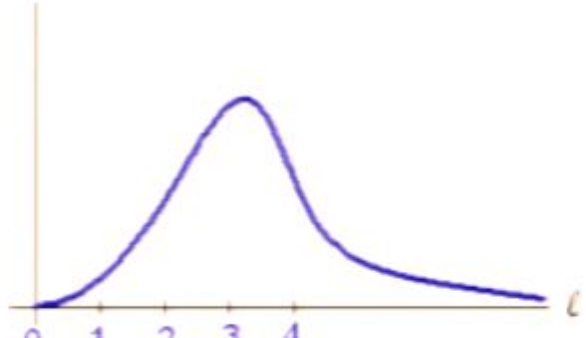
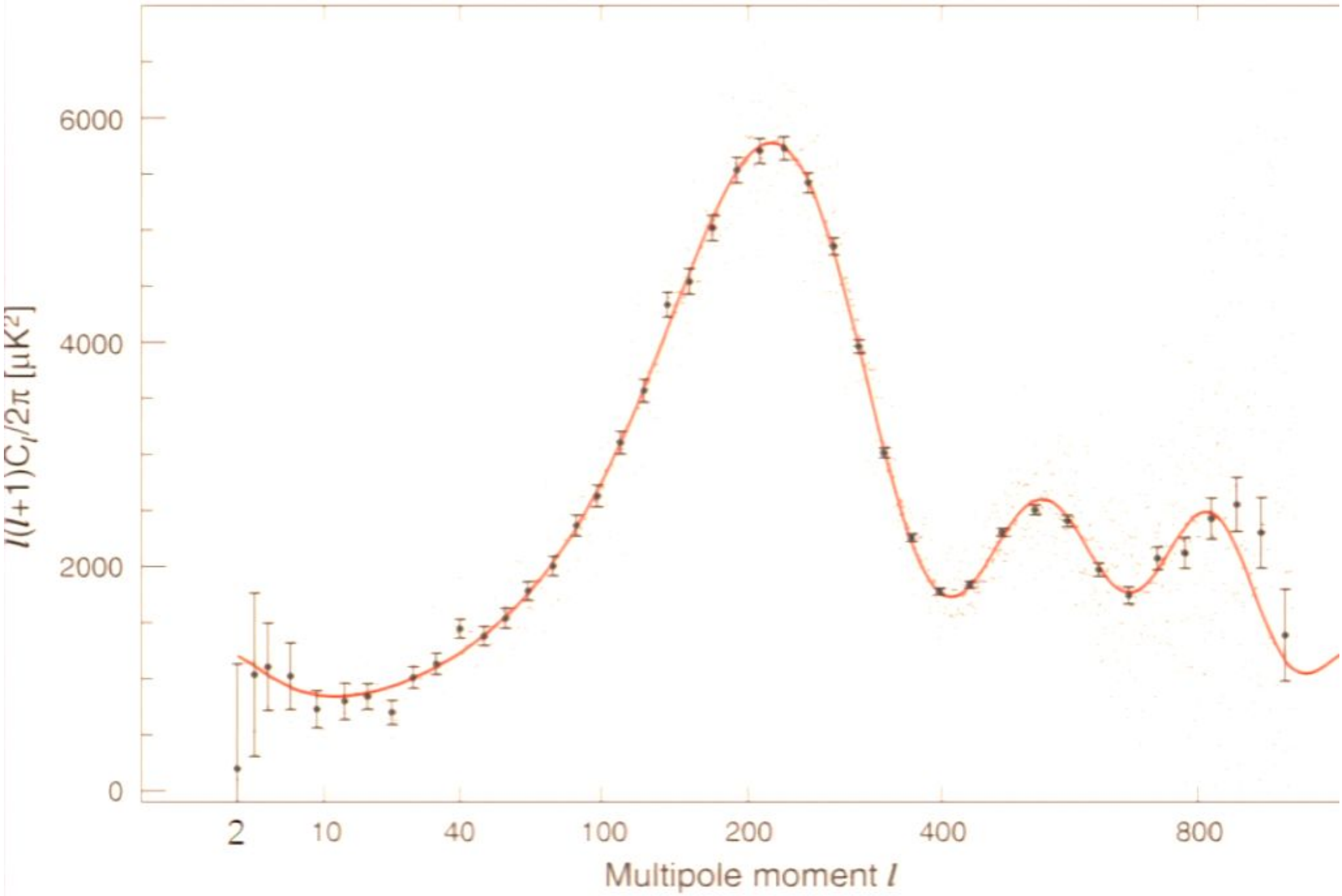
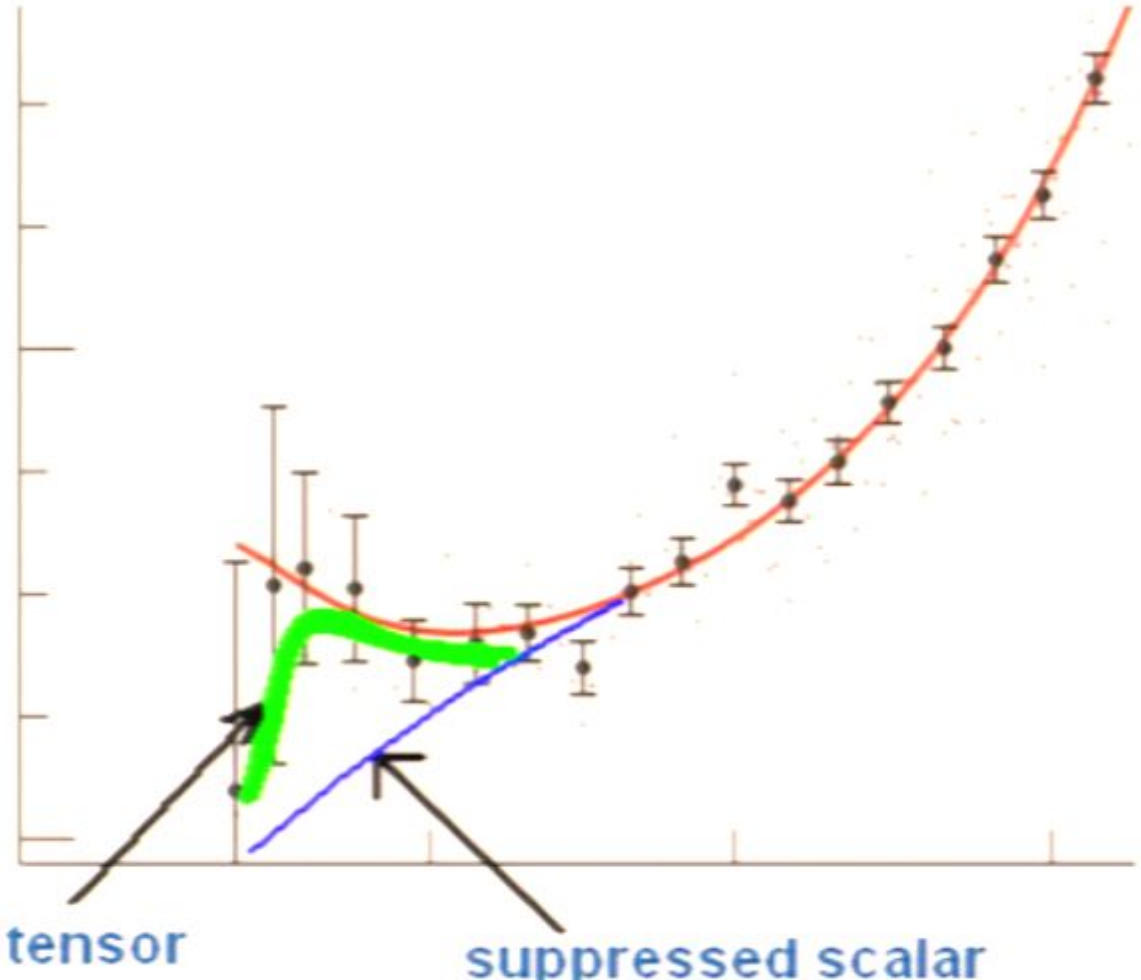


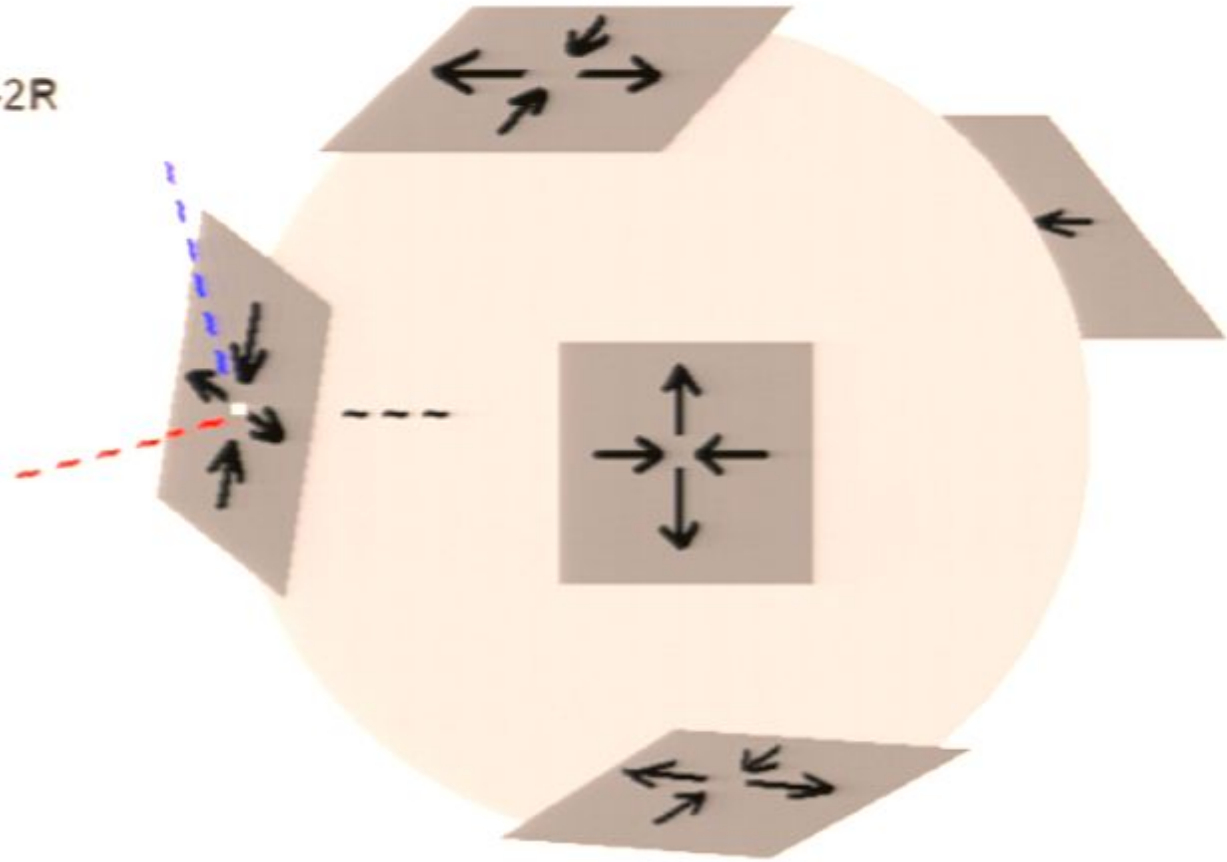

6000
4000
2000
0
$l(l+1)C_l/2\pi$ [μK^2]
2
10
40
100
200
400
800
Multipole moment l

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

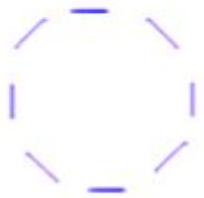


Polarization

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



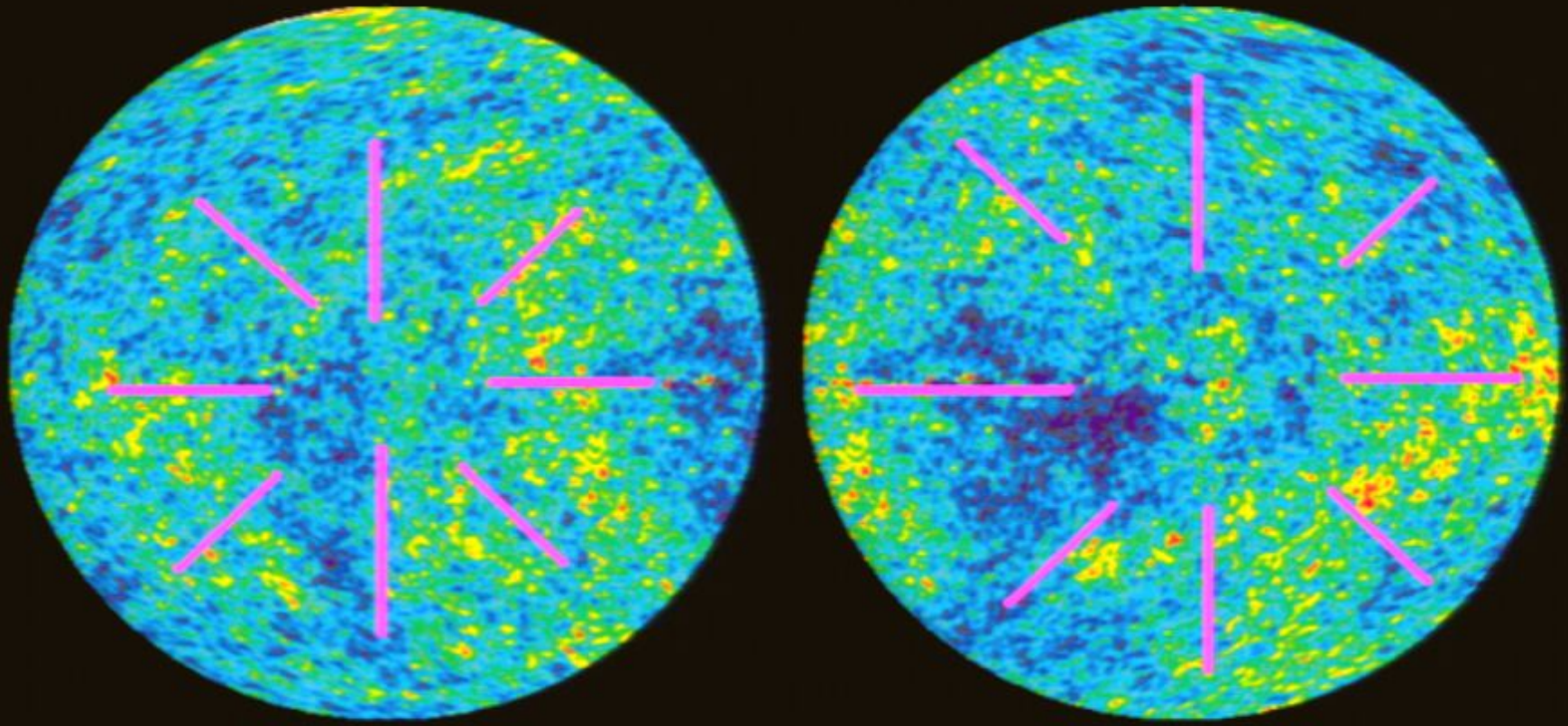
$\varepsilon_{ab}\partial_a P_{bc} = 0$ **Gradiant modes**

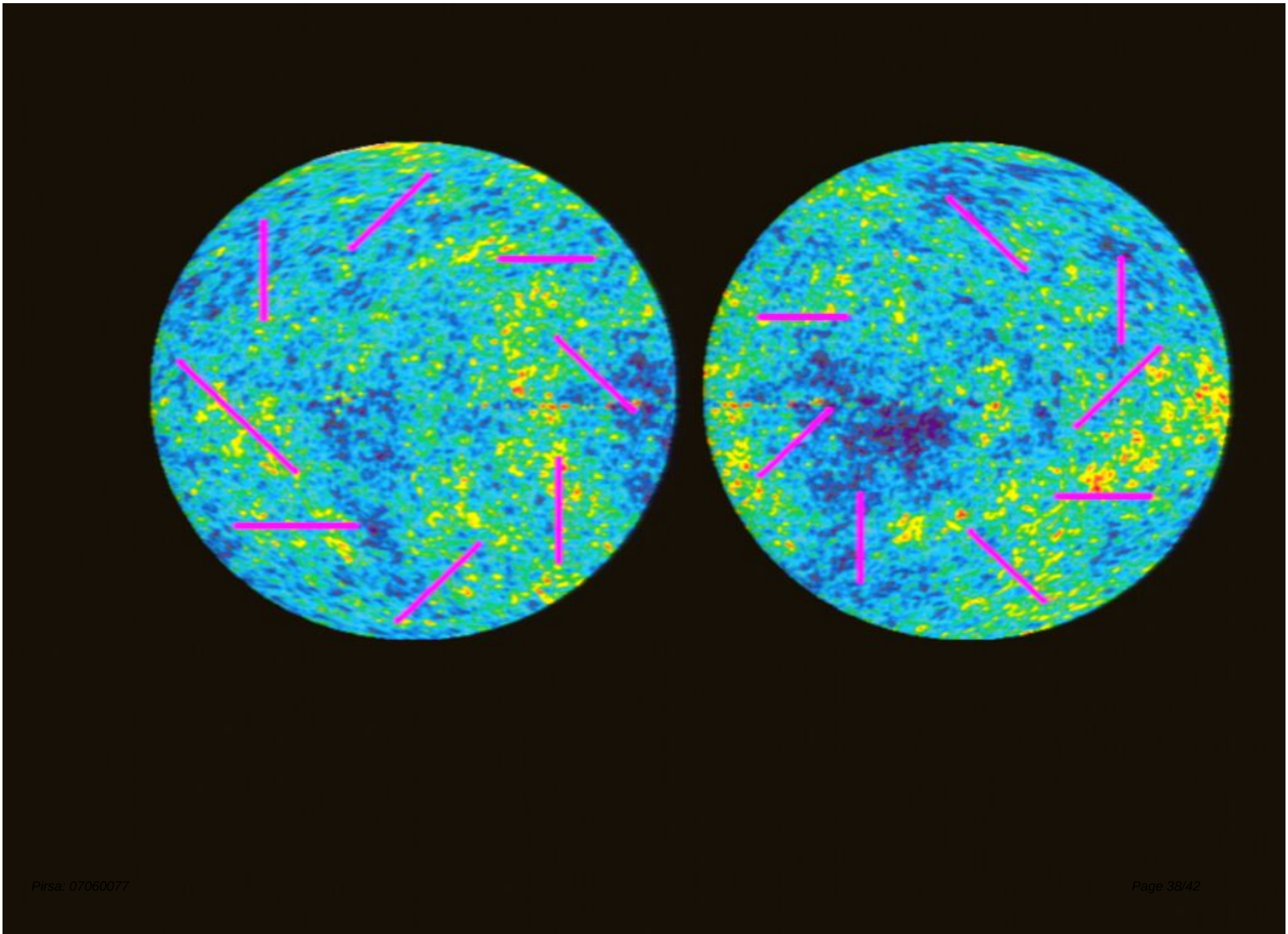


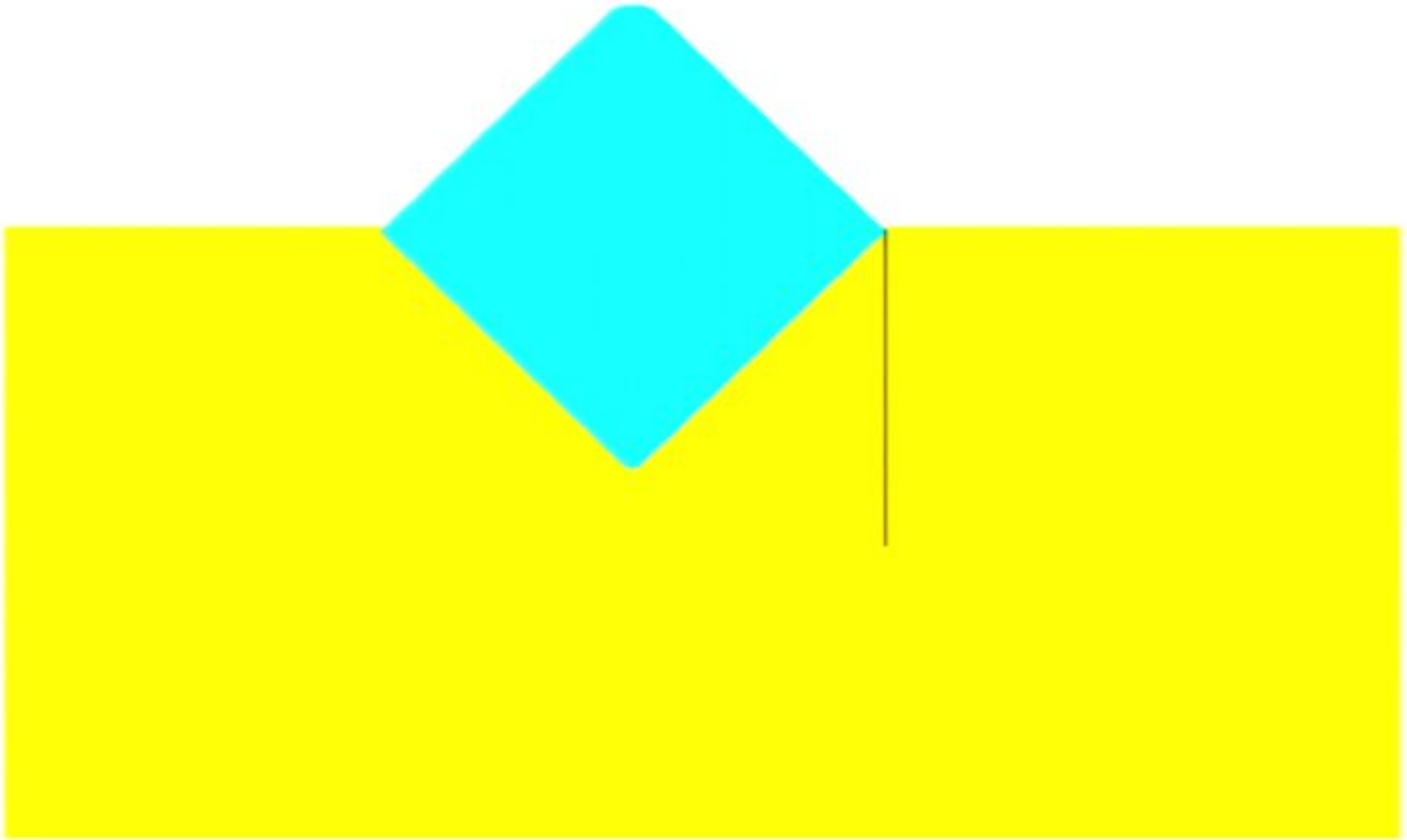
G-waves and density fluctuations

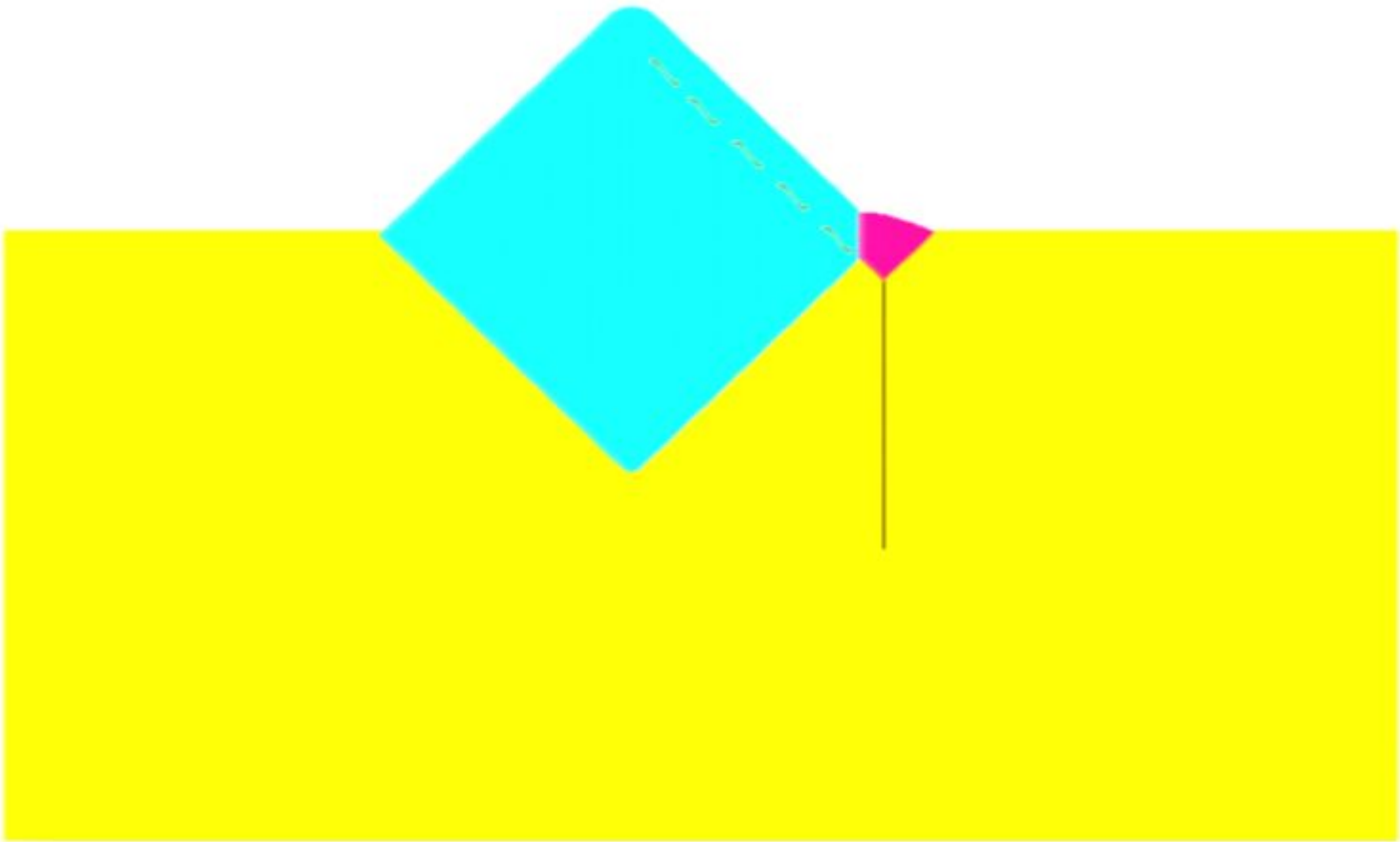
$\partial_b P_{bc} = 0$ **Curl modes**

Only G-waves

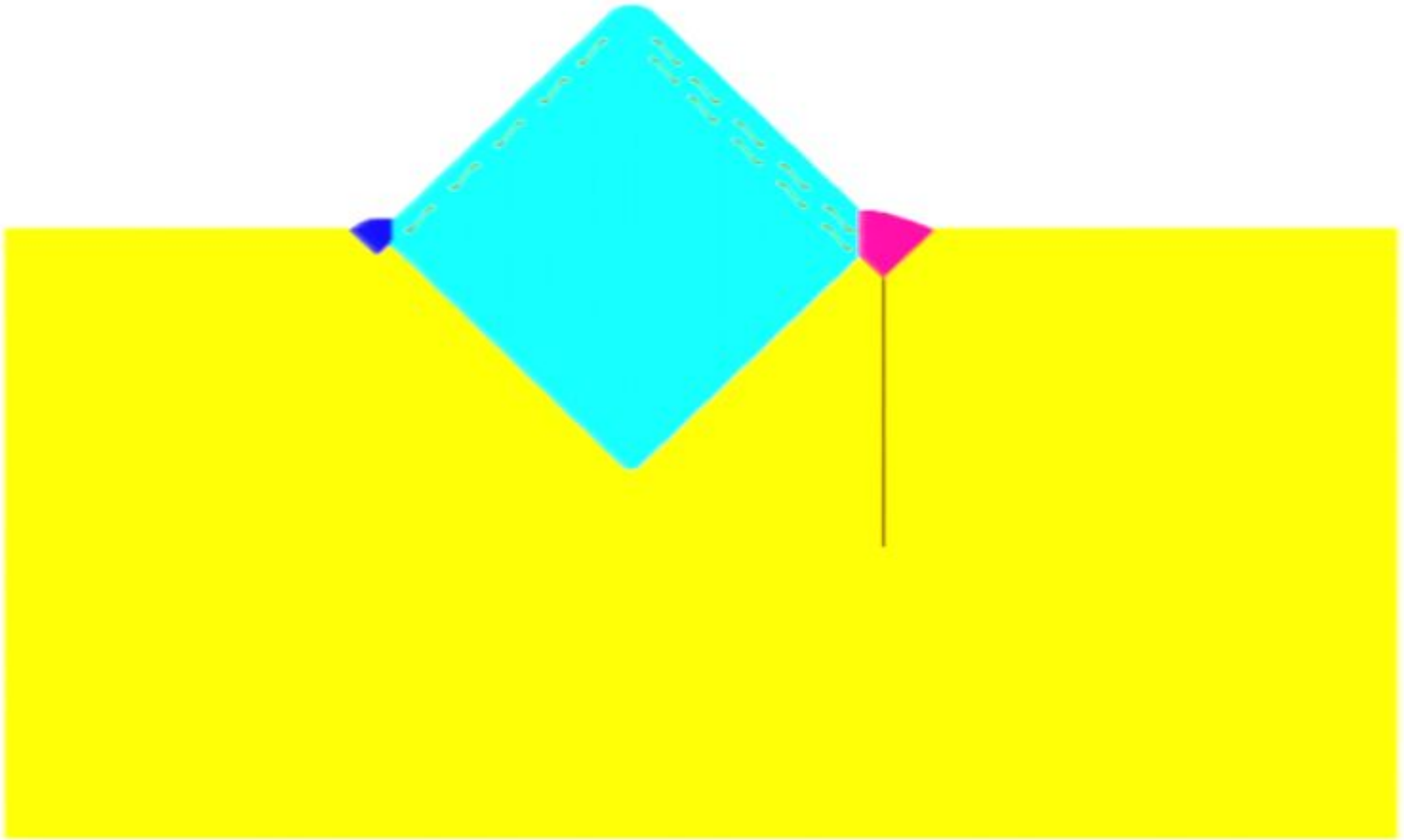


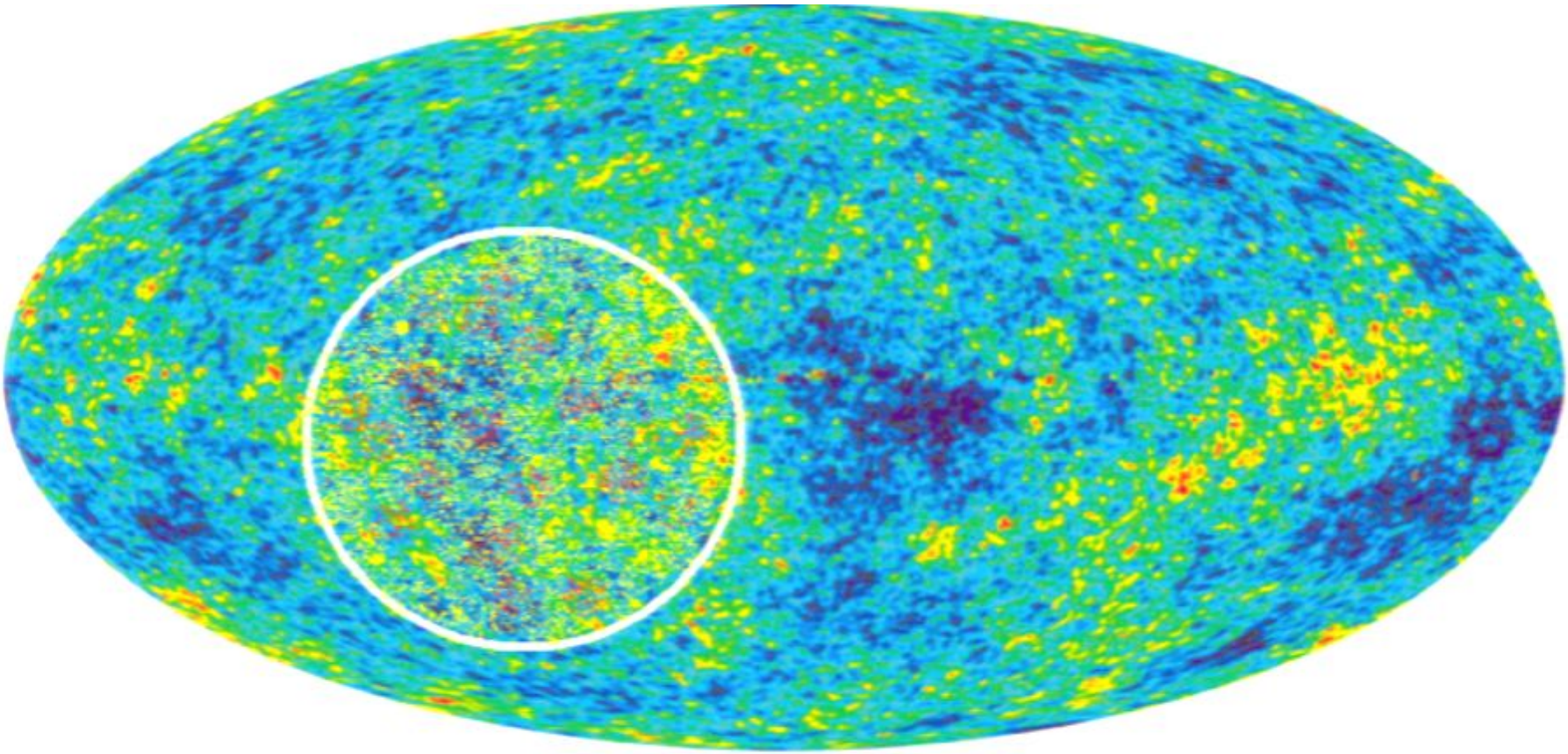






Guth. Weinberg. Vilenkin. Garriga. Freivogel. Bousso. Shenker. Sekino. Kleban. Bjorken. .....





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.