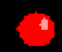
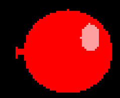
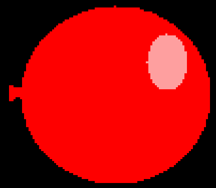
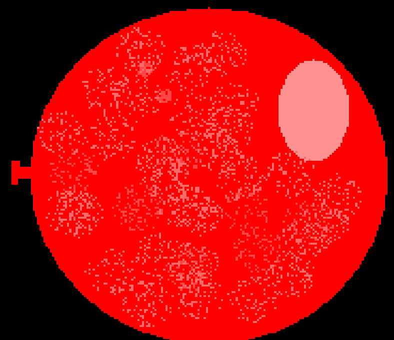
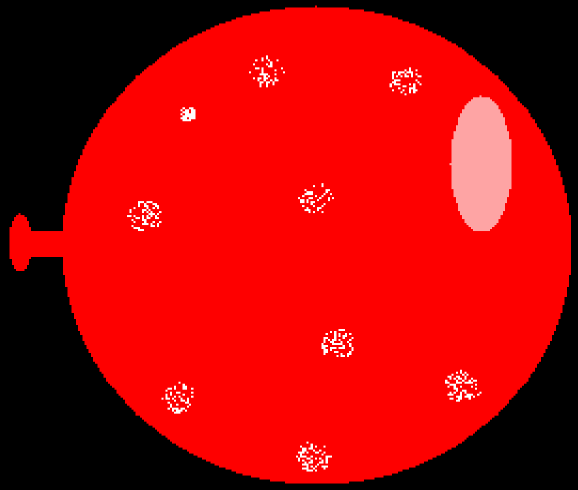
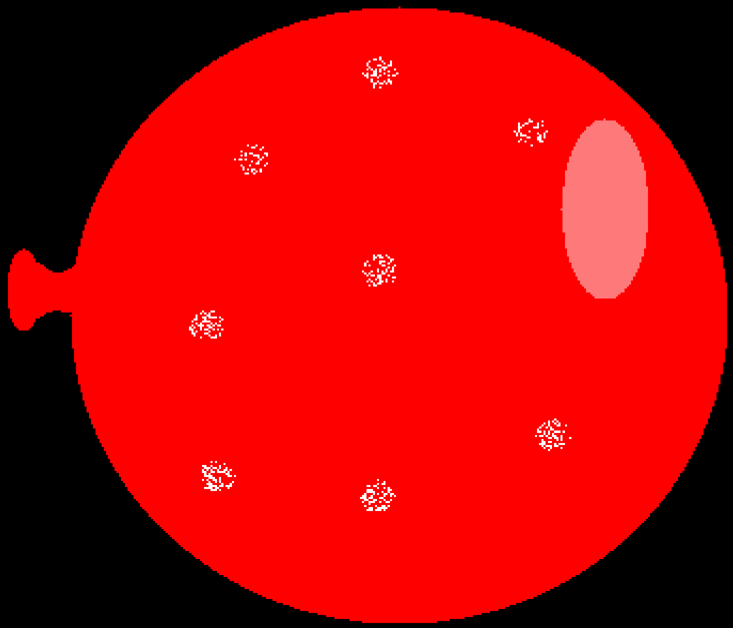


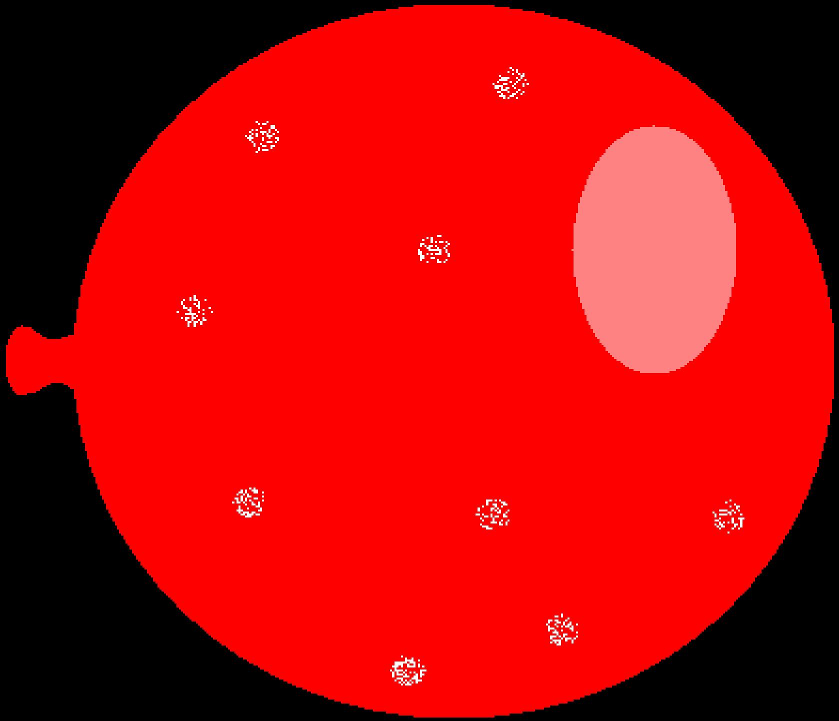


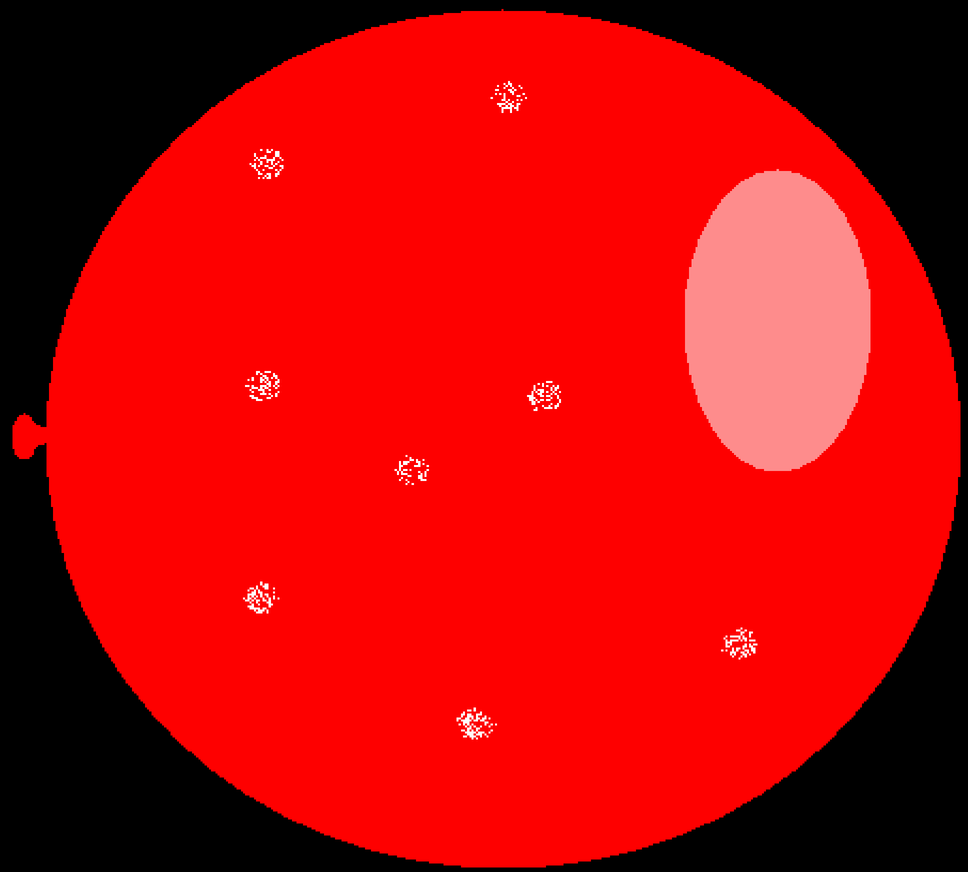


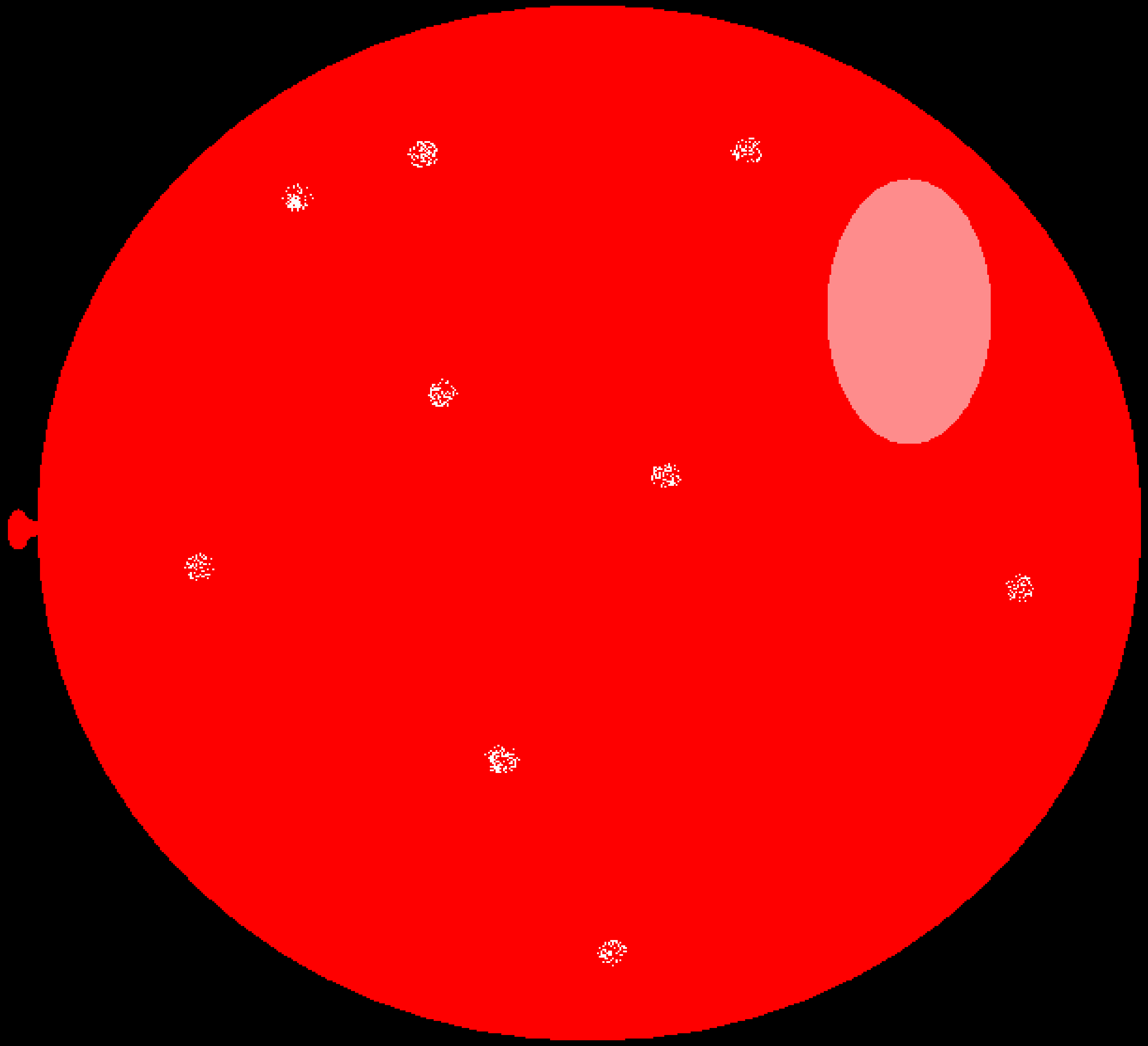


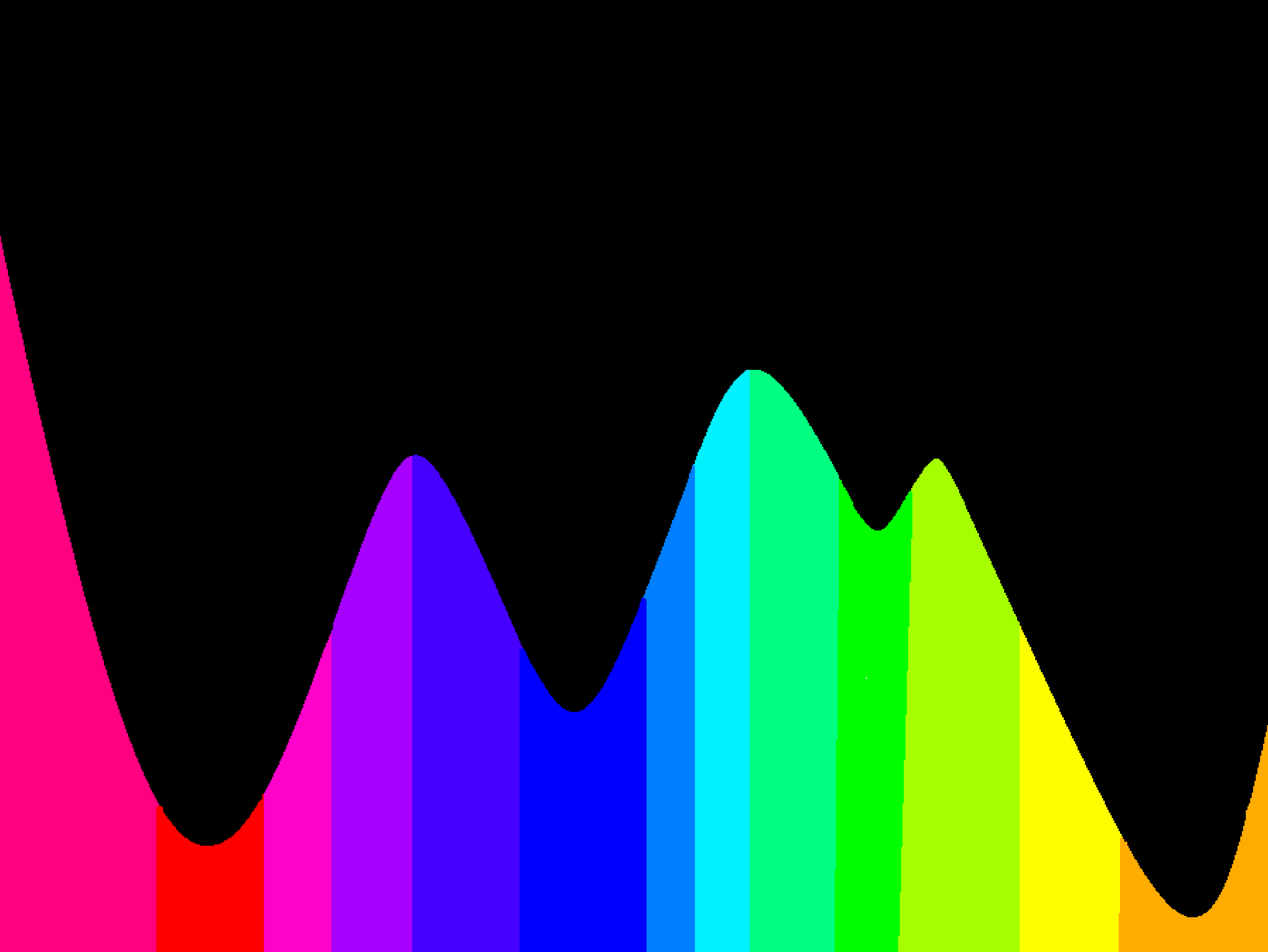


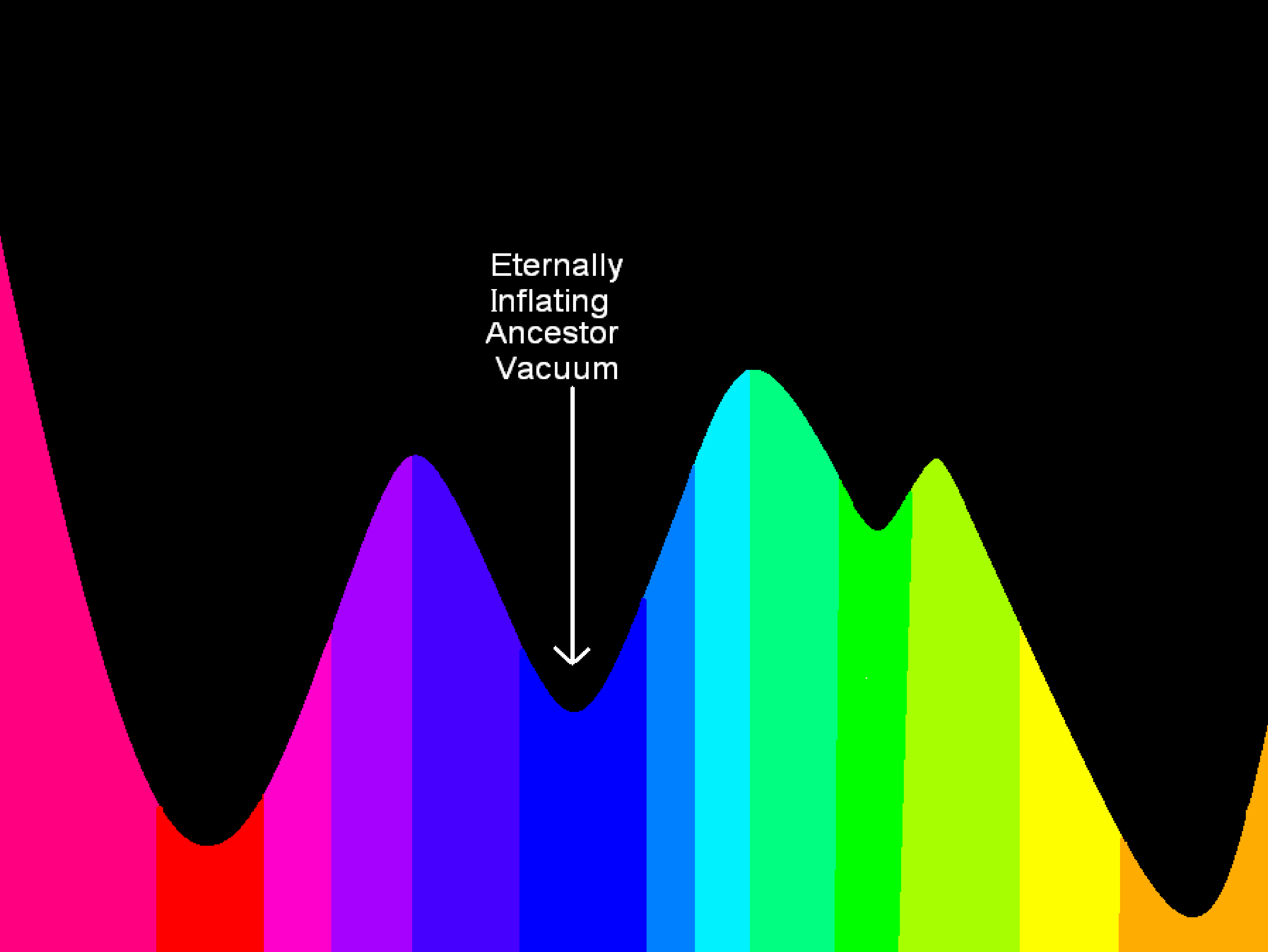


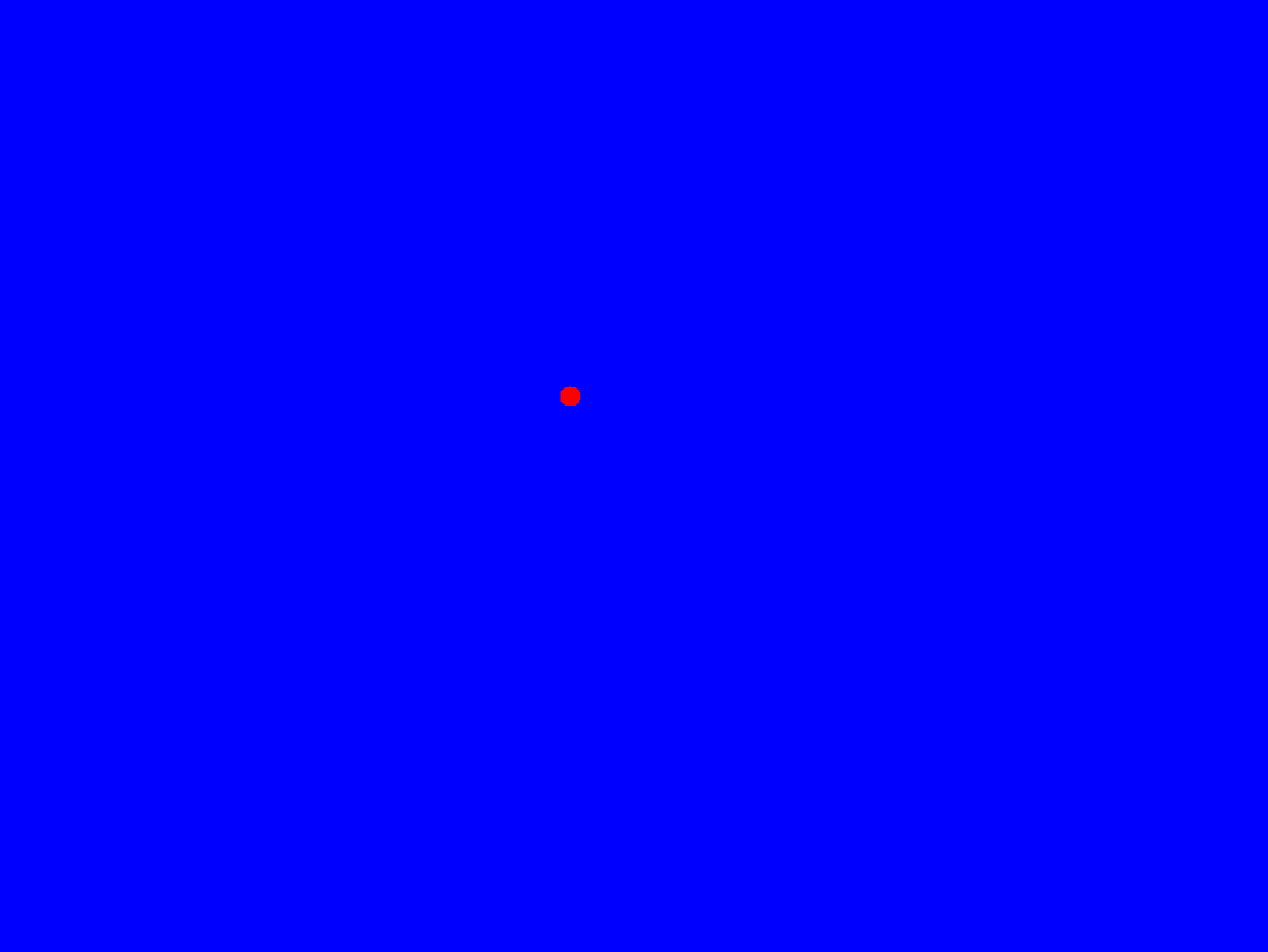


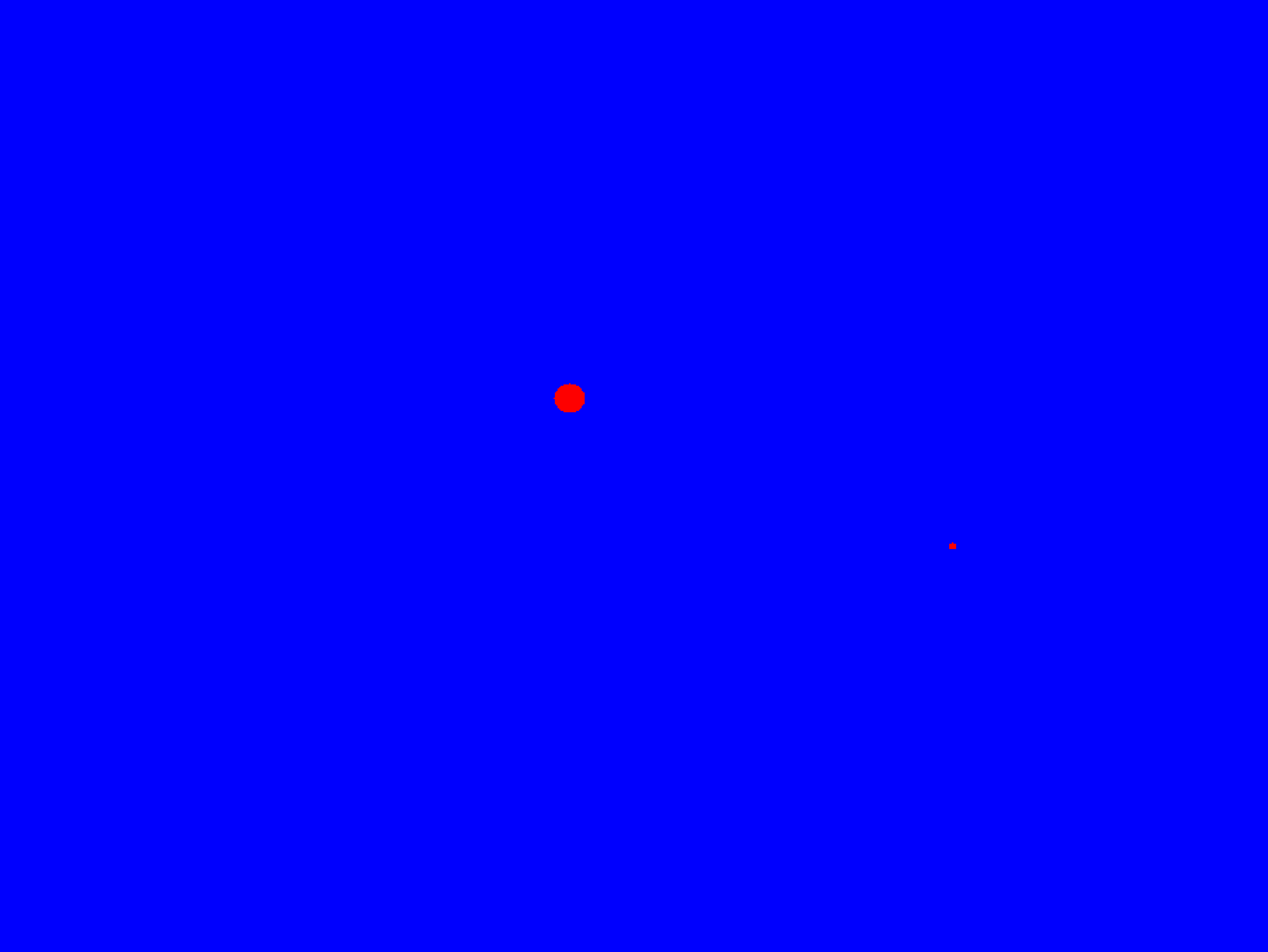


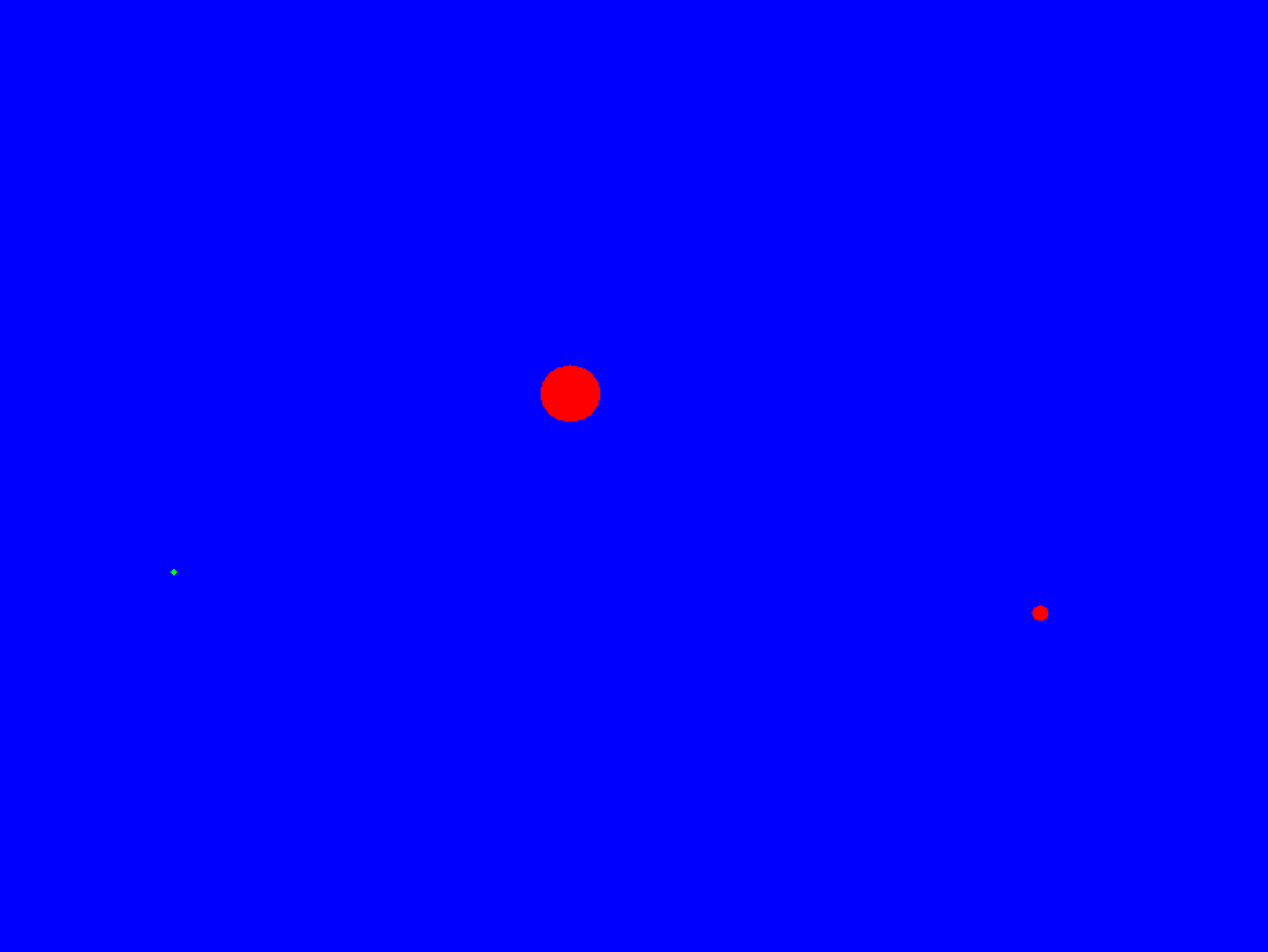


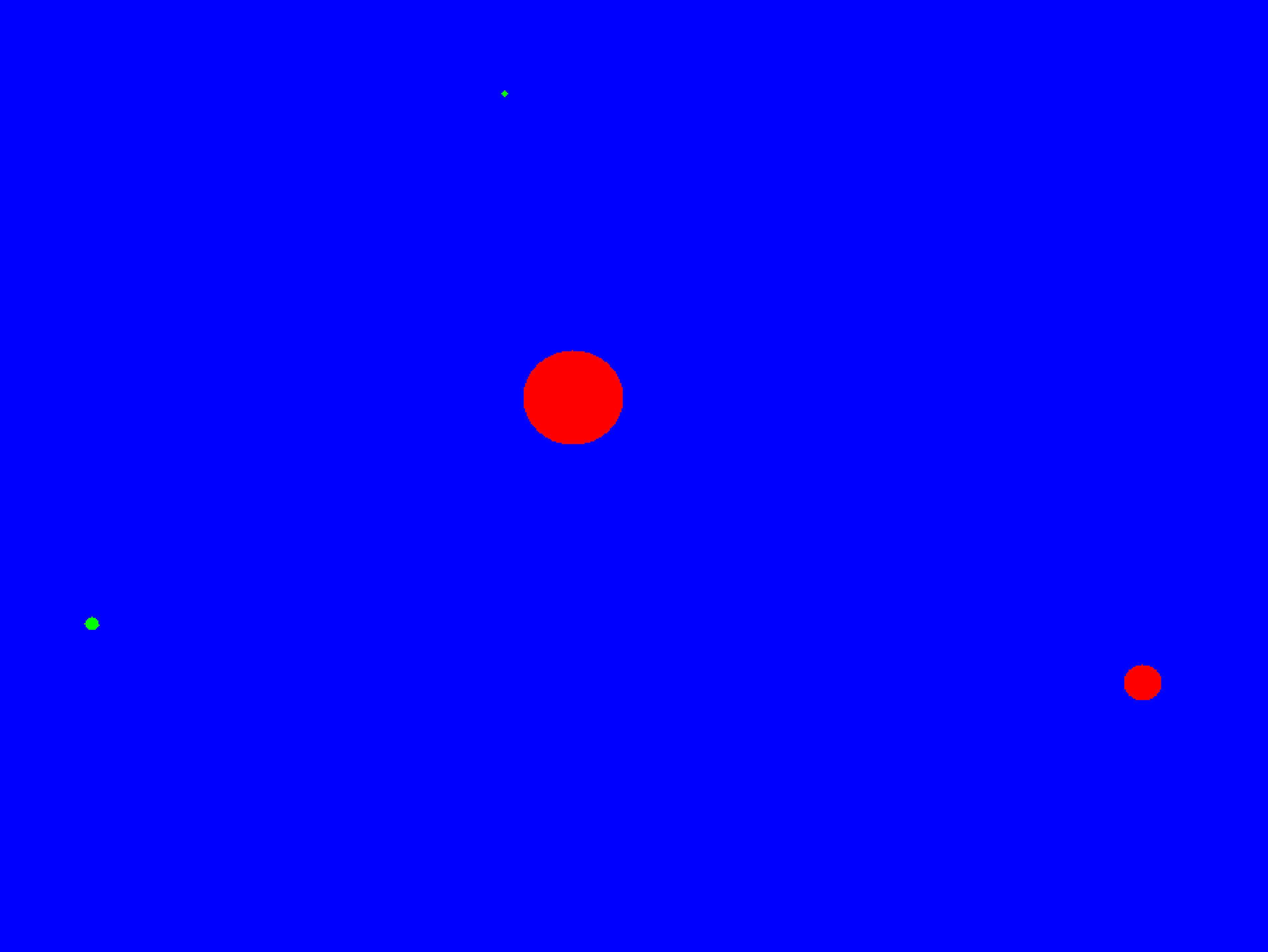


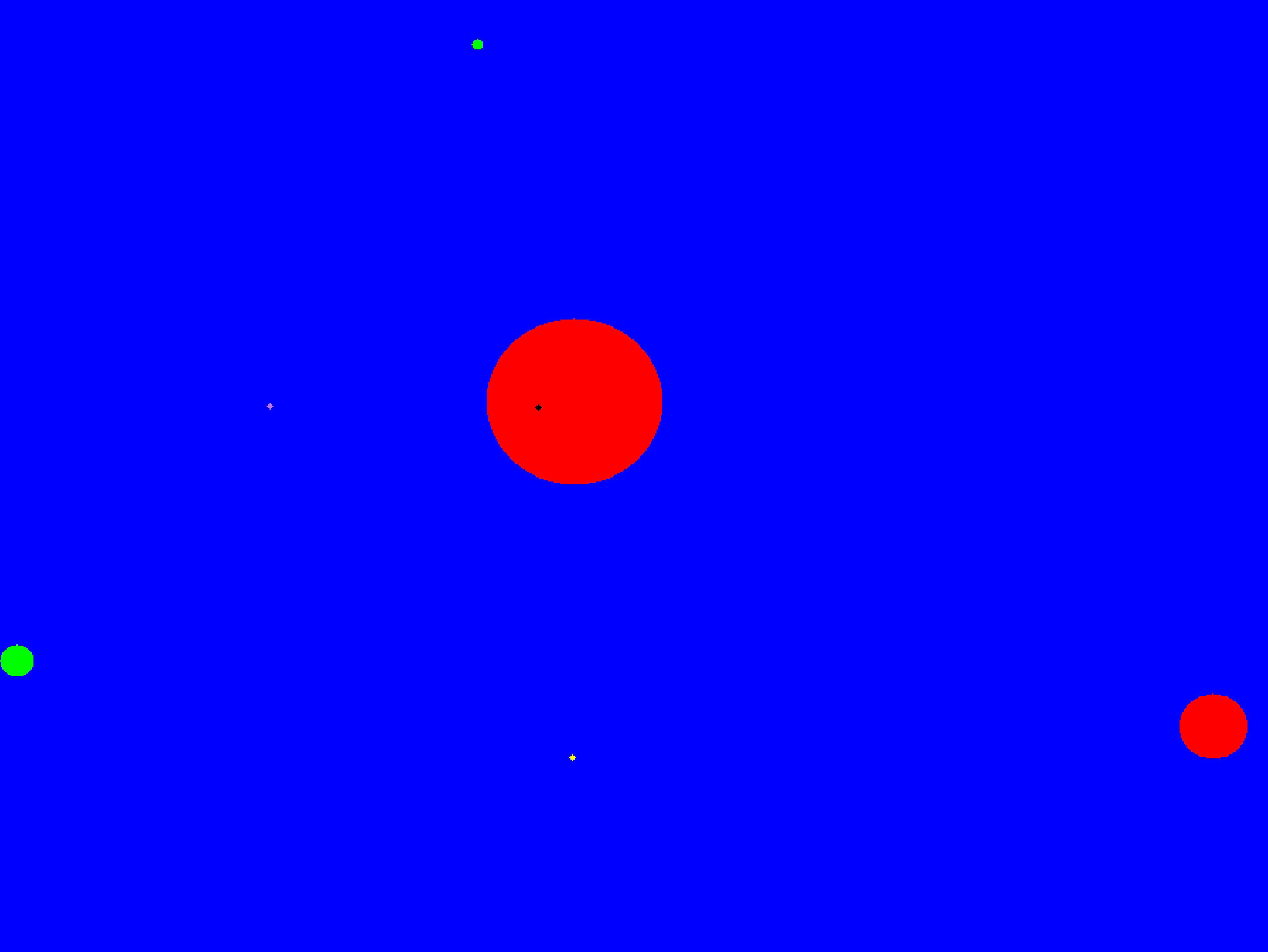

Eternally
Inflating
Ancestor
Vacuum

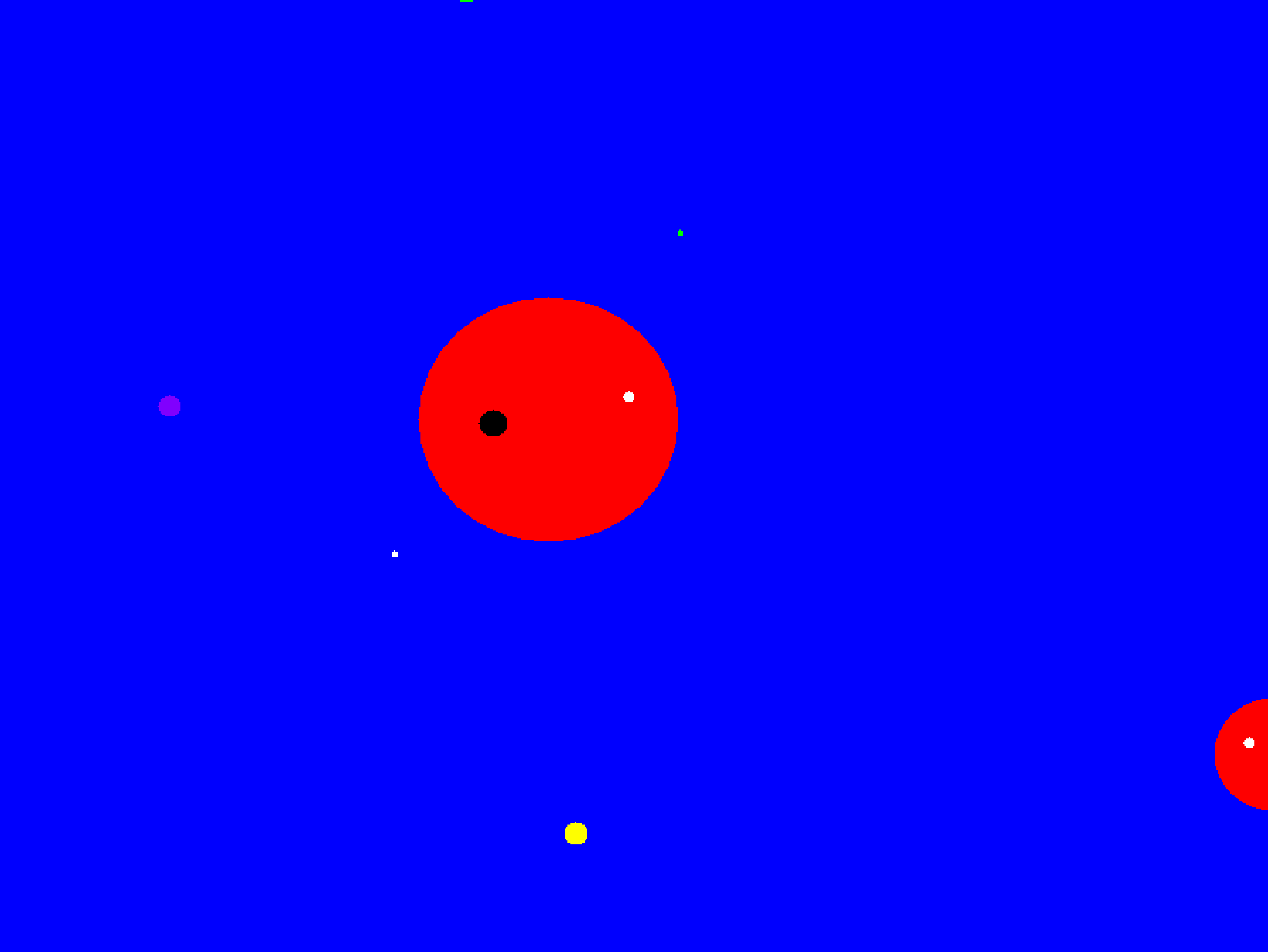


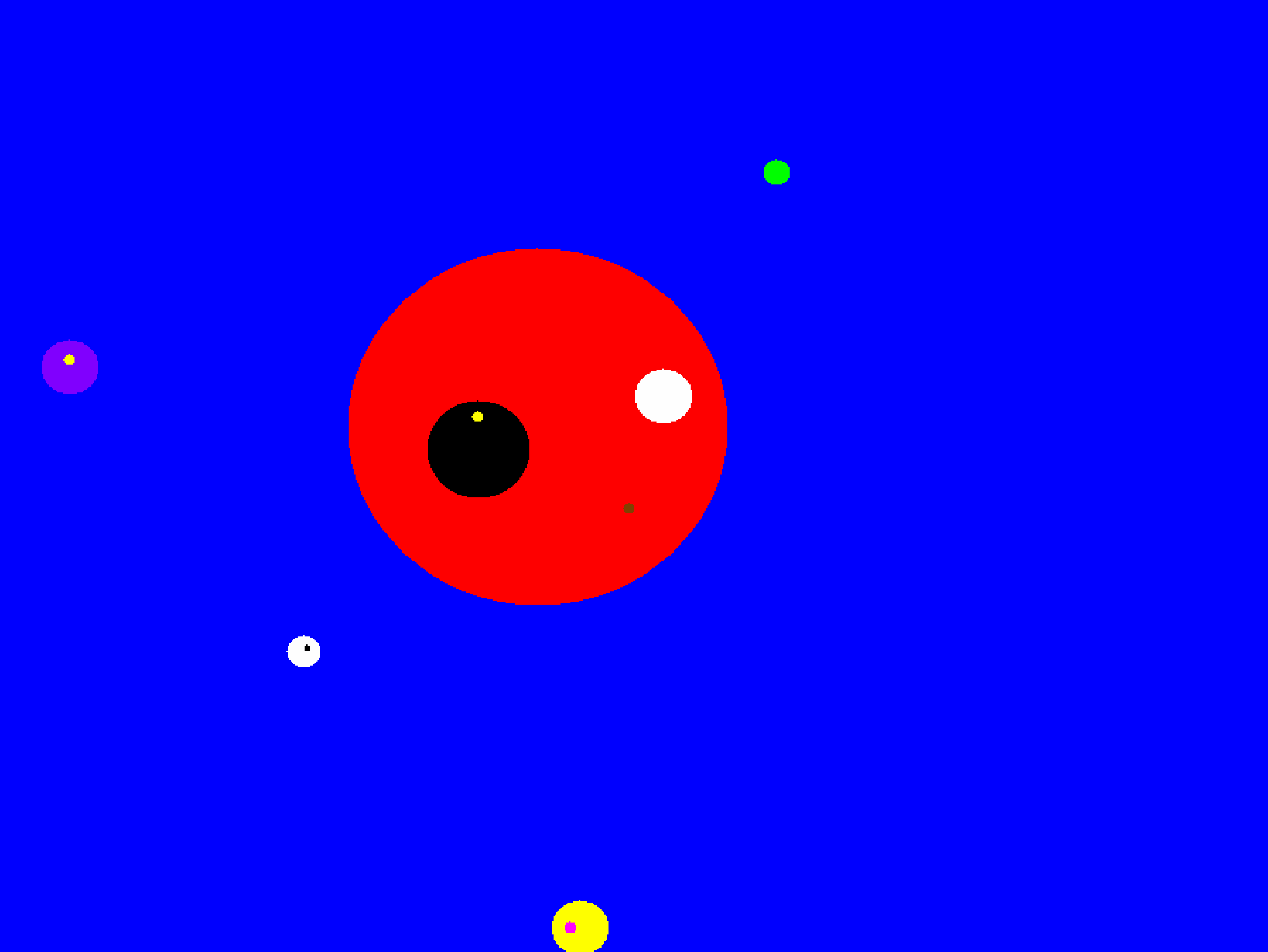


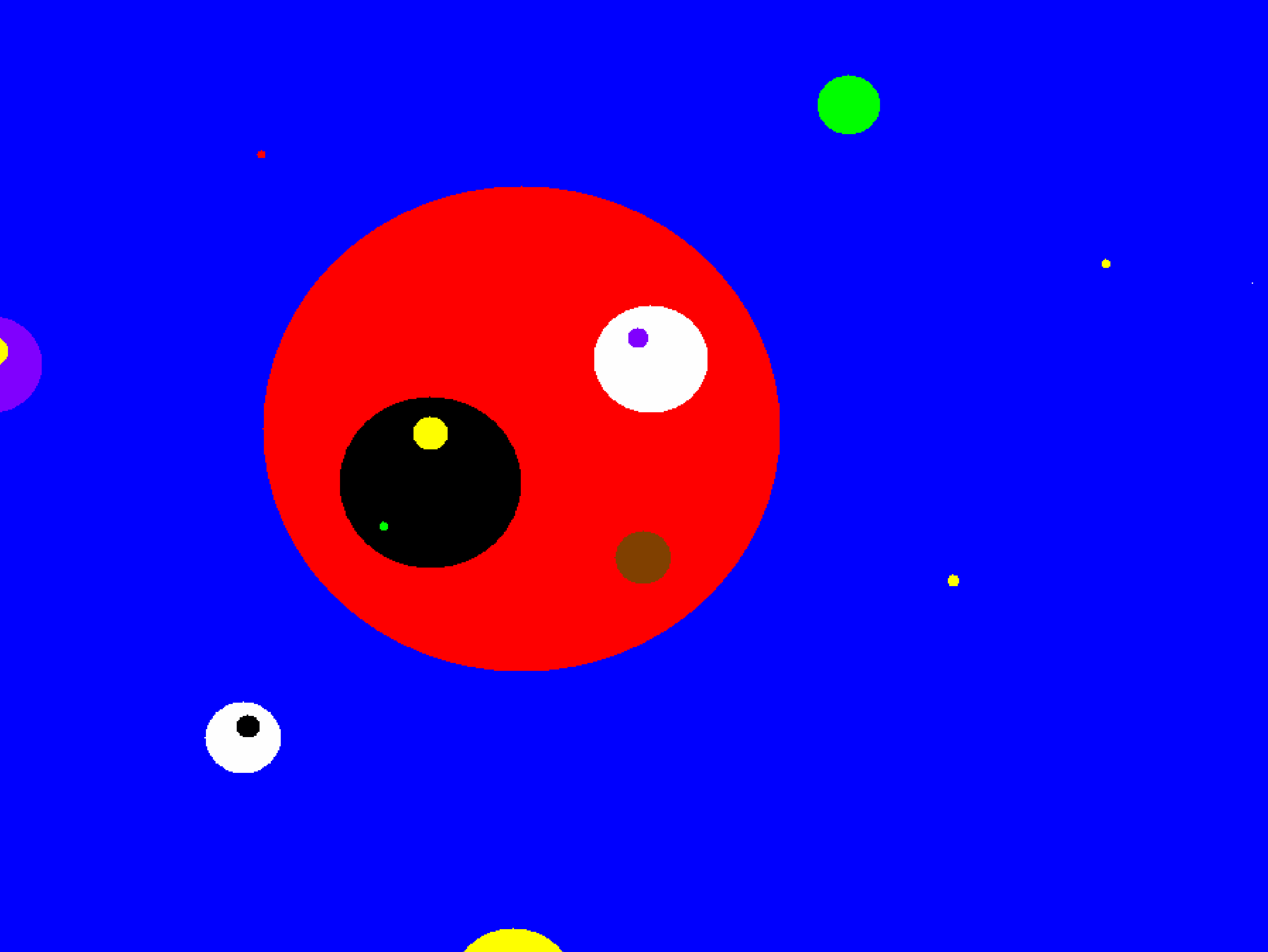


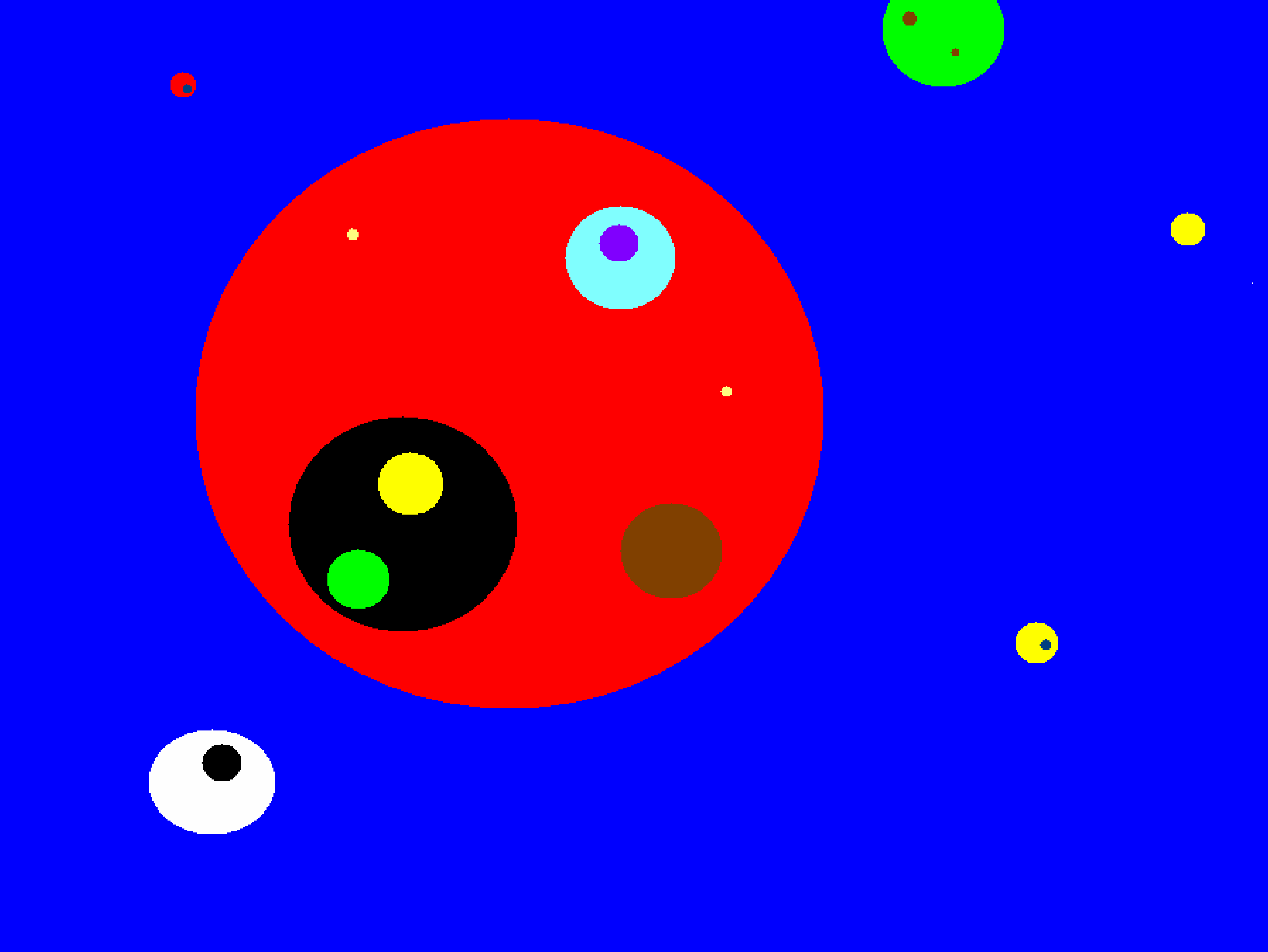













You are
here

A Theoretical Prejudice

"Ordinary" inflation* (Inside the green dot) 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.

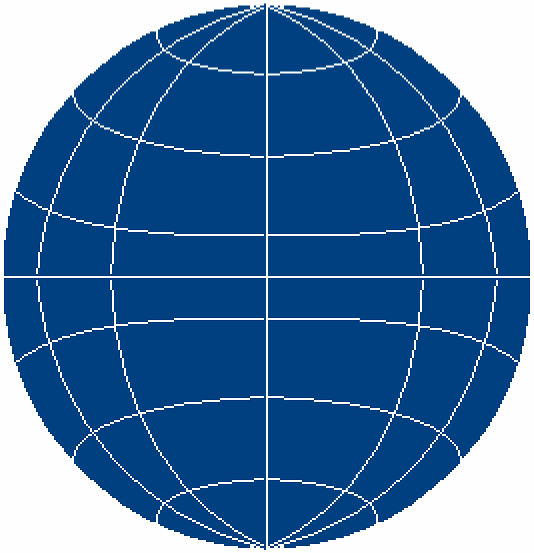
- Just how much ordinary inflation did take place? Did it obliterate all evidence of an earlier epoch?
- Can we look back to when the universe may have nucleated from another point on the Landscape? If so, what will we see?
- Can we see into other bubbles?

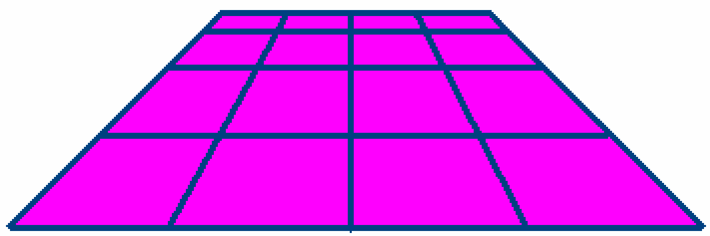
FRW Cosmology

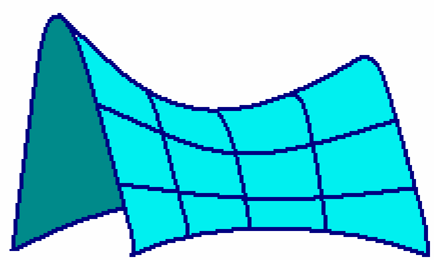
$$ds^2 = -dt^2 + a^2(t)\ \{\ dR^2 + \sin^2 R\ \ (d\theta^2 + \sin^2\theta\ \ d\varphi^2\ )\ \}$$

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

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

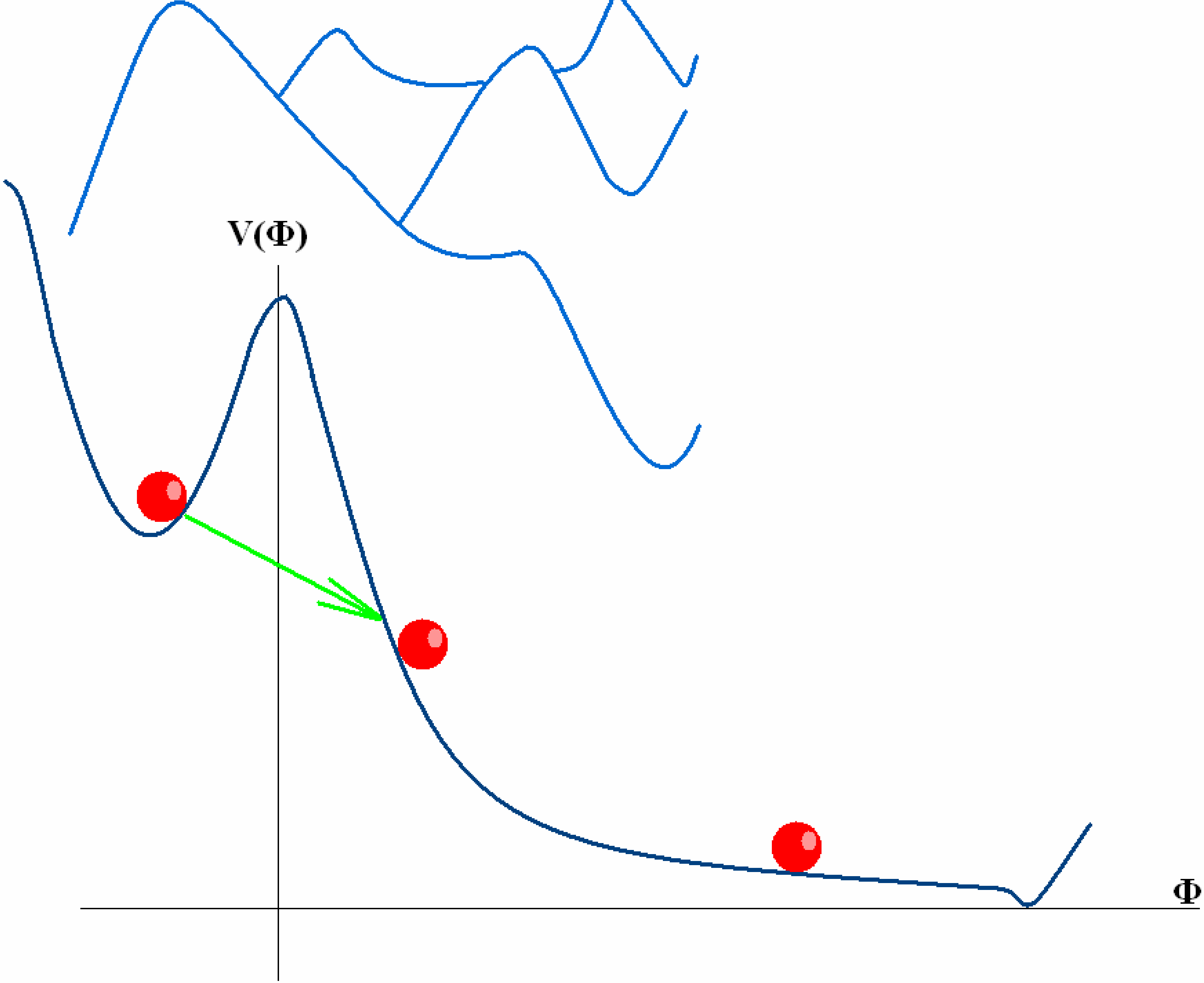


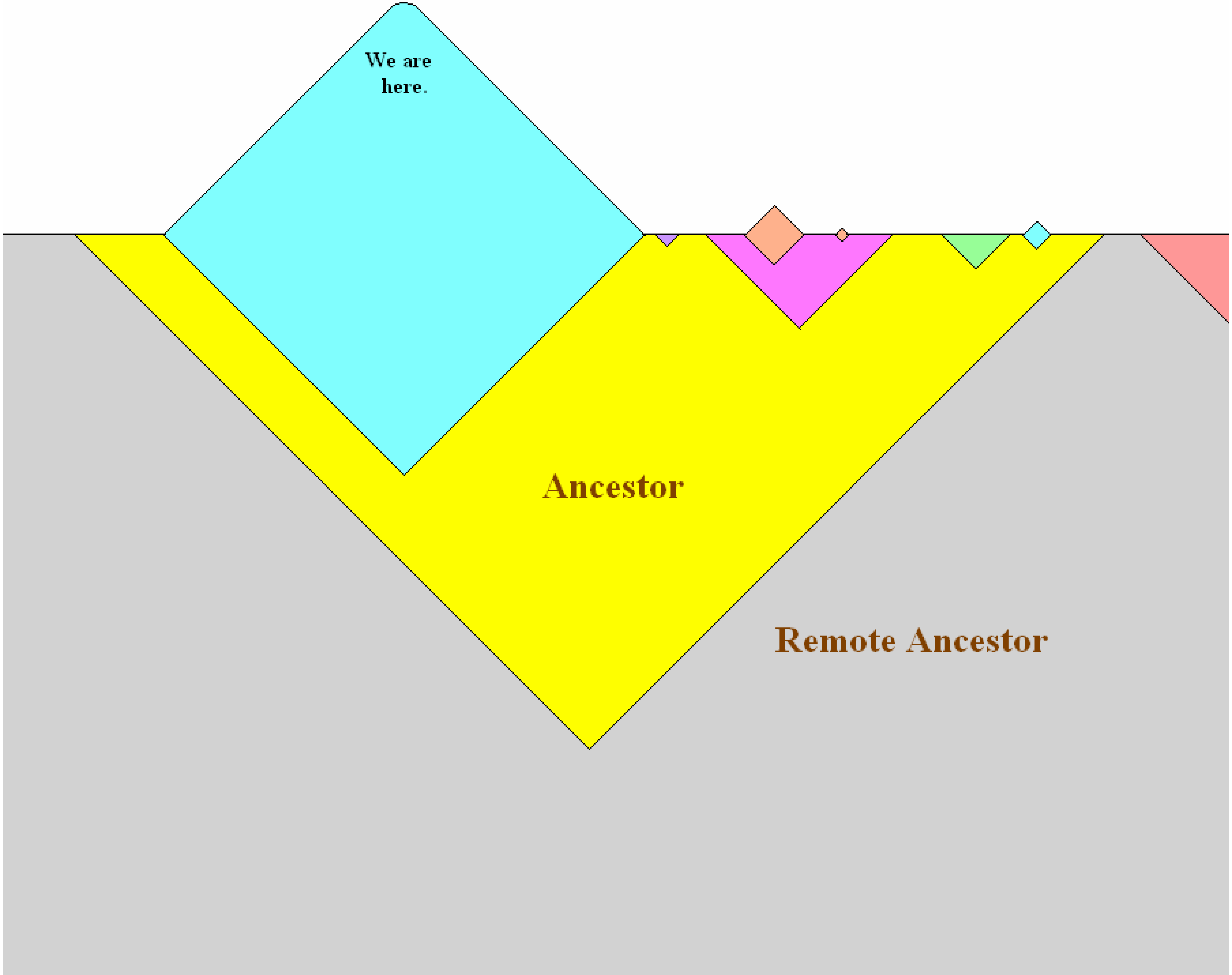




Data is inconclusive

- Inflation flattens. Best fit: Curvature slightly negative—radius of curvature ~ 10 horizon lengths. However, zero curvature is within 1-sigma error bars.
- Lowest ℓ primordial fluctuations anomalous? Maybe.

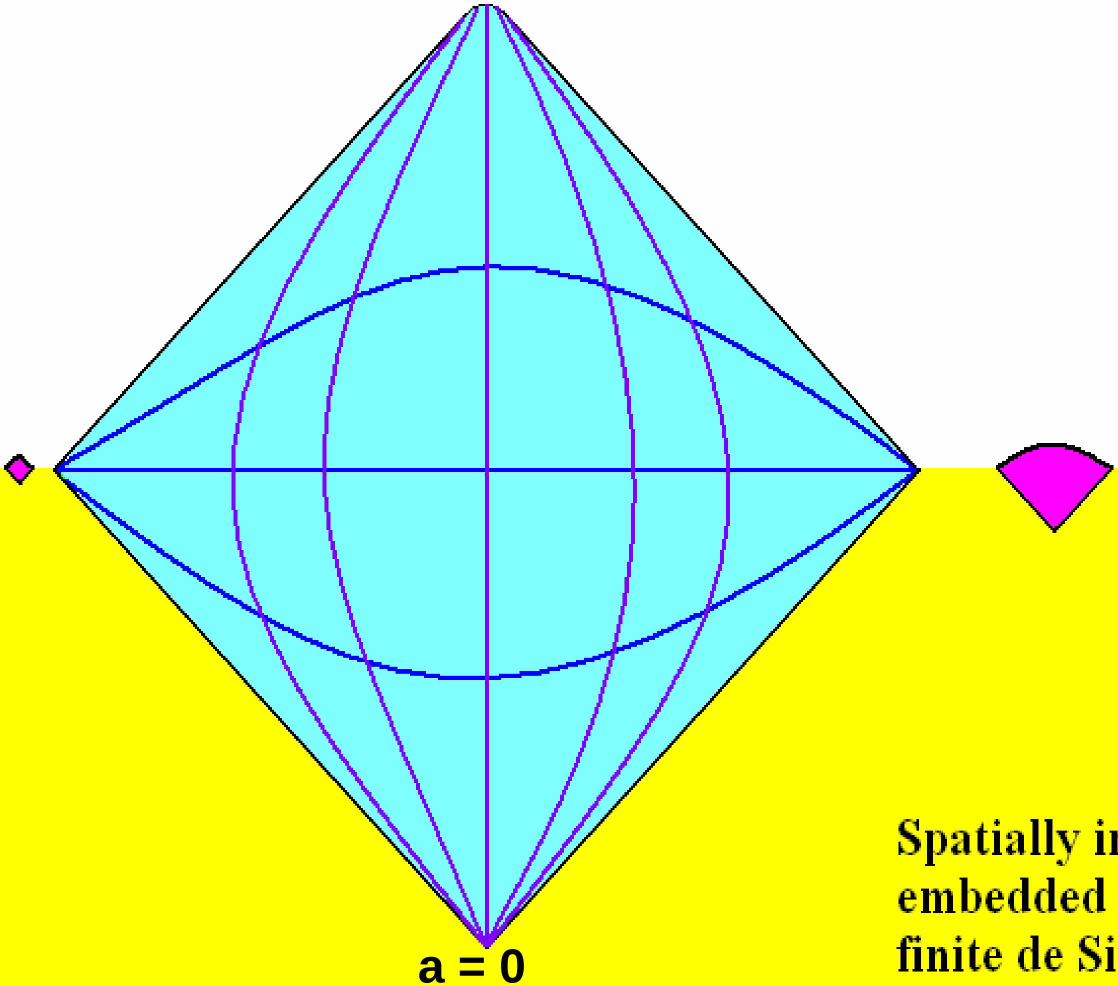

V(Φ)
Φ


We are here.
Ancestor
Remote Ancestor

$\mathbf{t} = \infty$

Metric diverges as $t \longrightarrow \infty$

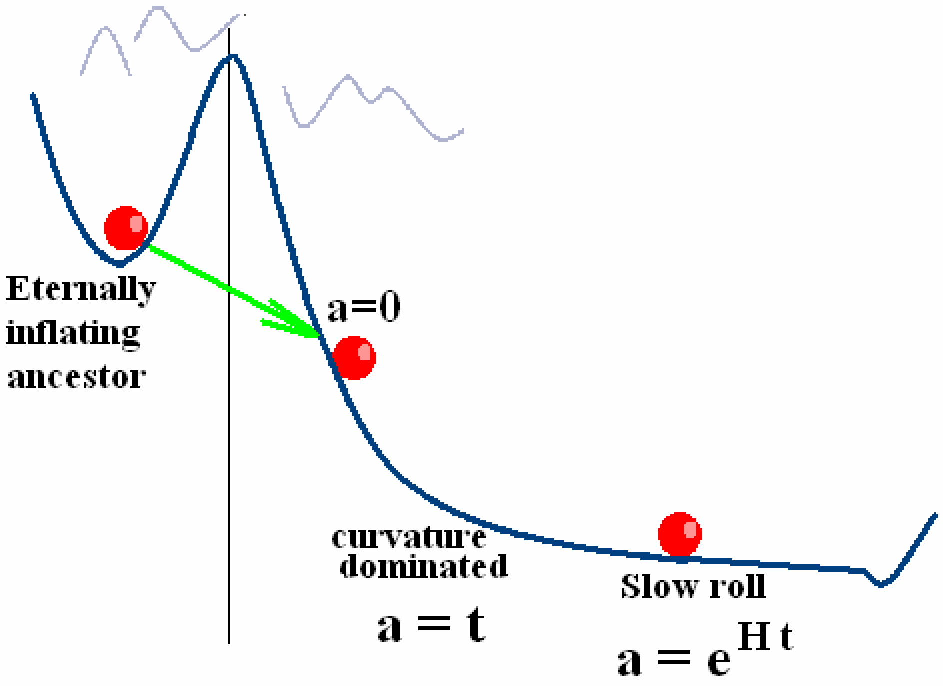
Ancestor

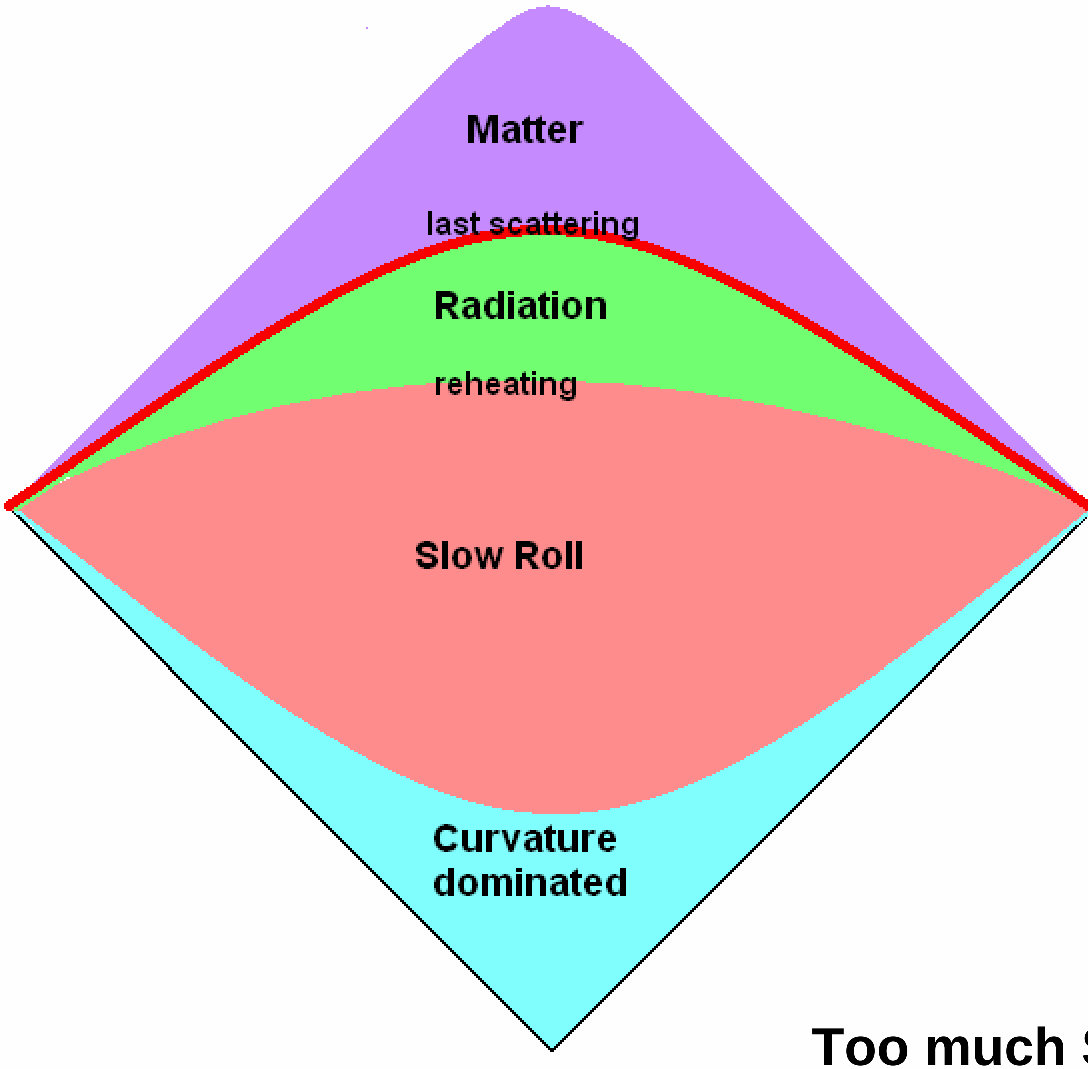


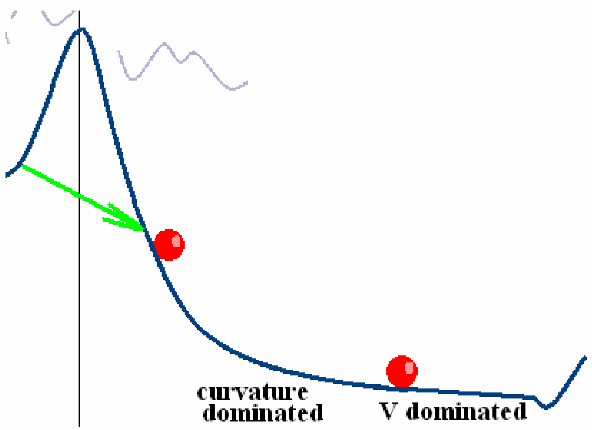
Spatially infinite FRW
embedded in a spatially
finite de Sitter universe.

<u>Negatively curved</u>

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



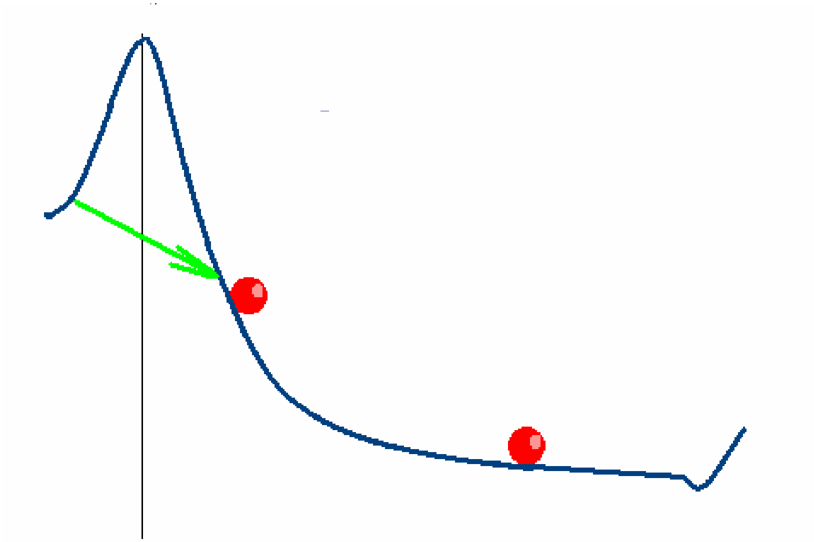




Too much Slow Roll inflation would obliterate everything that came before.

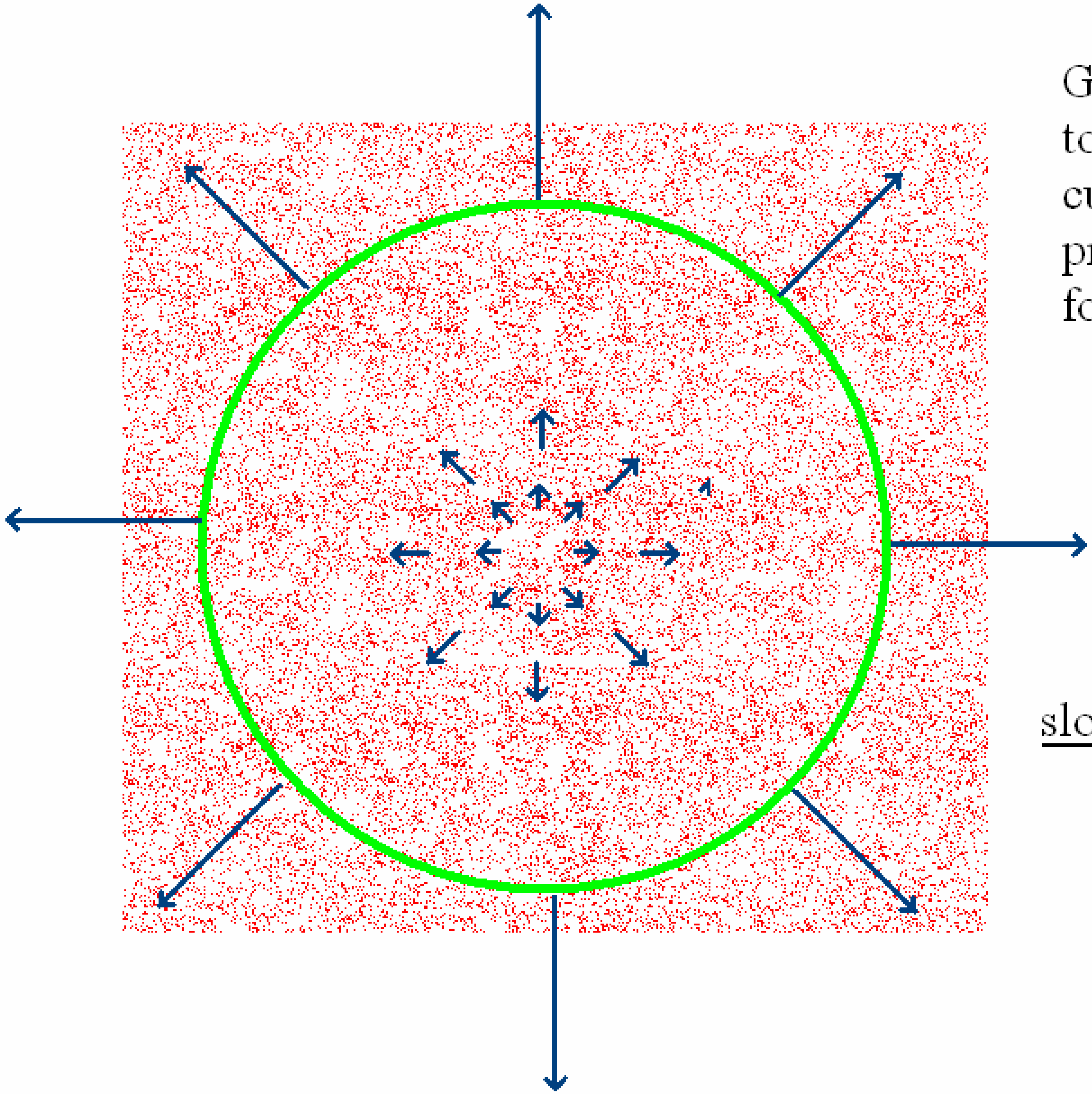
Why did slow roll inflation happen?

- 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
<u>slow roll Inflation</u>

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

At decoupling

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

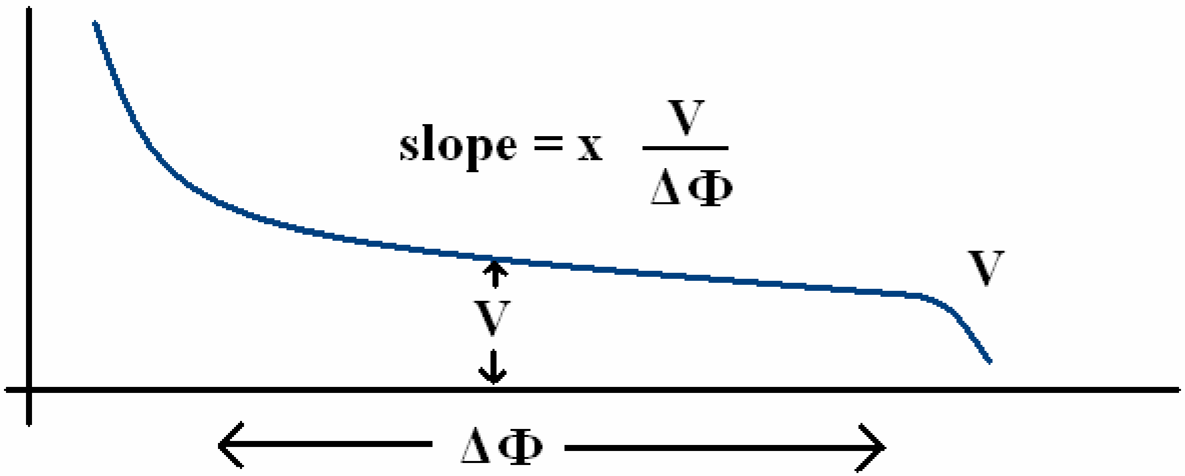
B. Freivogel,
M. Kleban,
M. Rodriguez Martinez,
L.S.

Or in terms of e-foldings

$$N_{observation} > 50$$

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

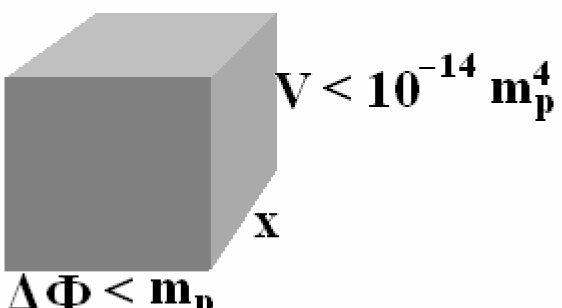
A very simplified model of Landscape Statistics

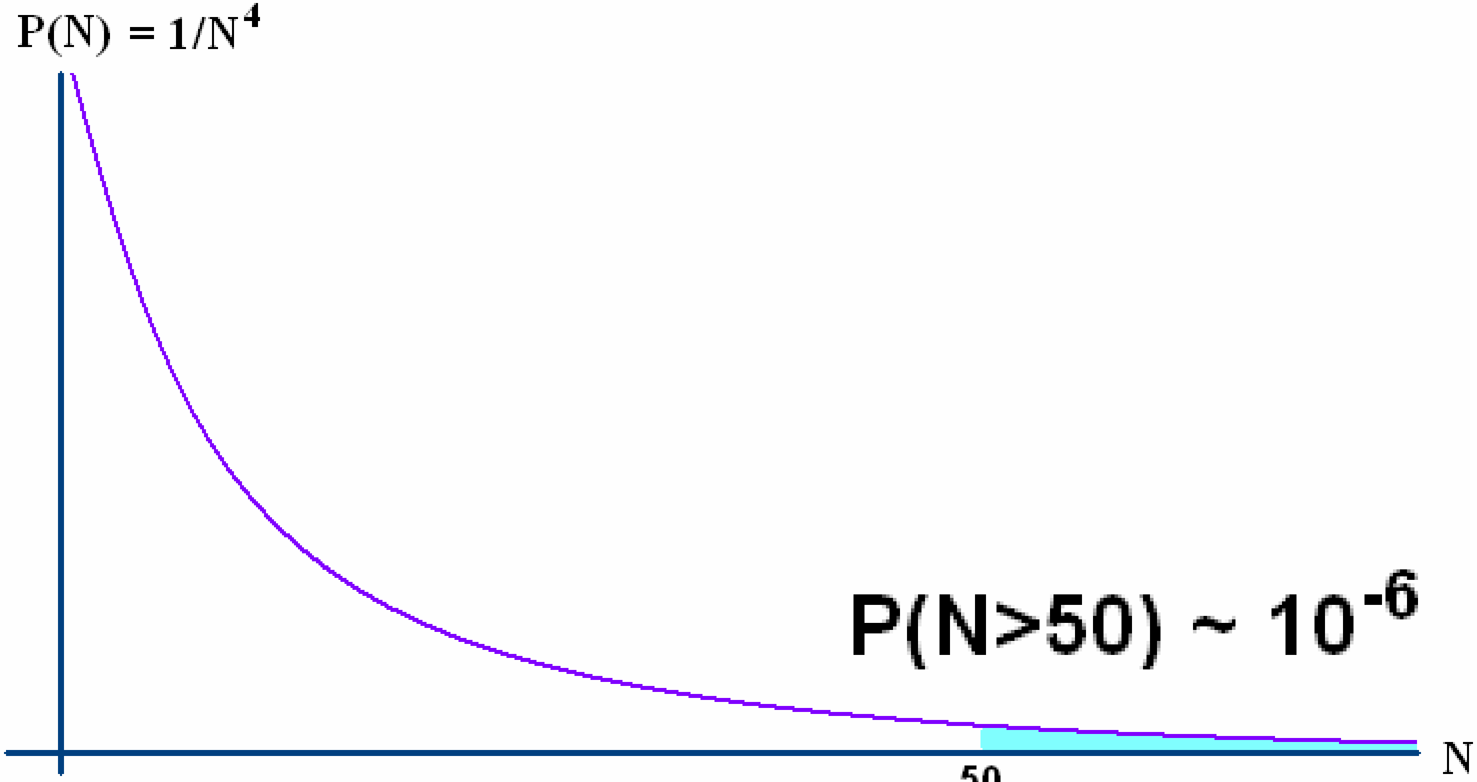


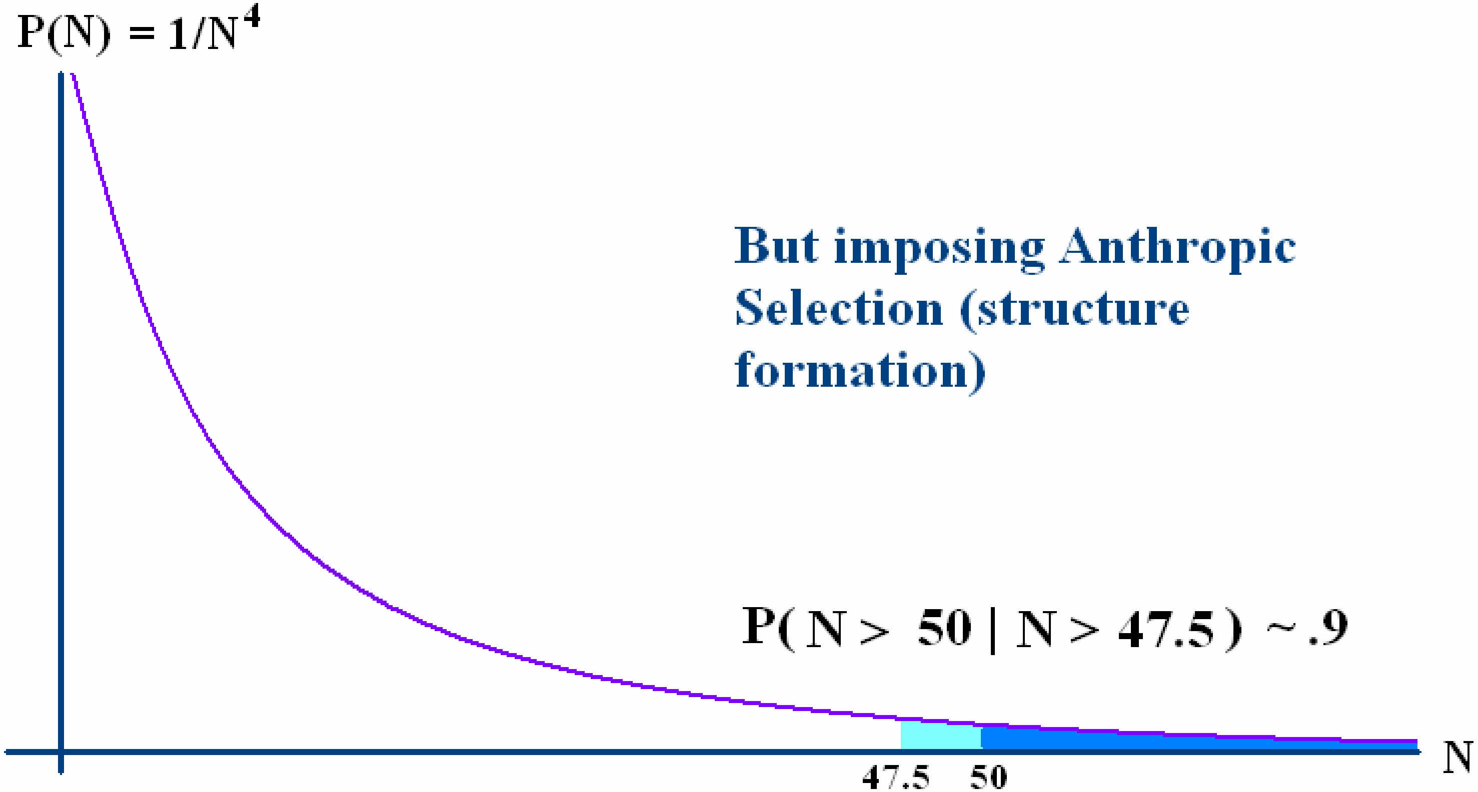
$$N = \int H\, dt \simeq \frac{\Delta^2}{x}$$

$$\frac{\delta\rho}{\rho} = \frac{H\,\Delta}{x} \sim 10^{-5}$$

Pick a point at random.

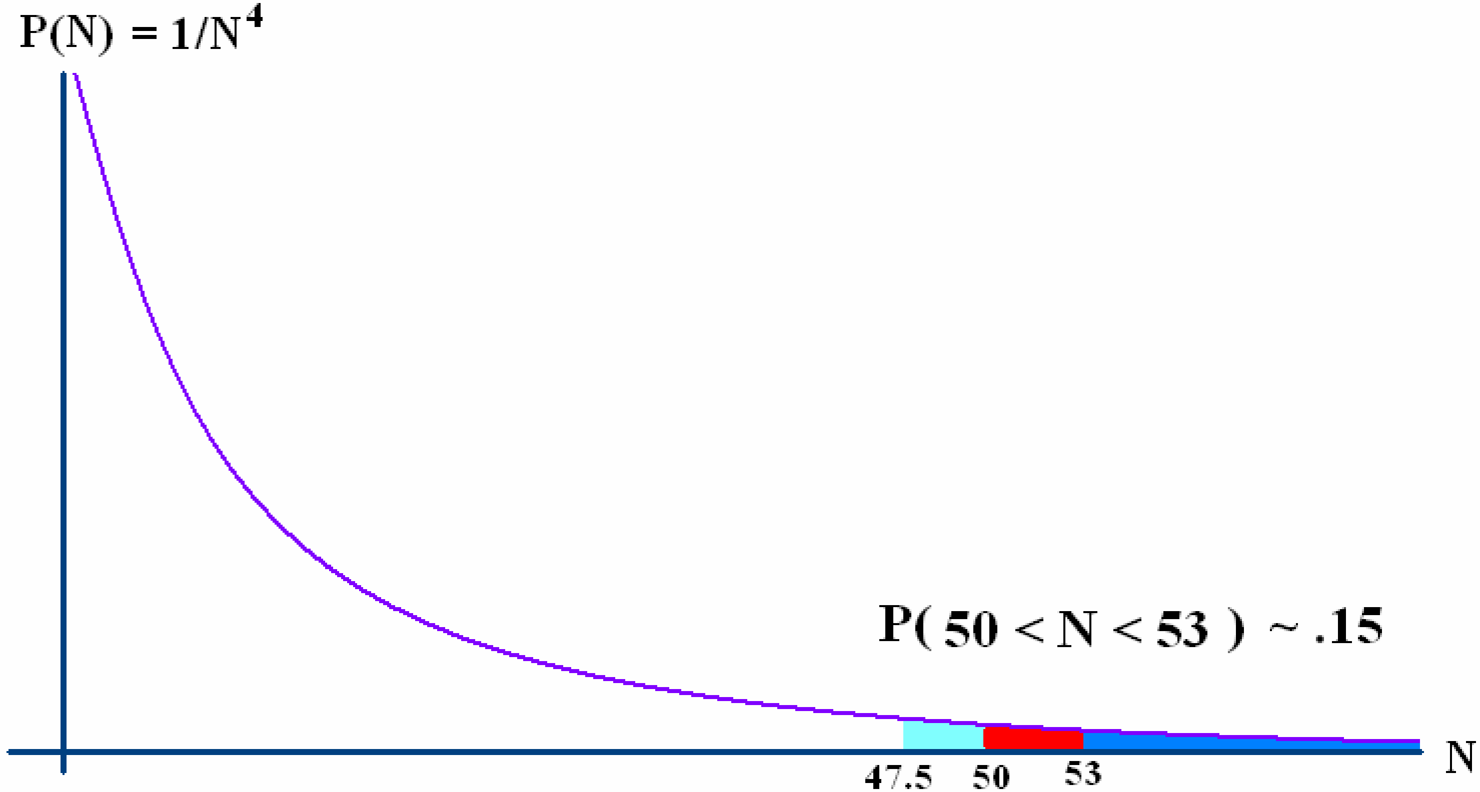



P(N) = 1/N^4
P(N>50) ~ 10^-6
50
N



This is the only known explanation for inflation.

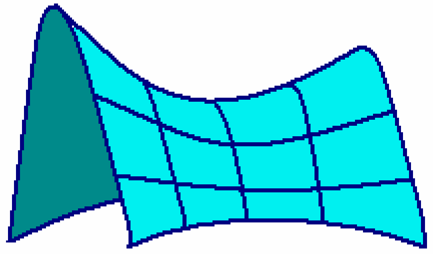
Note: $P(N > 100 \mid N > 50) \sim .1$

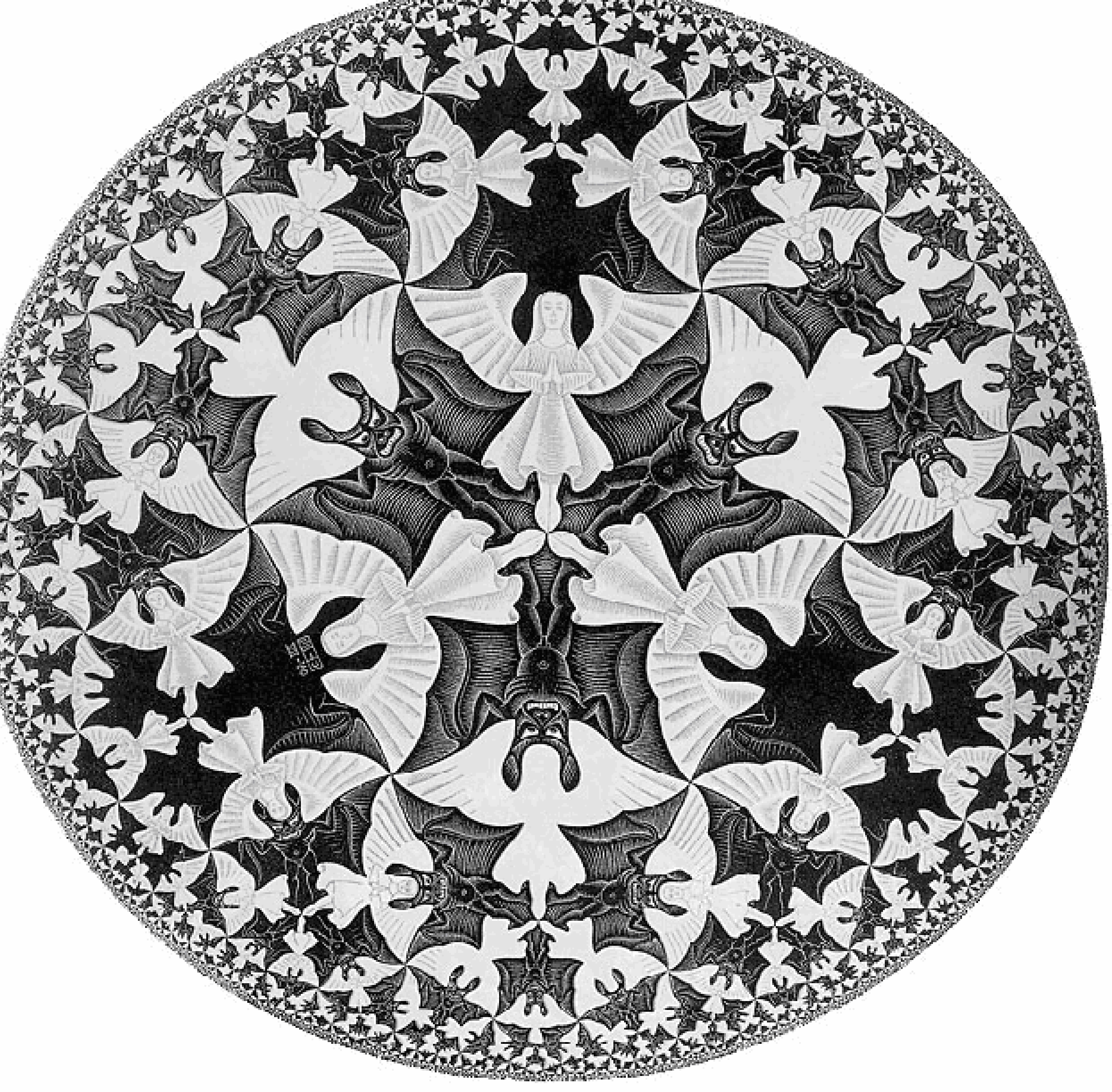


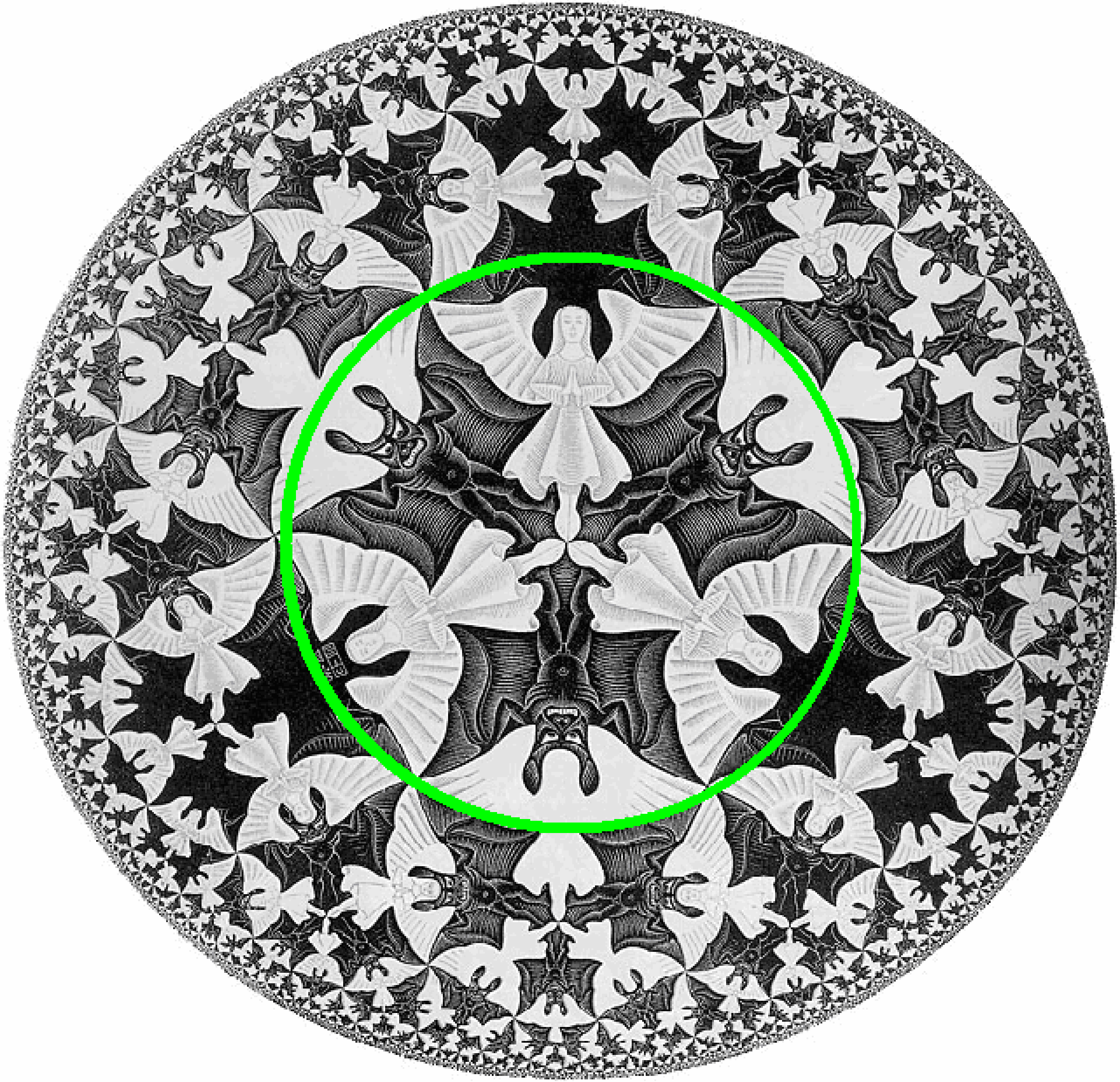
P(N) = 1/N^4
P(50 < N < 53) ~ .15
47.5
50
53
N

Fossil # 1

Negative Curvature

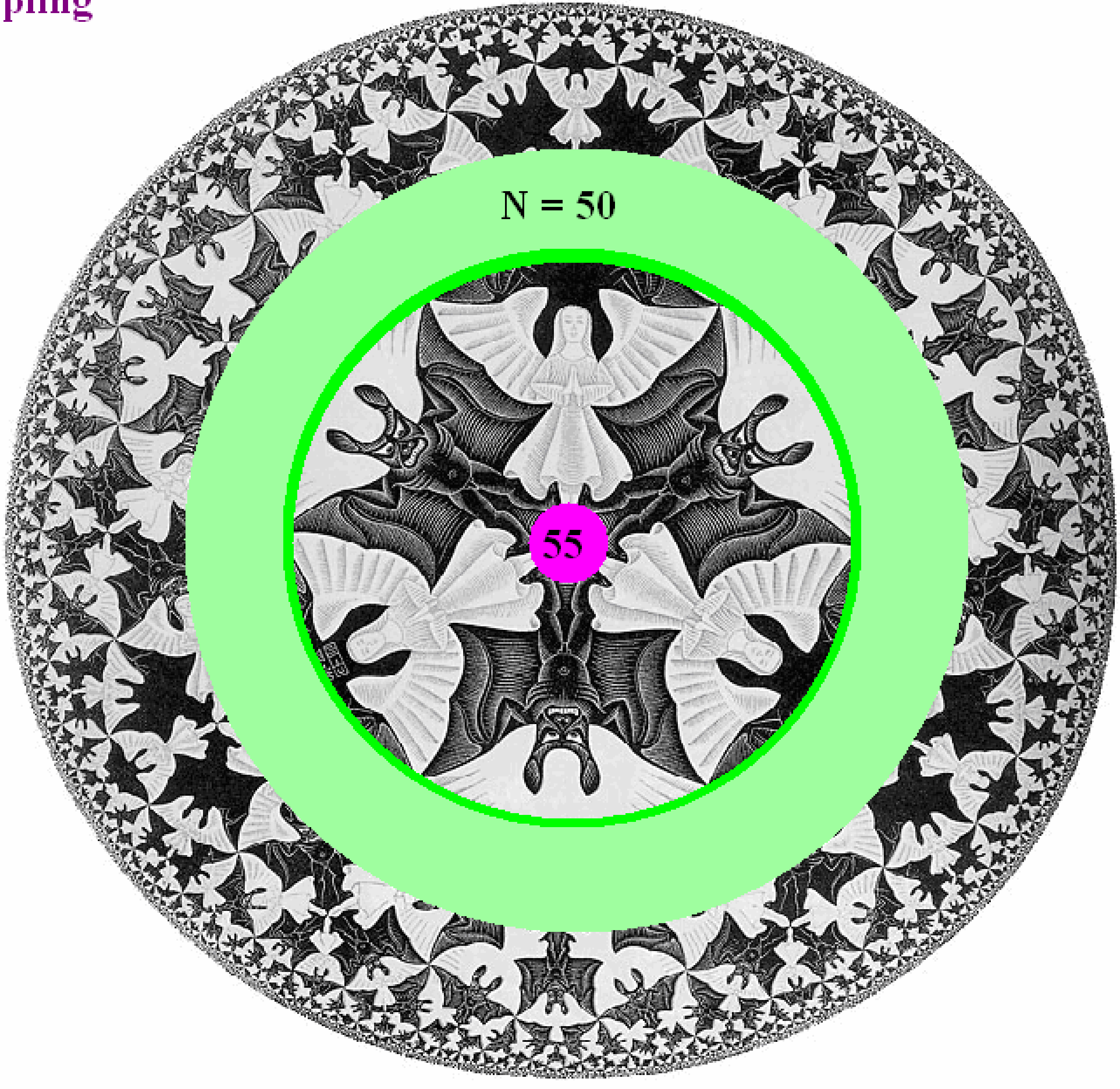


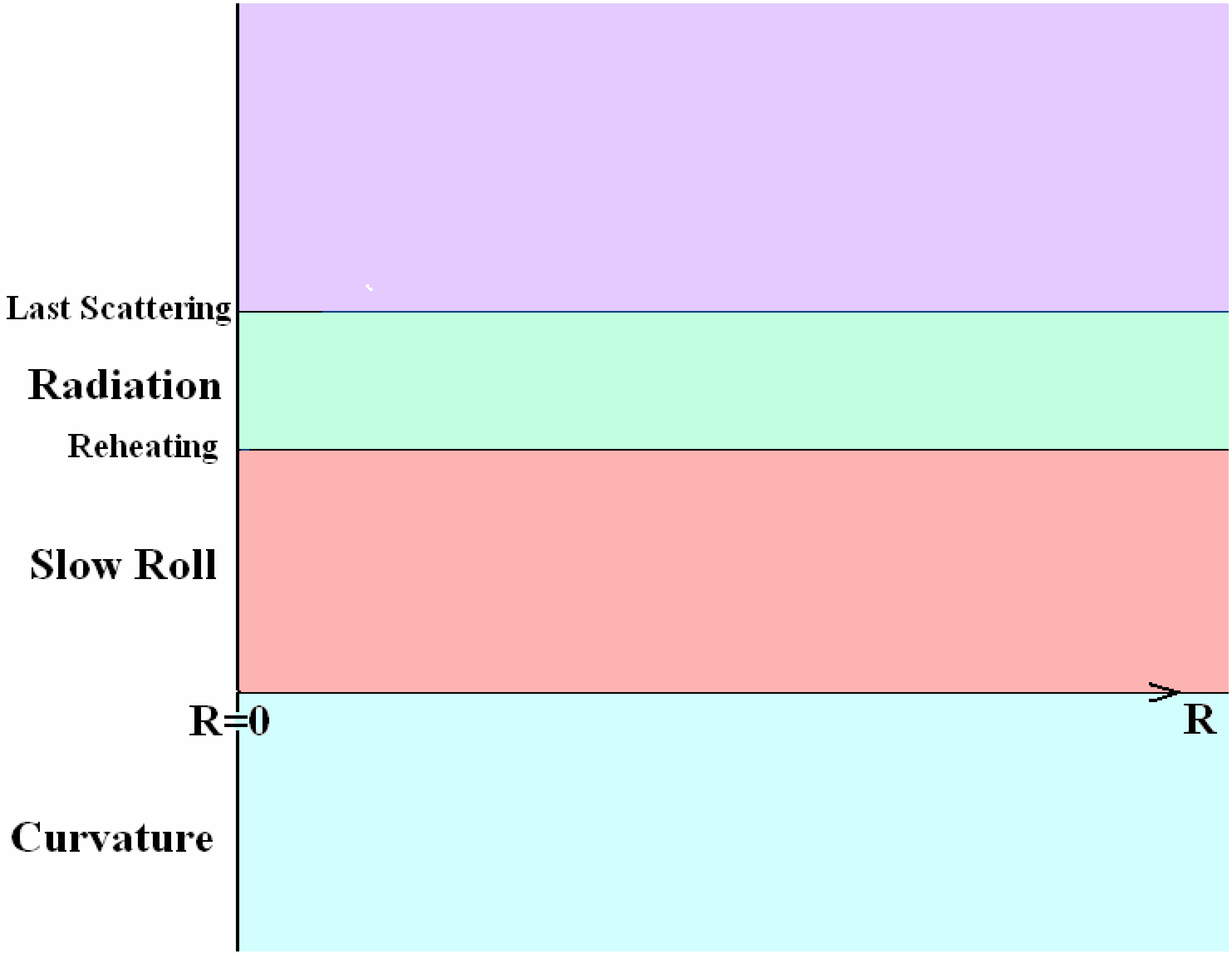




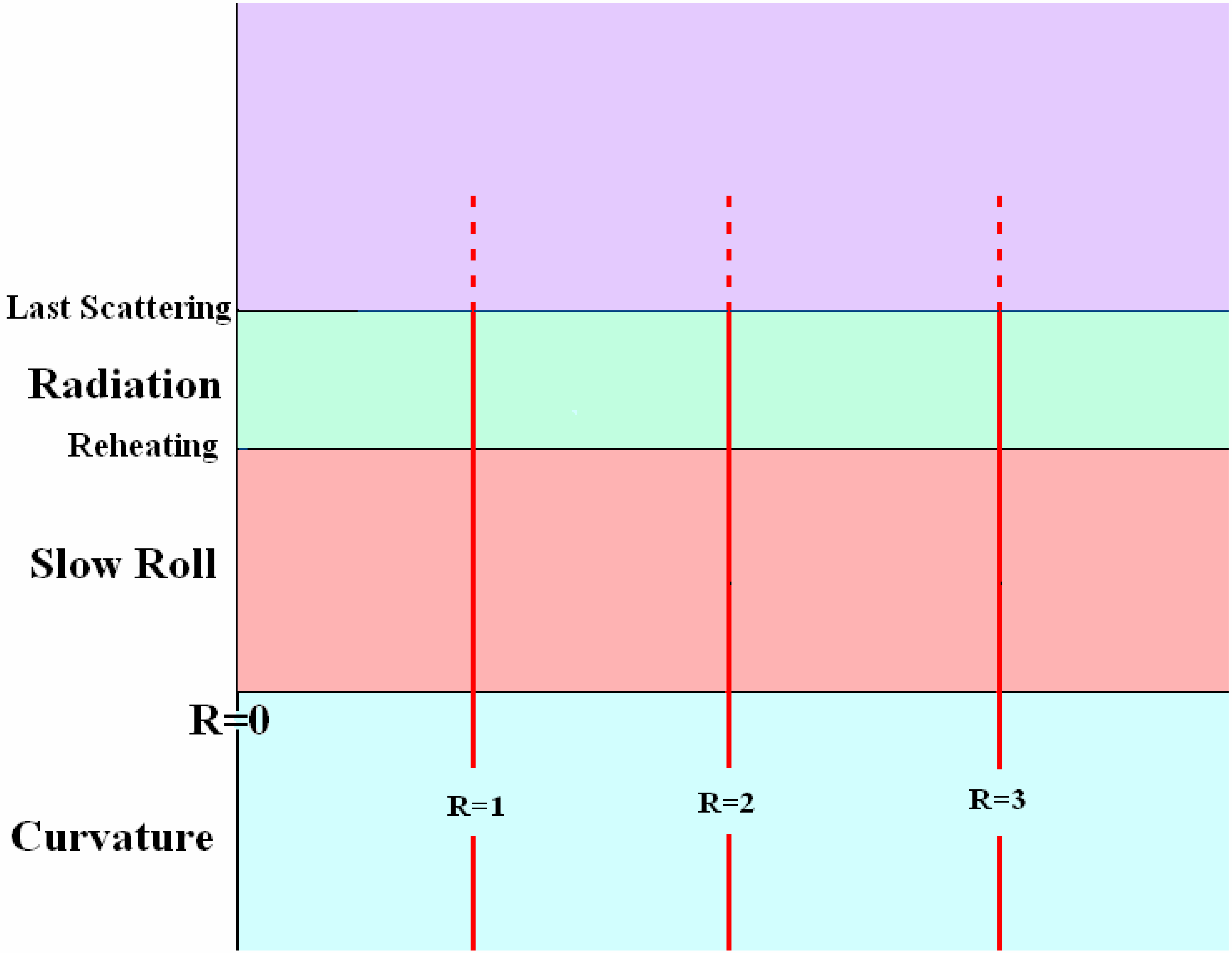
R = 1

Looking back
to Decoupling

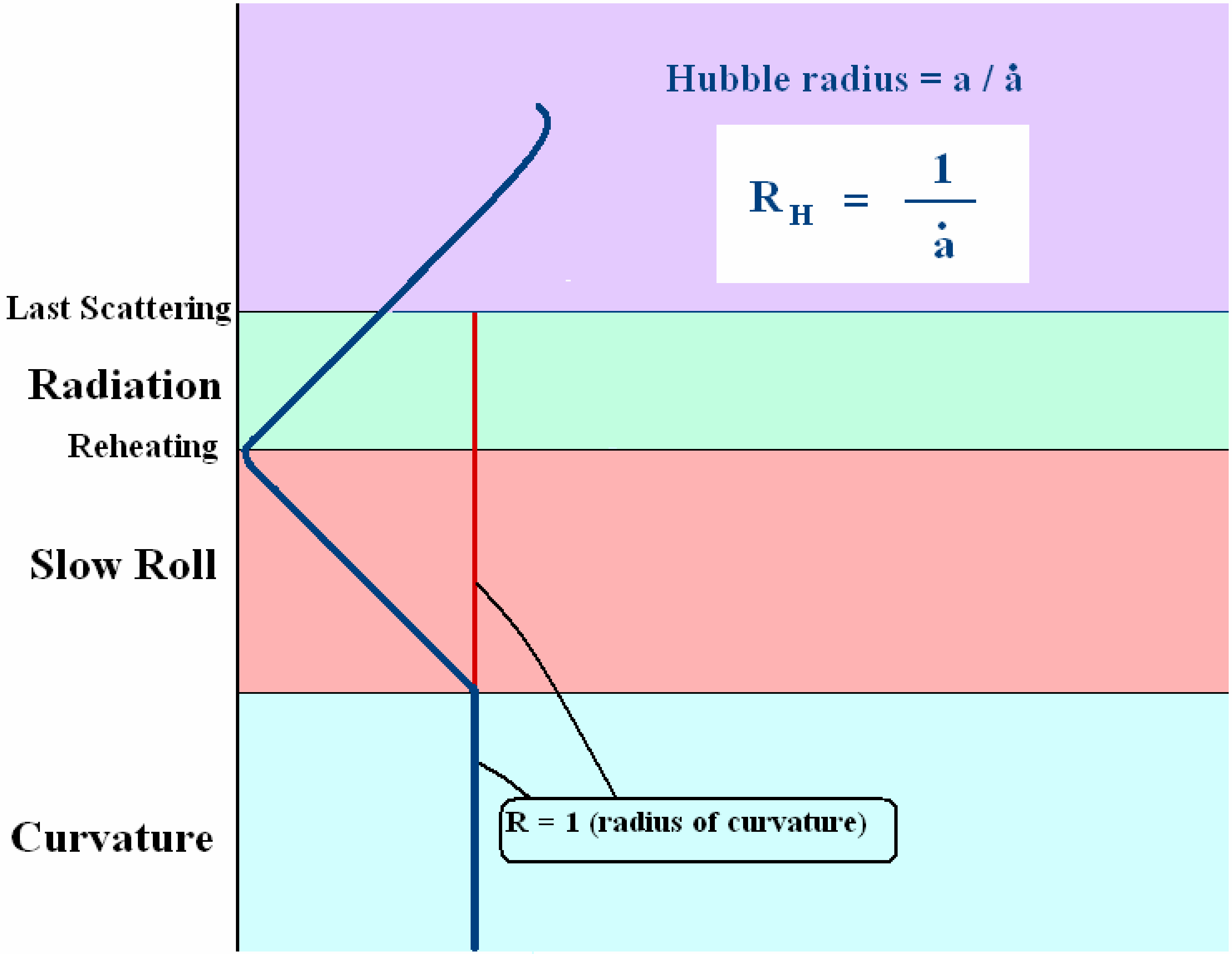




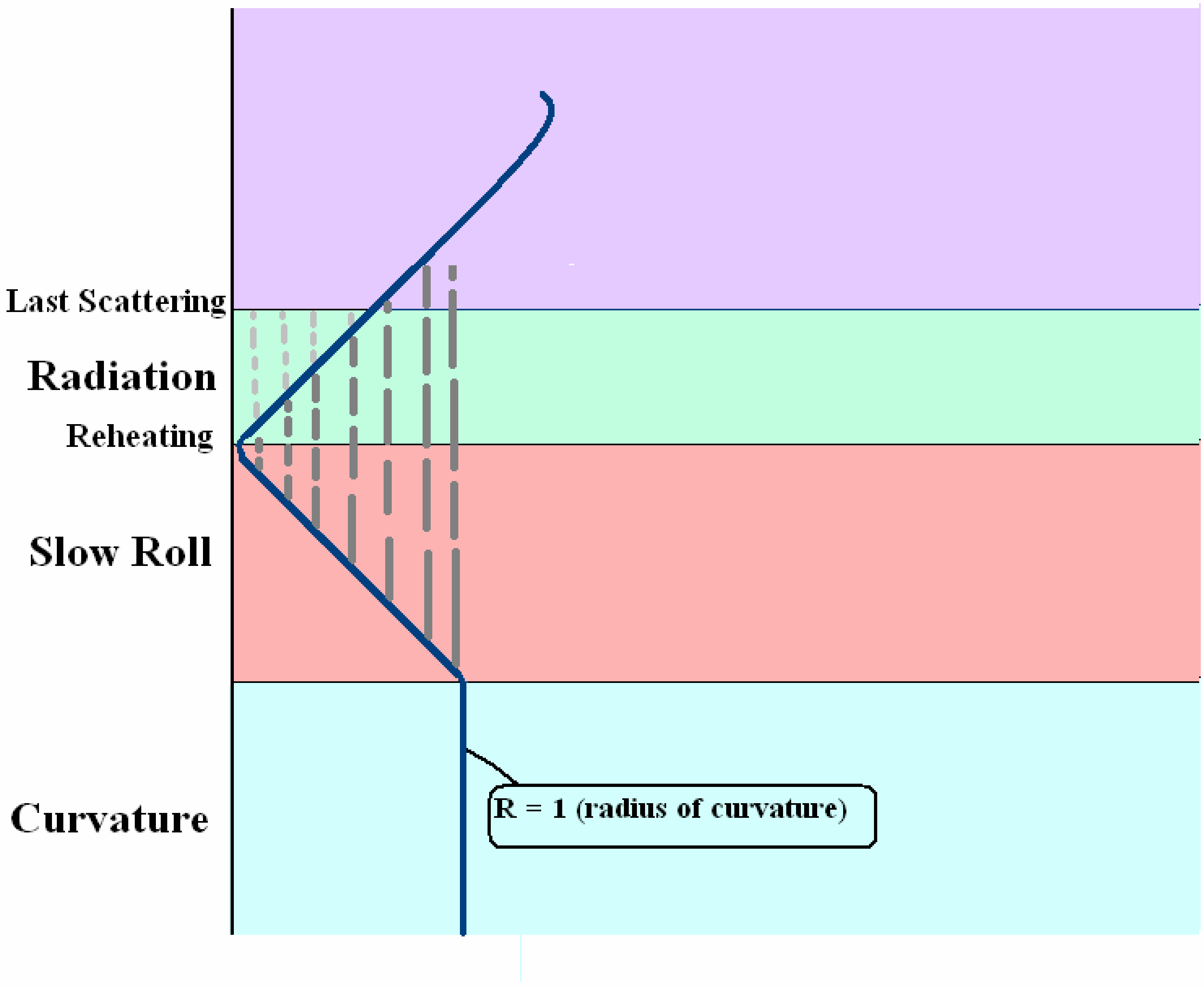
R = Co-moving radial distance



Note: R is dimensionless.



Hubble radius = a / ȧ
$R_H = \frac{1}{\dot{a}}$
Last Scattering
Radiation
Reheating
Slow Roll
Curvature
R = 1 (radius of curvature)


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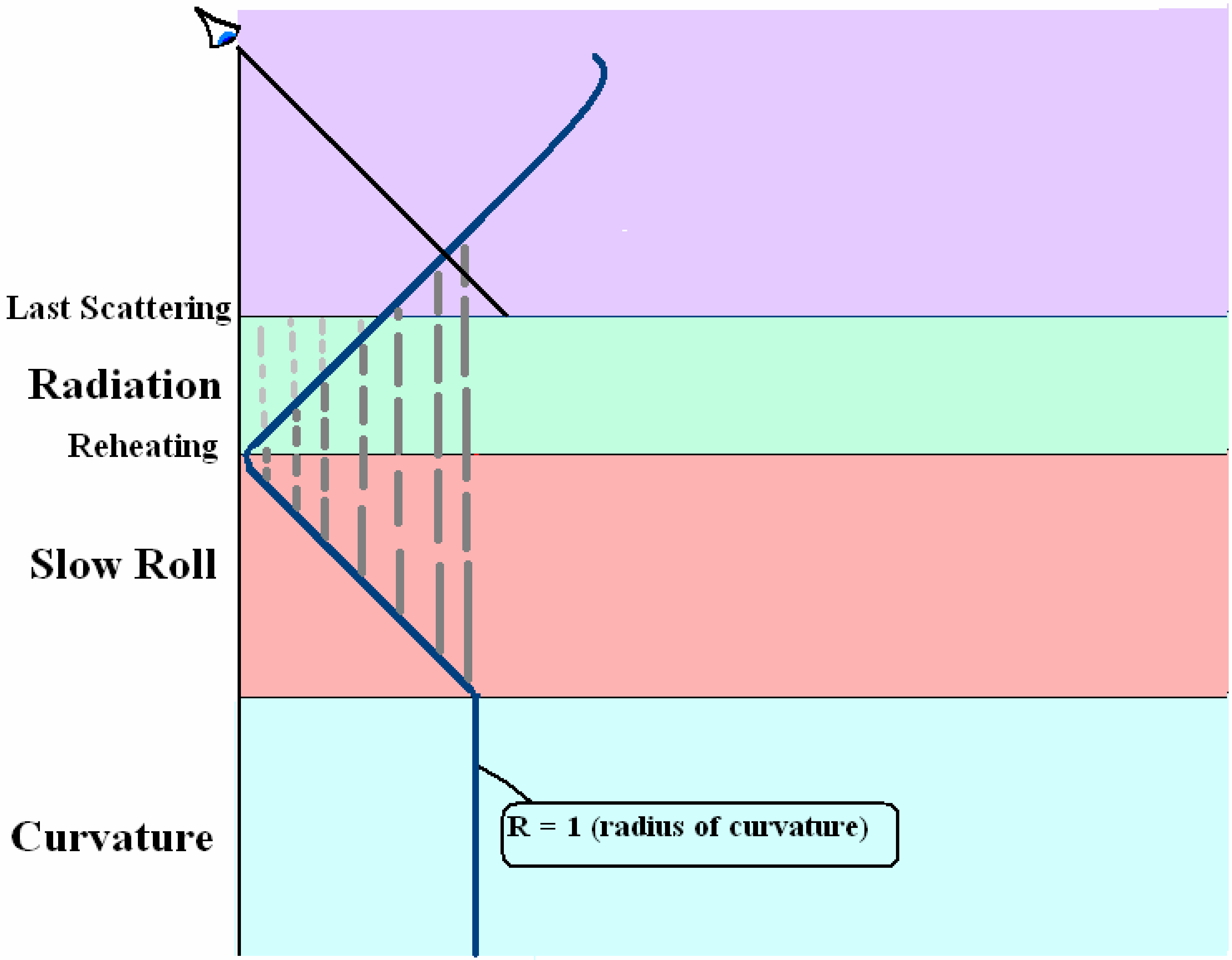
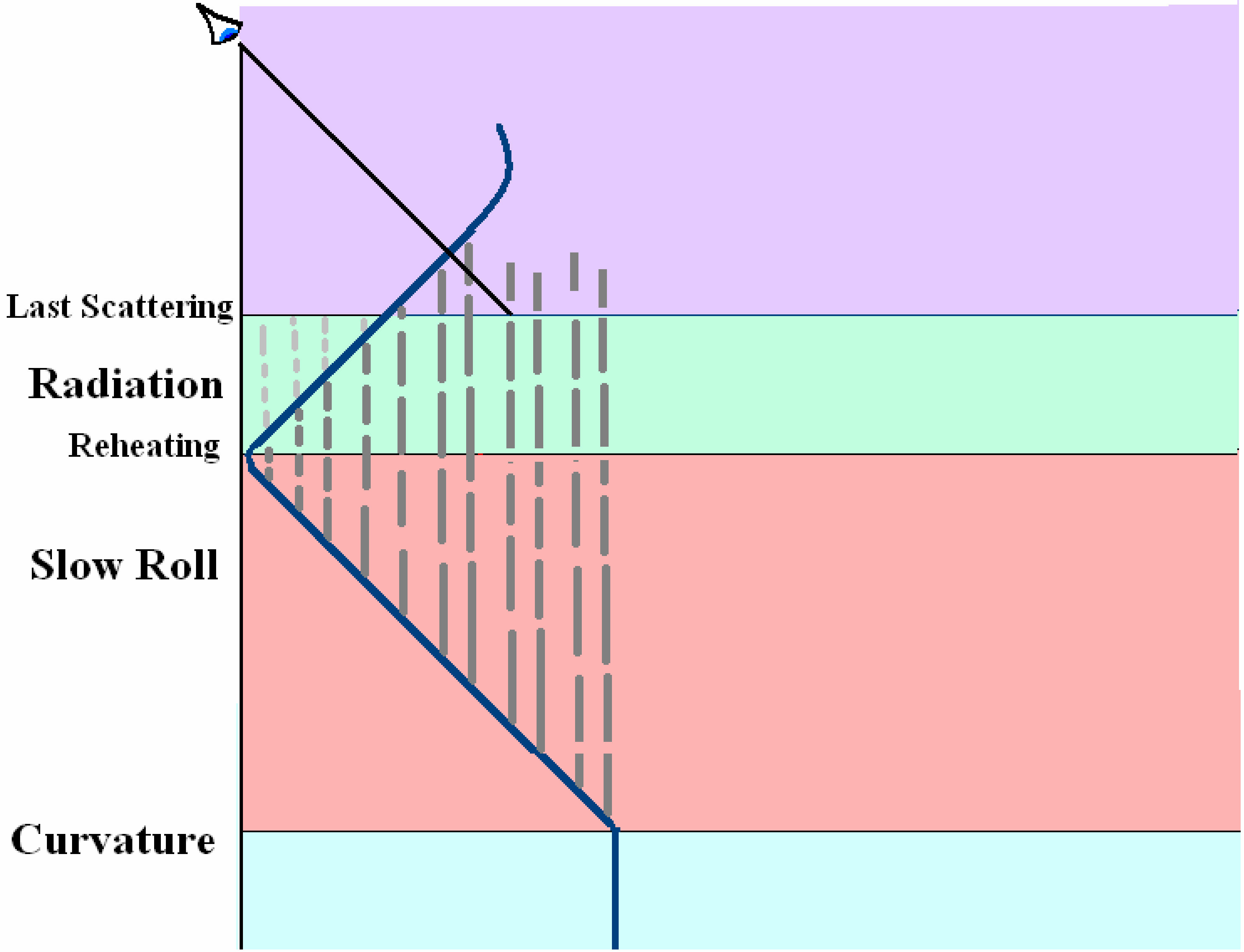
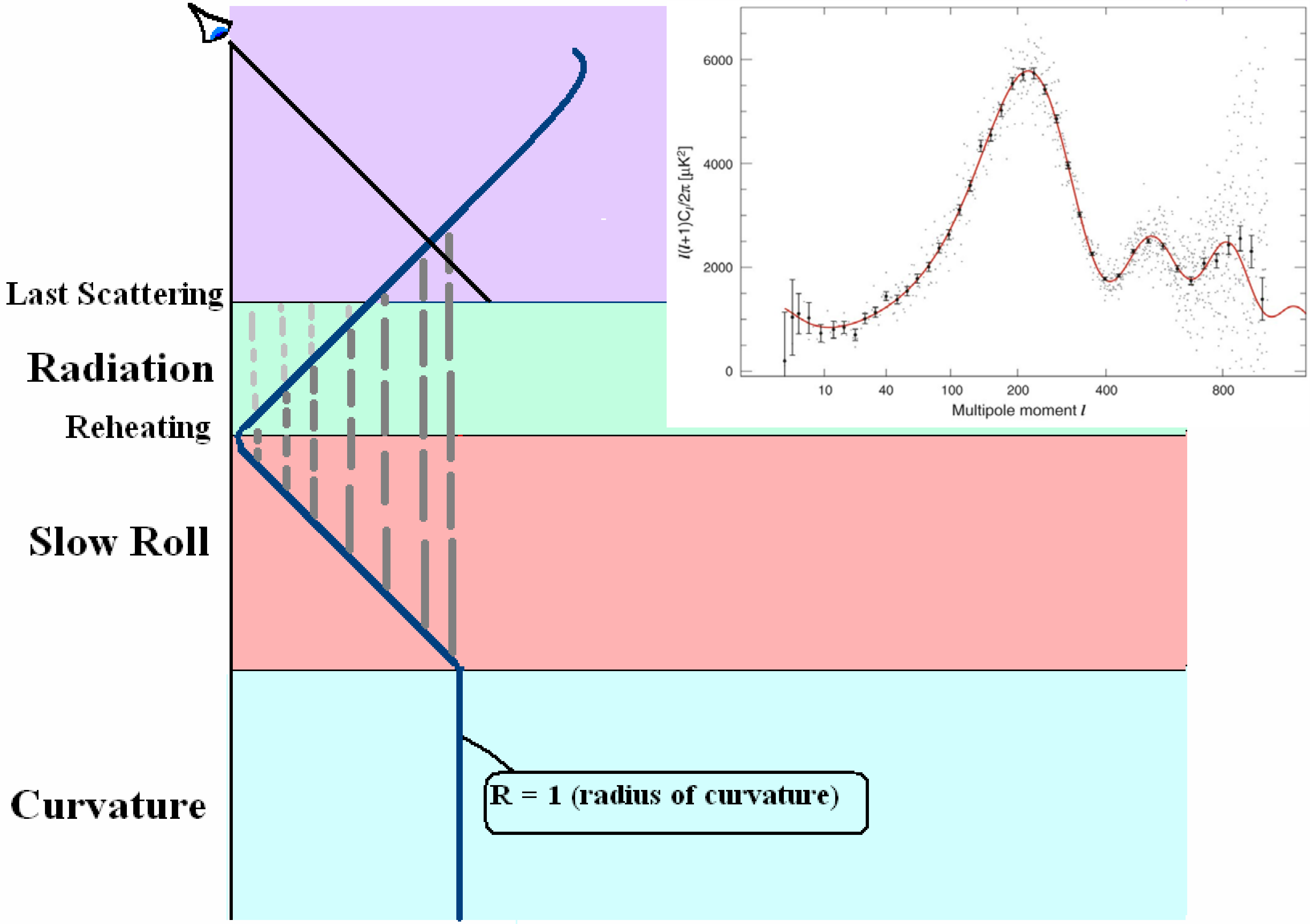
Curvature
R = 1 (radius of curvature)

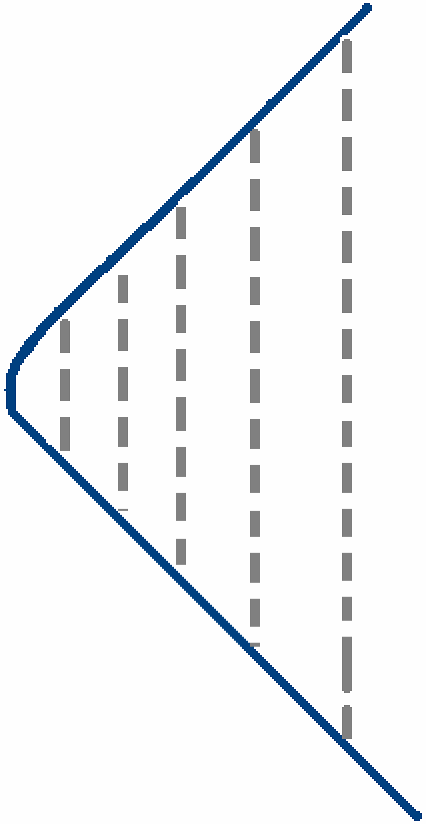


Last Scattering
Radiation
Reheating
Slow Roll
Curvature
R = 1 (radius of curvature)


Last Scattering
Radiation
Reheating
Slow Roll
Curvature



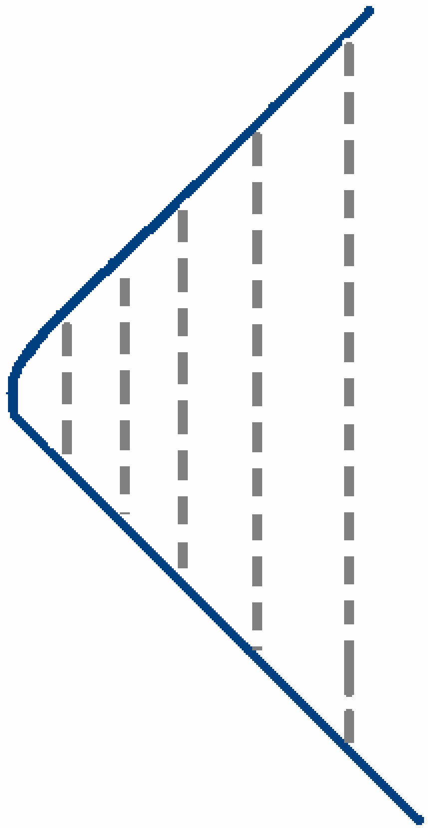
Last Scattering
Radiation
Reheating
Slow Roll
Curvature
R = 1 (radius of curvature)
$l(l+1)C_l/2\pi$ [μK^2]
6000
4000
2000
0
10
40
100
200
400
800
Multipole moment l



Gravity waves (Tensor modes) are also produced during inflation but their amplitude is almost certainly too small to detect.

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

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

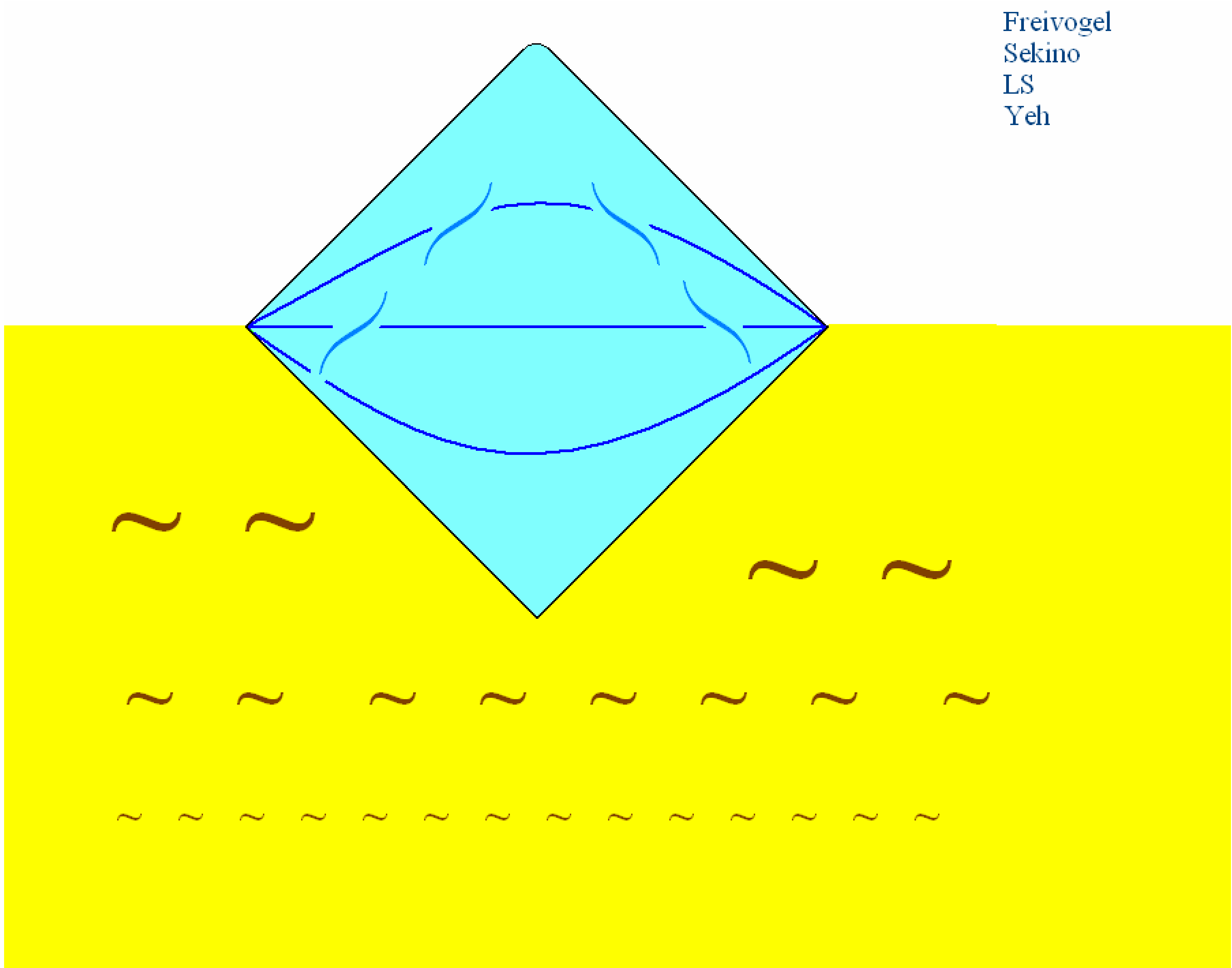


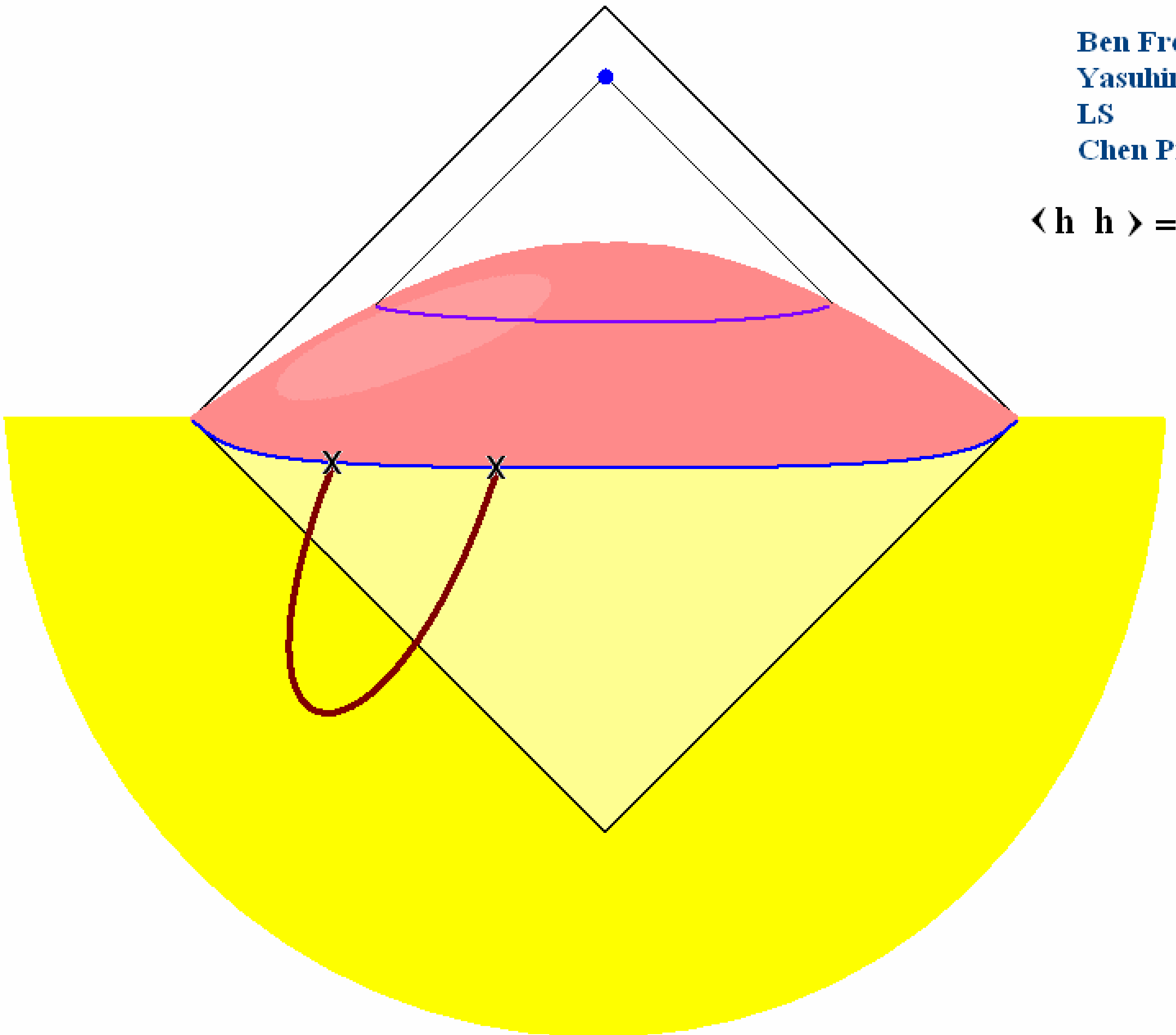
Gravity waves (Tensor modes) are also produced during inflation but their amplitude is almost certainly too small to detect.

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

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

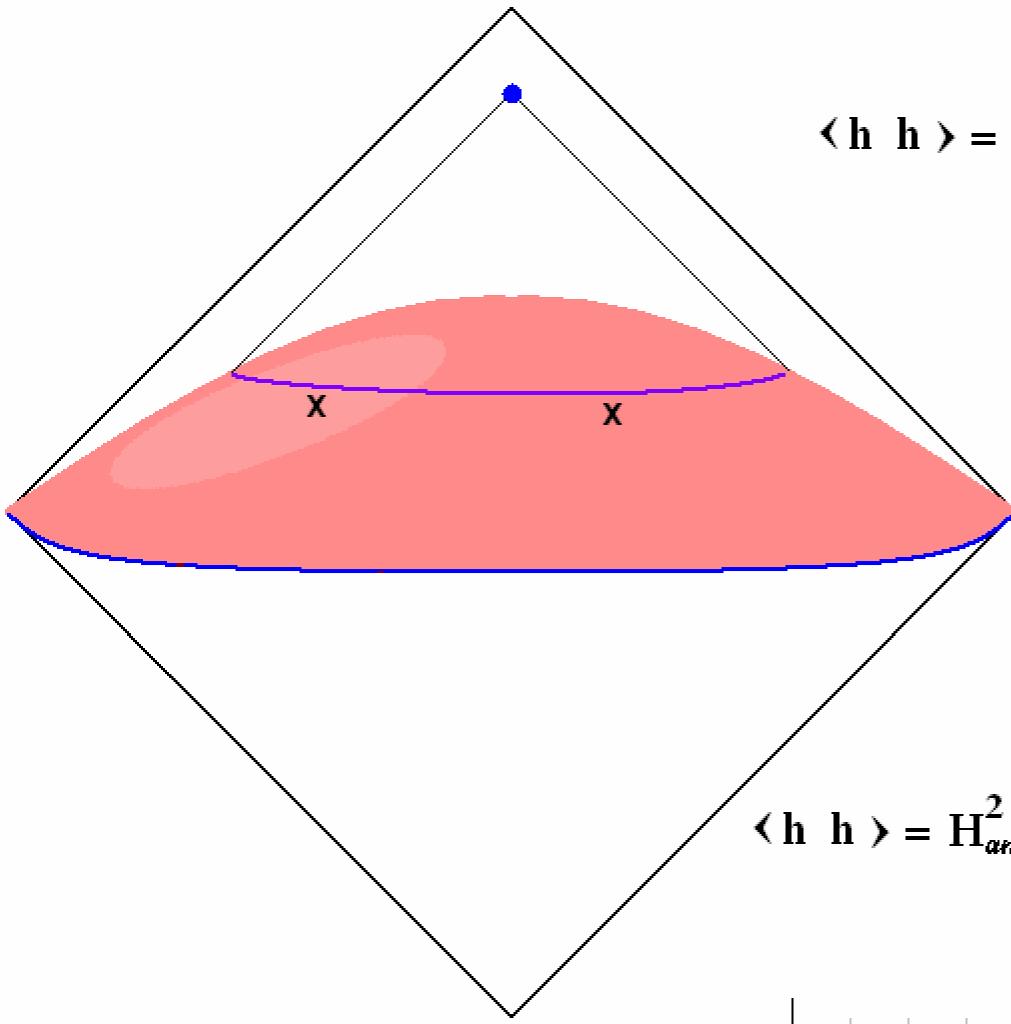
$H_{ancestor}$ may have been much larger than H_{SR}.


Freivogel
Sekino
LS
Yeh



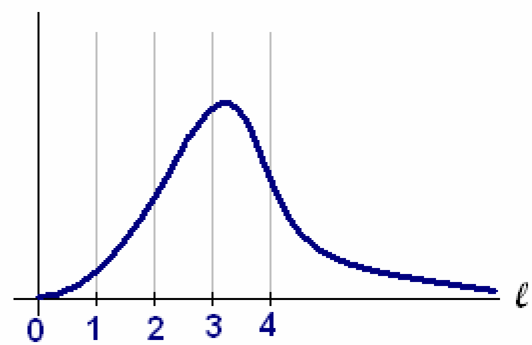
Ben Freivogel
Yasuhiro Sekino
LS
Chen Pin Yeh

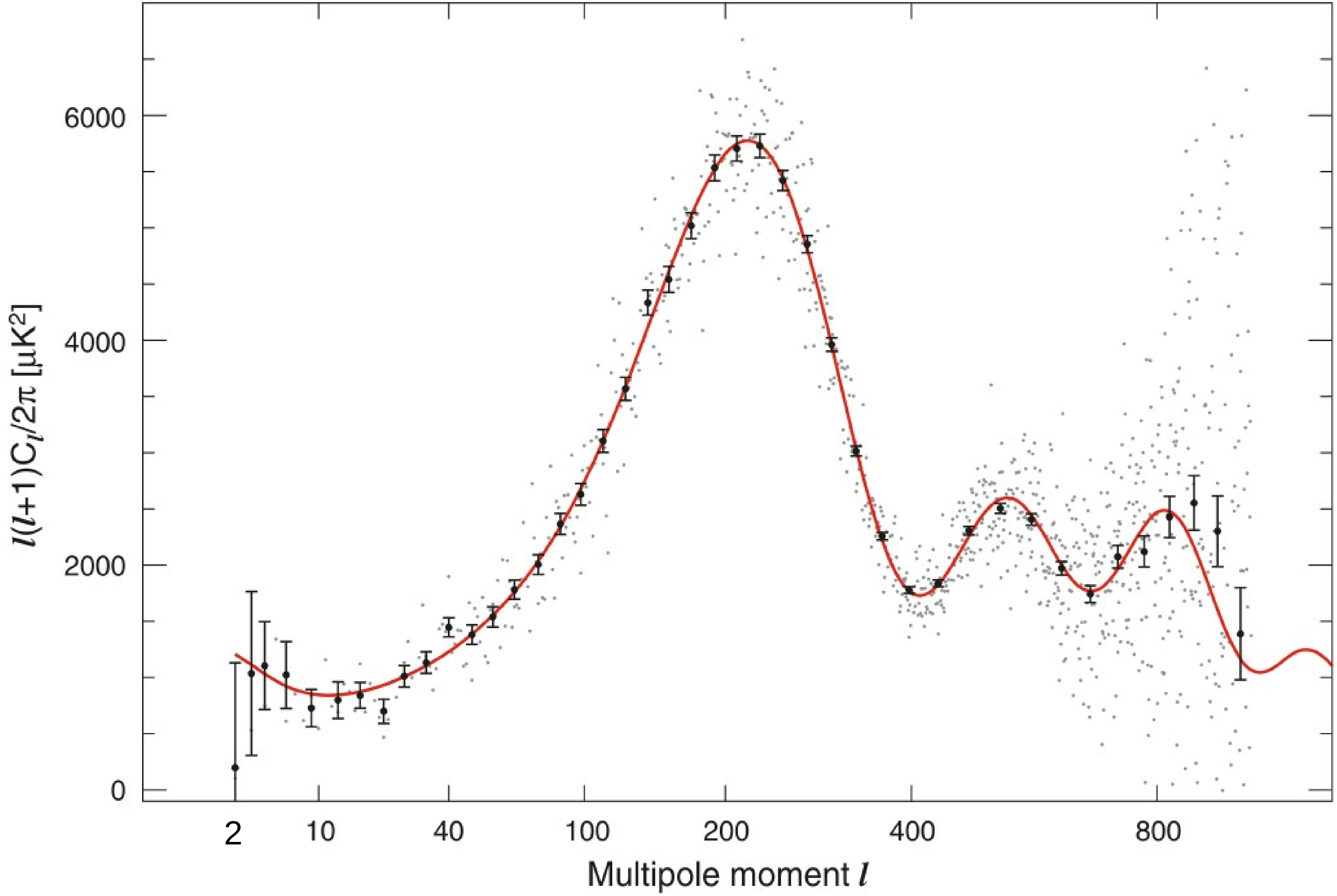
$$\langle h \; h \rangle = \ell^2 \; H^2_{ancestor}$$



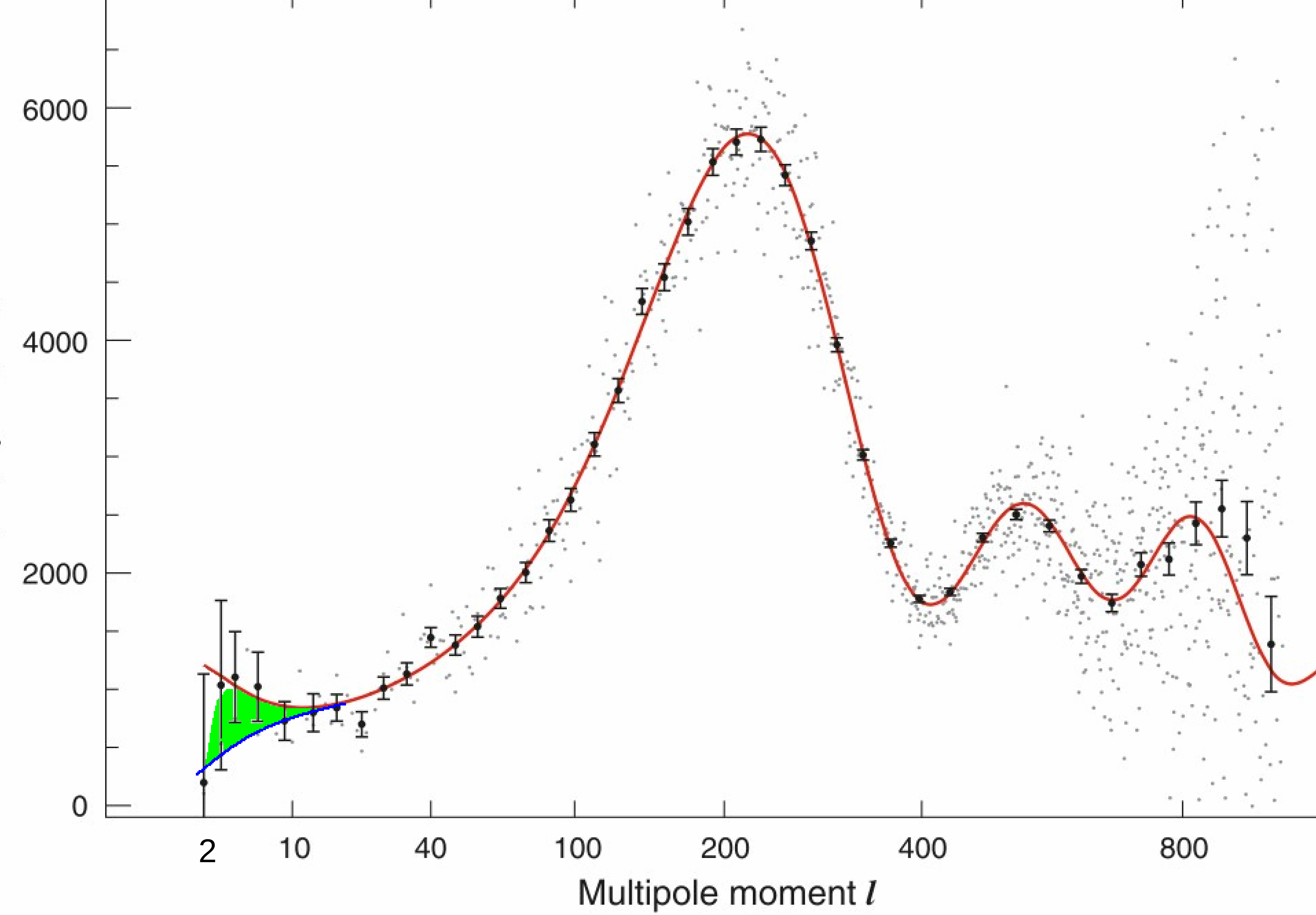
$$\langle h\ h \rangle = H^2_{ancestor}\,\ell^2 \qquad (R \geq 1)$$

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



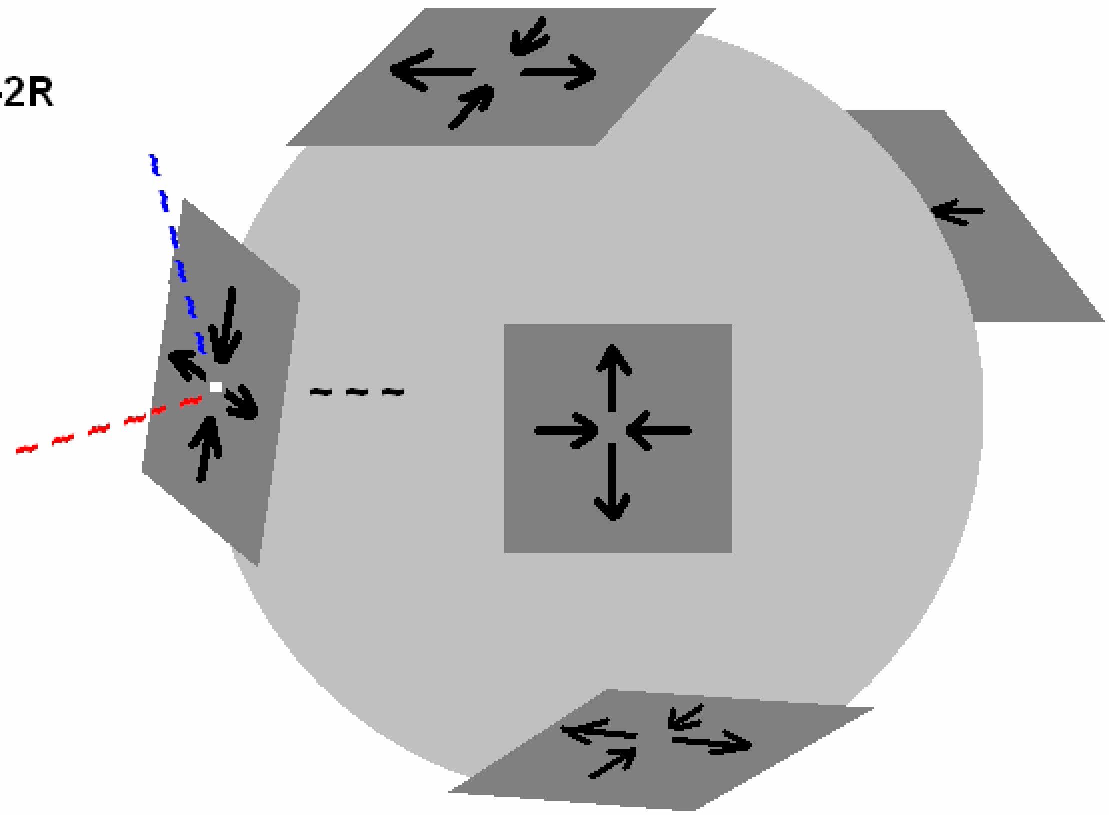


6000
4000
2000
0
l(l+1)C_l/2π [μK²]
2
10
40
100
200
400
800
Multipole moment l



6000
4000
2000
0
2
10
40
100
200
400
800
Multipole moment l

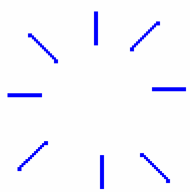
$$h_{ij} \sim H_{ancestor}\, e^{-2R}$$

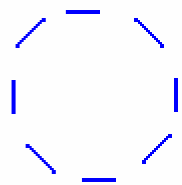


$\varepsilon_{ab}\partial_a P_{bc} = 0$

Gradiant modes

G-waves and density fluctuations

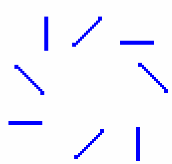


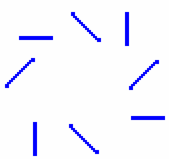


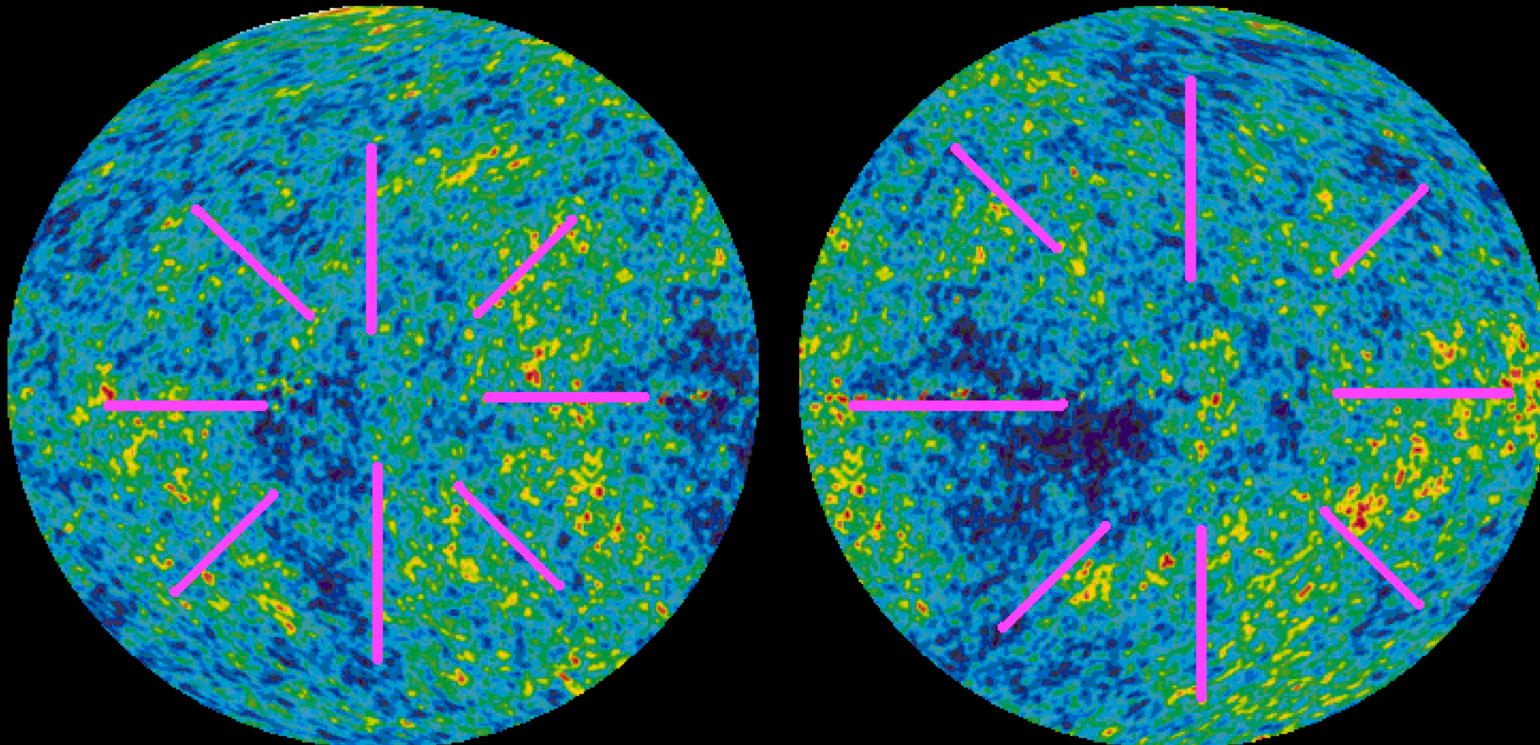
$\partial_b P_{bc} = 0$

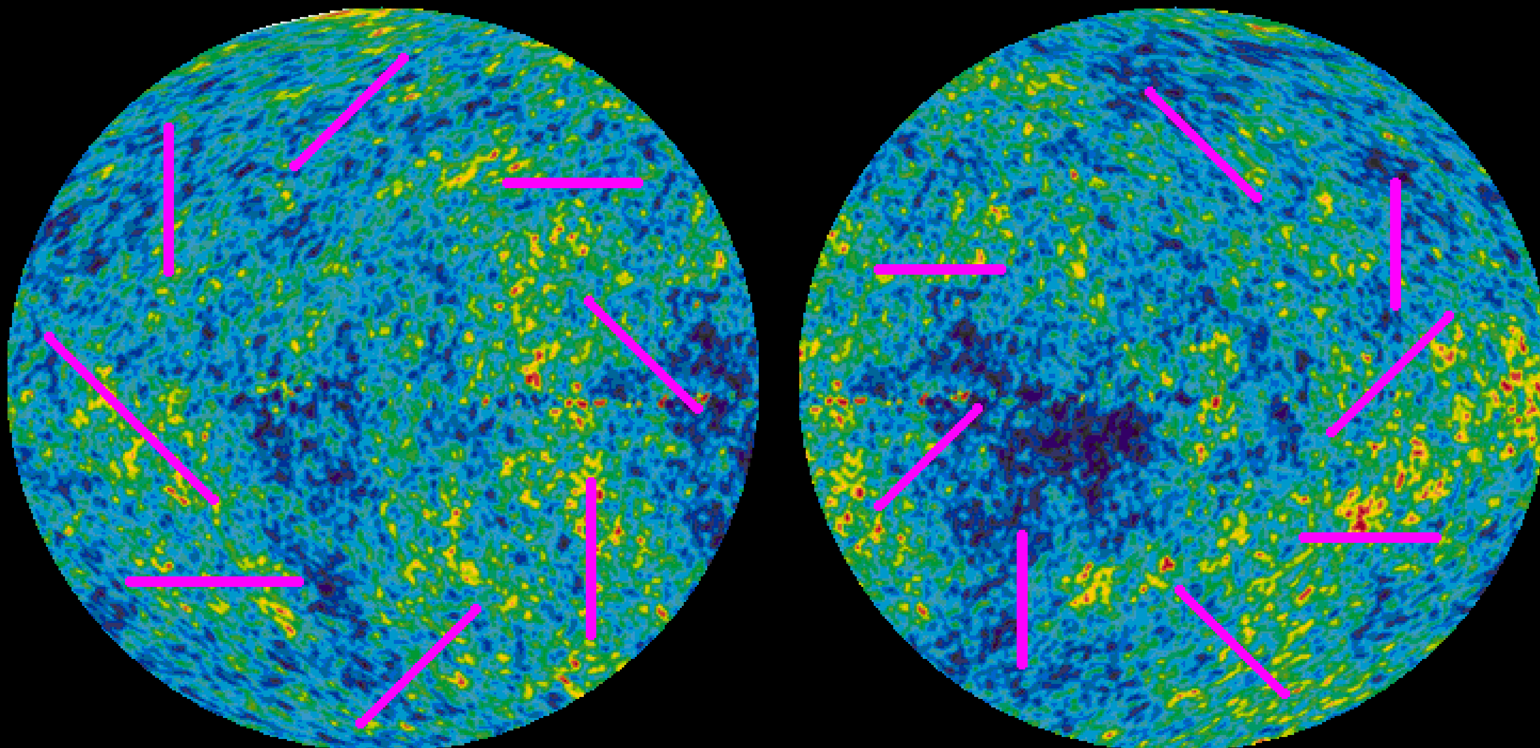
Curl modes

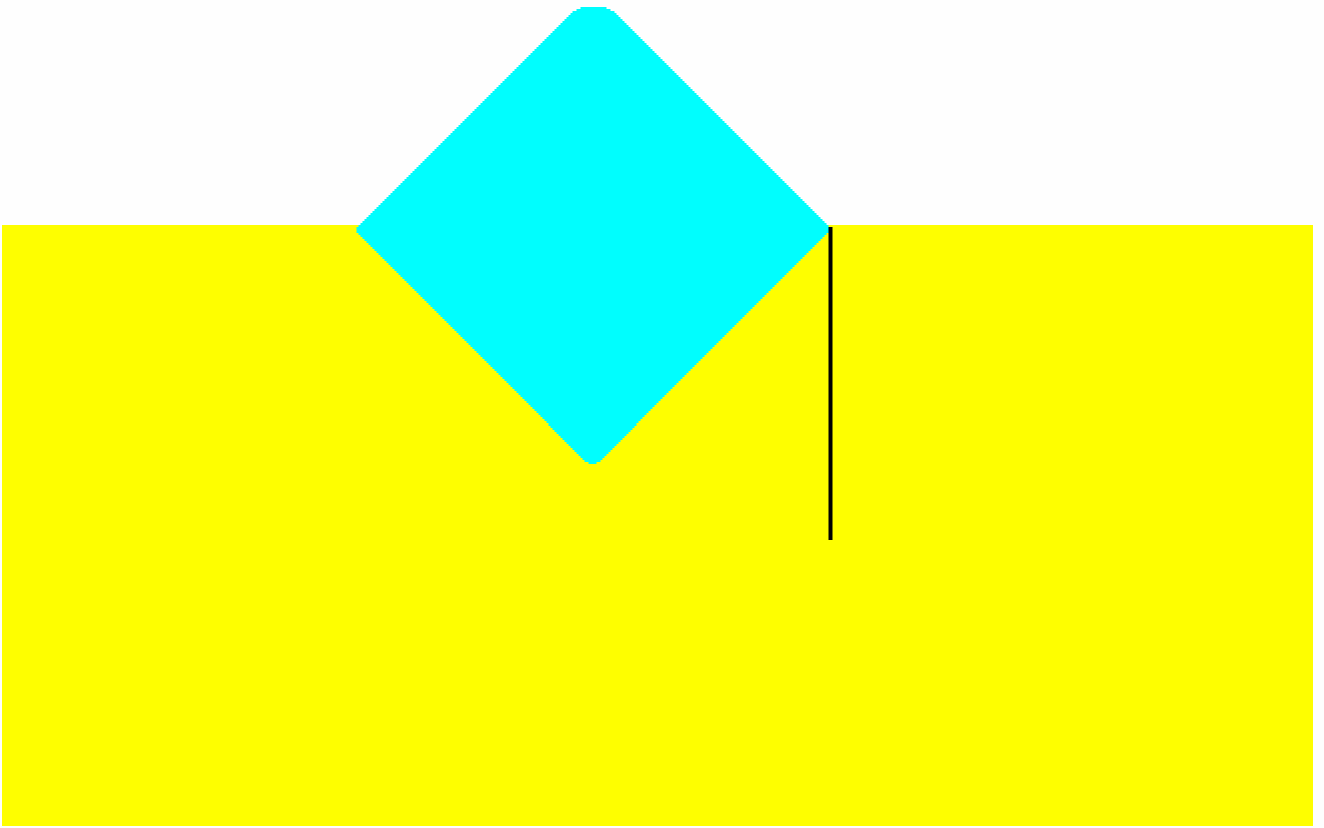
Only G-waves

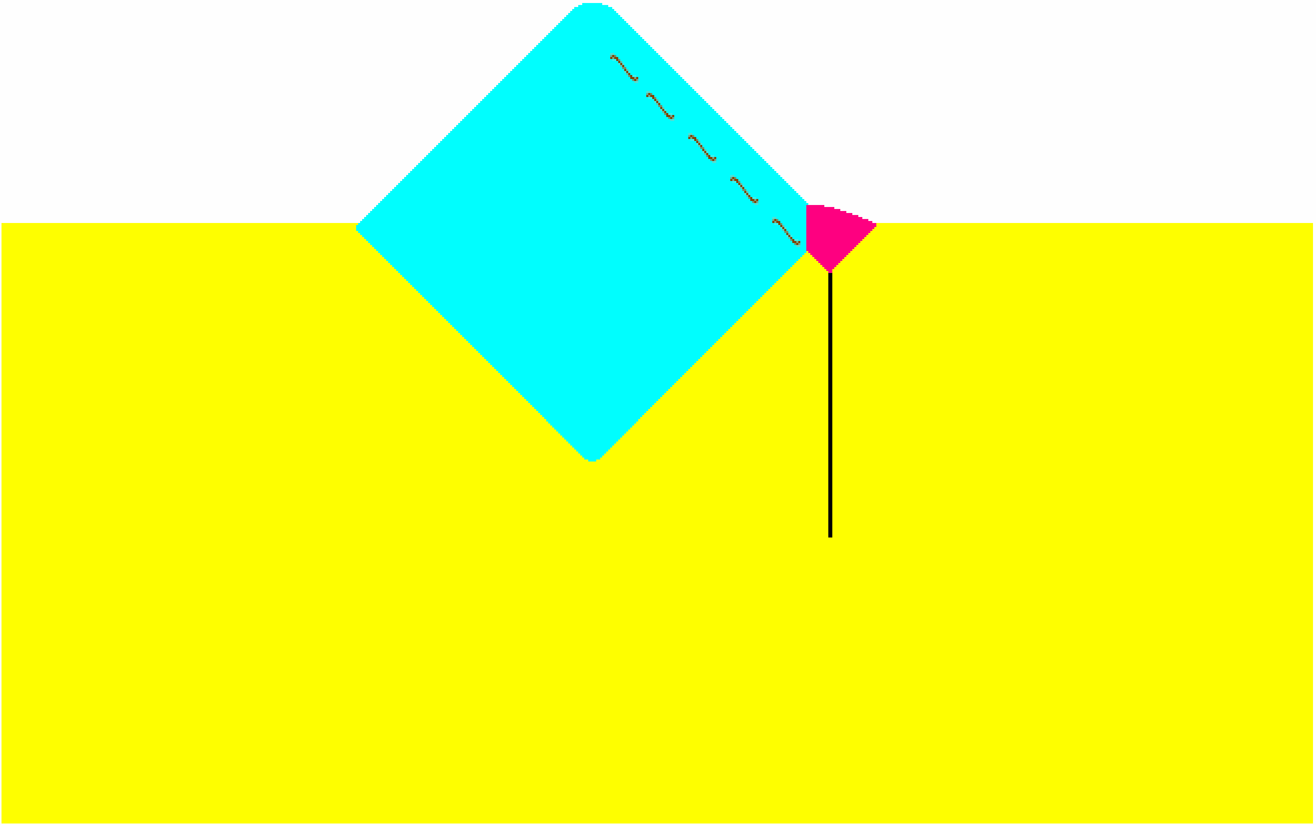




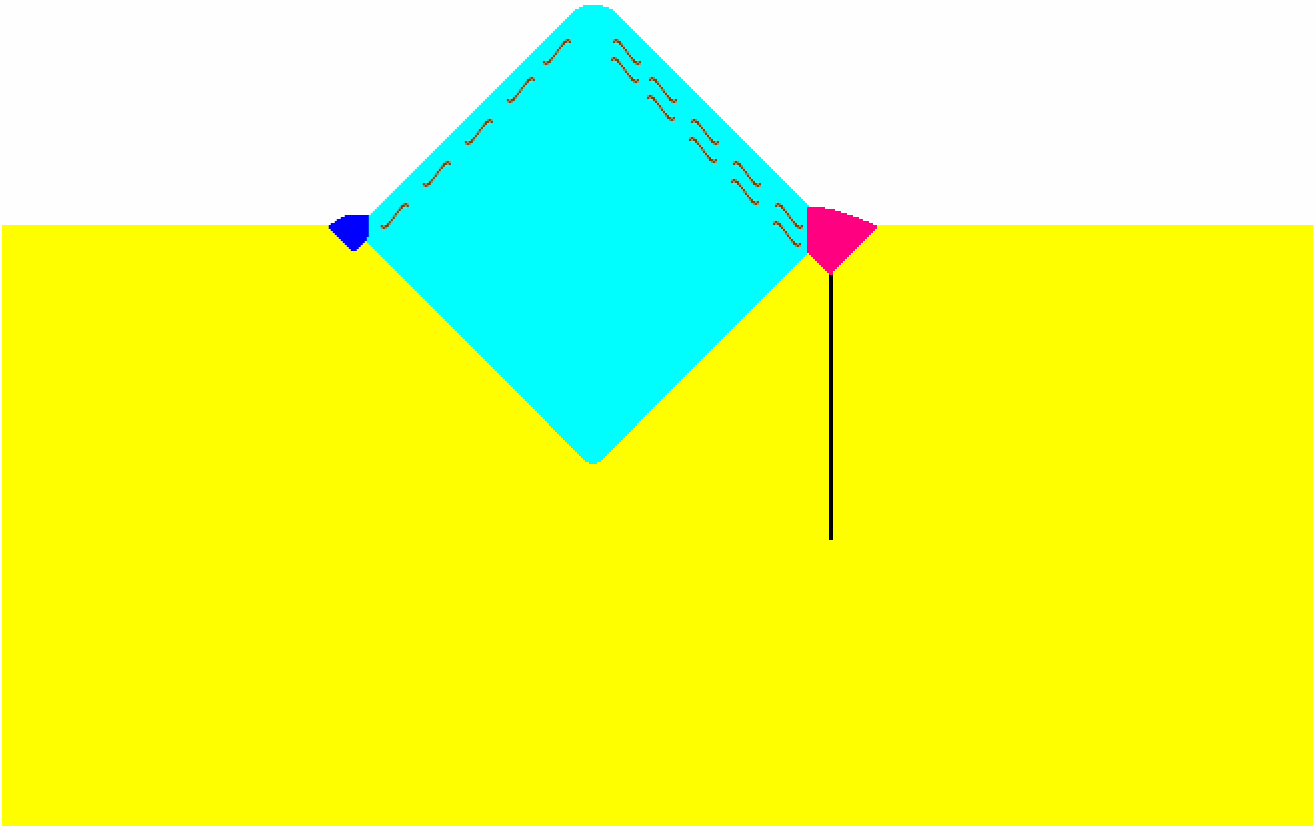


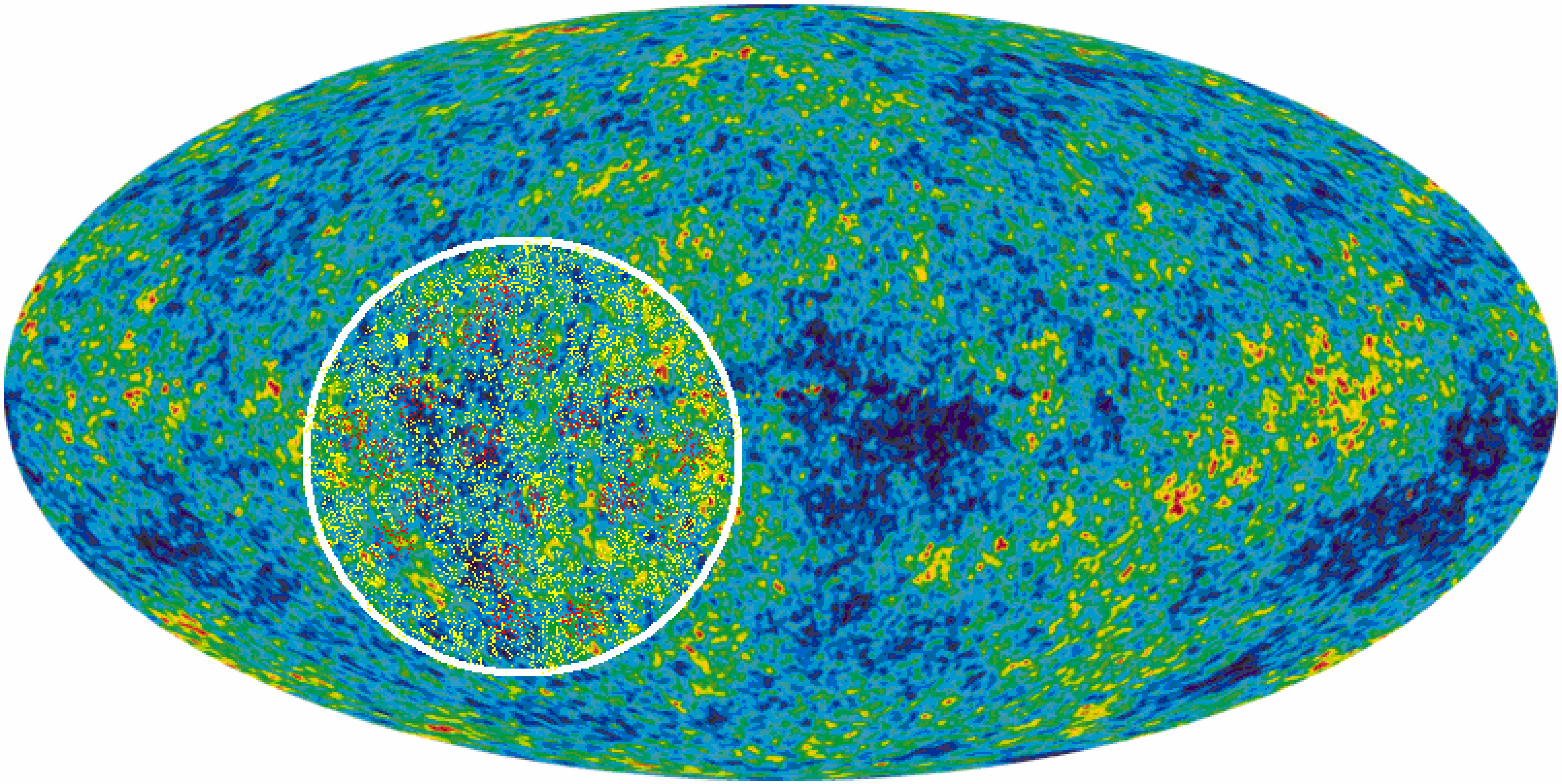






Guth, Weinberg, Vilenkin, Garriga, Freivogel, Bousso, Shenker, Sekino, Kleban, Bjorken, …………..





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

Or tiny point sources of gravity waves.

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

Fossils

- Negative curvature
- Large scale tensor fluctuations that quickly fade with l.
- Bubble collisions. Rings or spots.