Title: New physics from inflation

Date: Nov 08, 2007 05:30 PM

URL: http://pirsa.org/07110056

Abstract: I discuss how physics beyond the Planck scale and before inflation might leave an imprint on the primordial spectrum. There are interesting limitations connected with the information paradox that suggests unexpected new ways to test ideas on quantum gravity.

New physics from inflation

Ulf Danielsson
Uppsala Universitet
Sweden

Outline

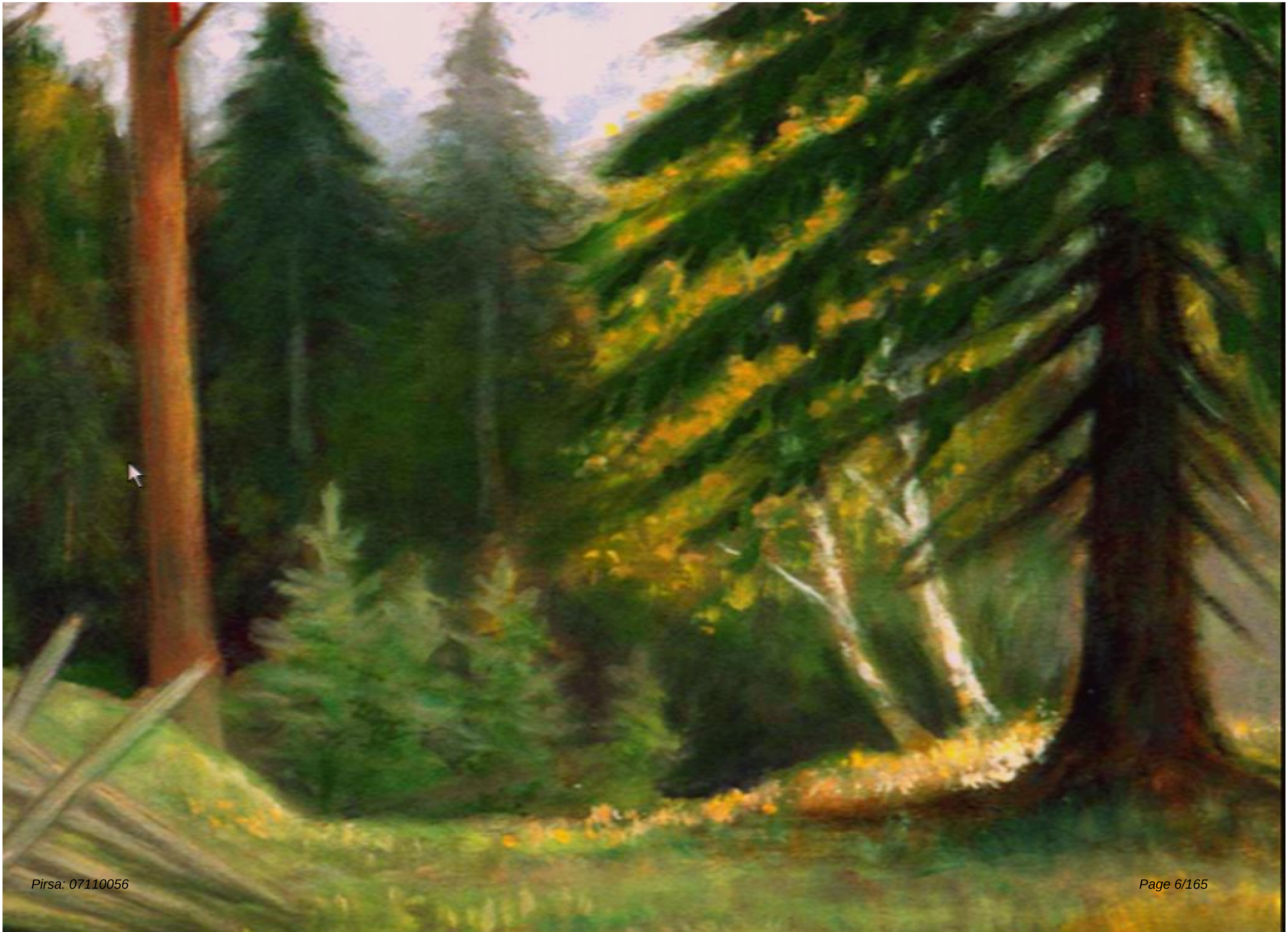
New physics from inflation

Ulf Danielsson
Uppsala Universitet
Sweden

New physics from inflation

Ulf Danielsson
Uppsala Universitet
Sweden

Nästa
Föregående
Senast visad
Gå till bild
Anpassat bildspel
Skärm
Hjälp
Paus
Avsluta bildspel



New physics from inflation

Ulf Danielsson
Uppsala Universitet
Sweden

Outline

Outline

Transplanckian physics

Initial conditions from where?

Outline

Transplanckian physics

Initial conditions from where?

An information paradox?

Outline

Transplanckian physics

Initial conditions from where?

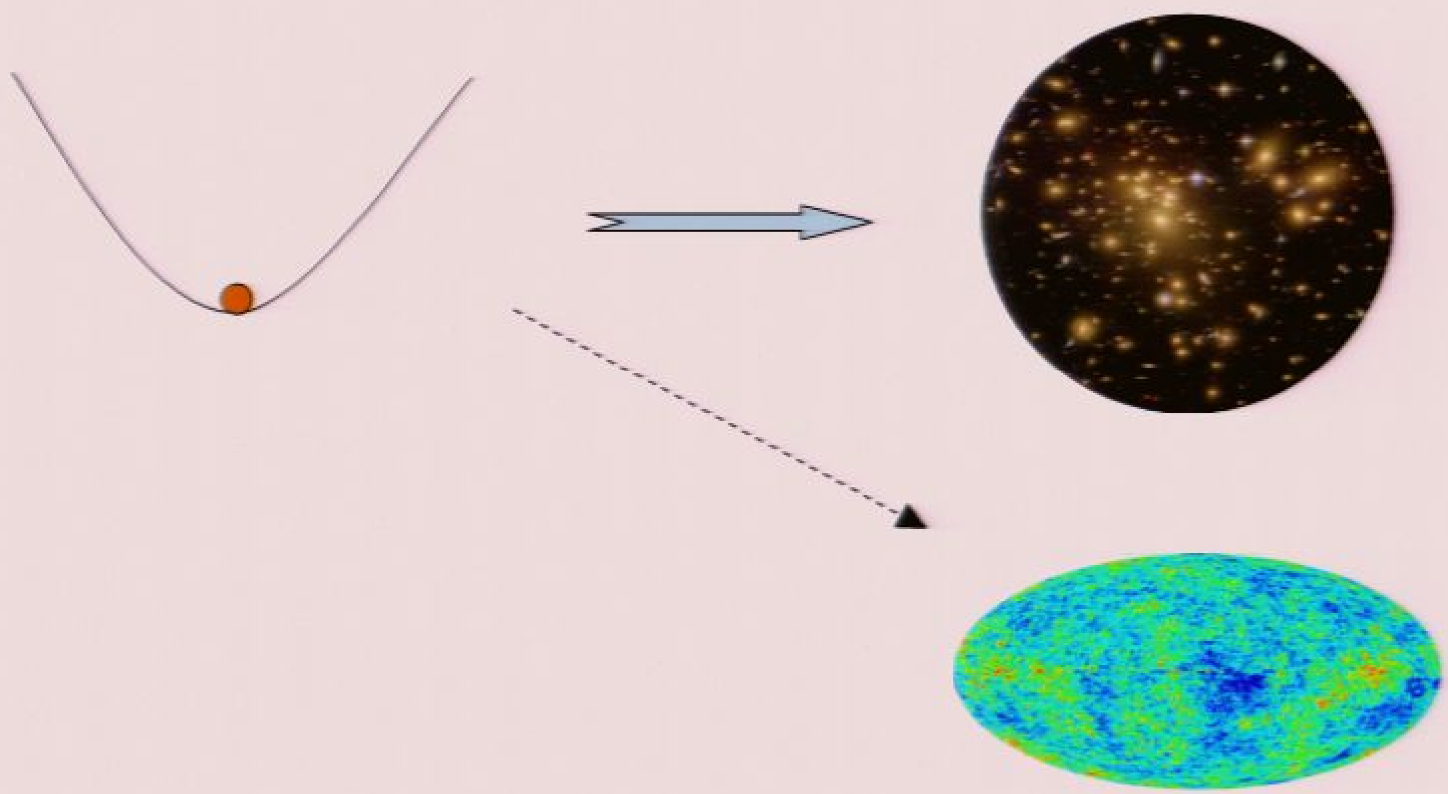
An information paradox?

Memories of things past

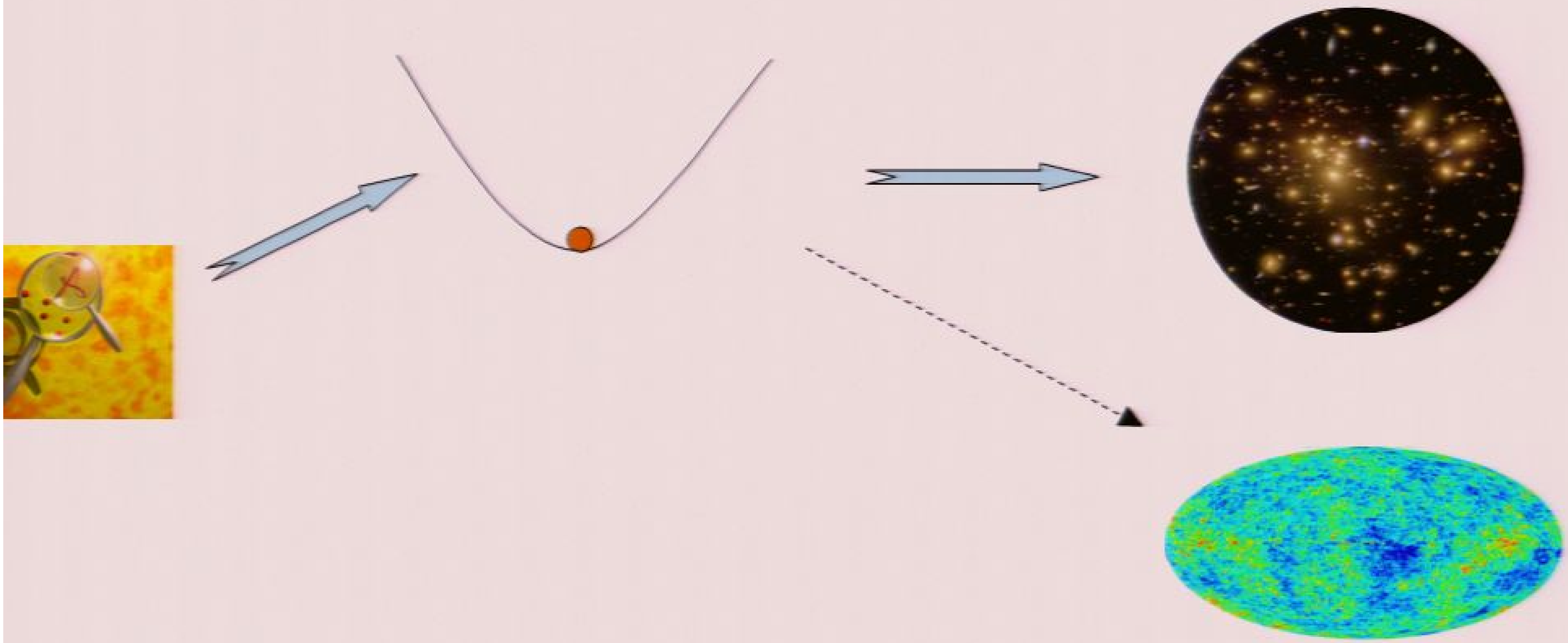
Transplanckian physics

Transplanckian physics

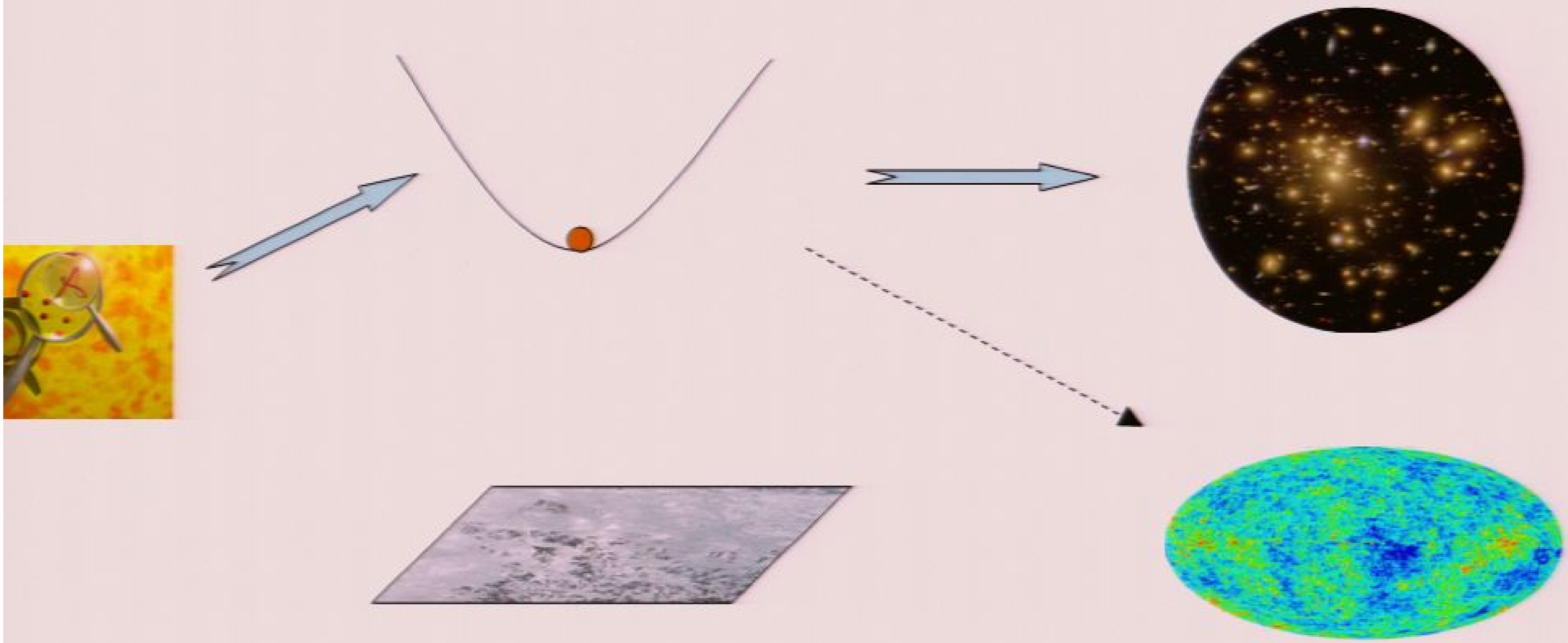
Transplanckian physics



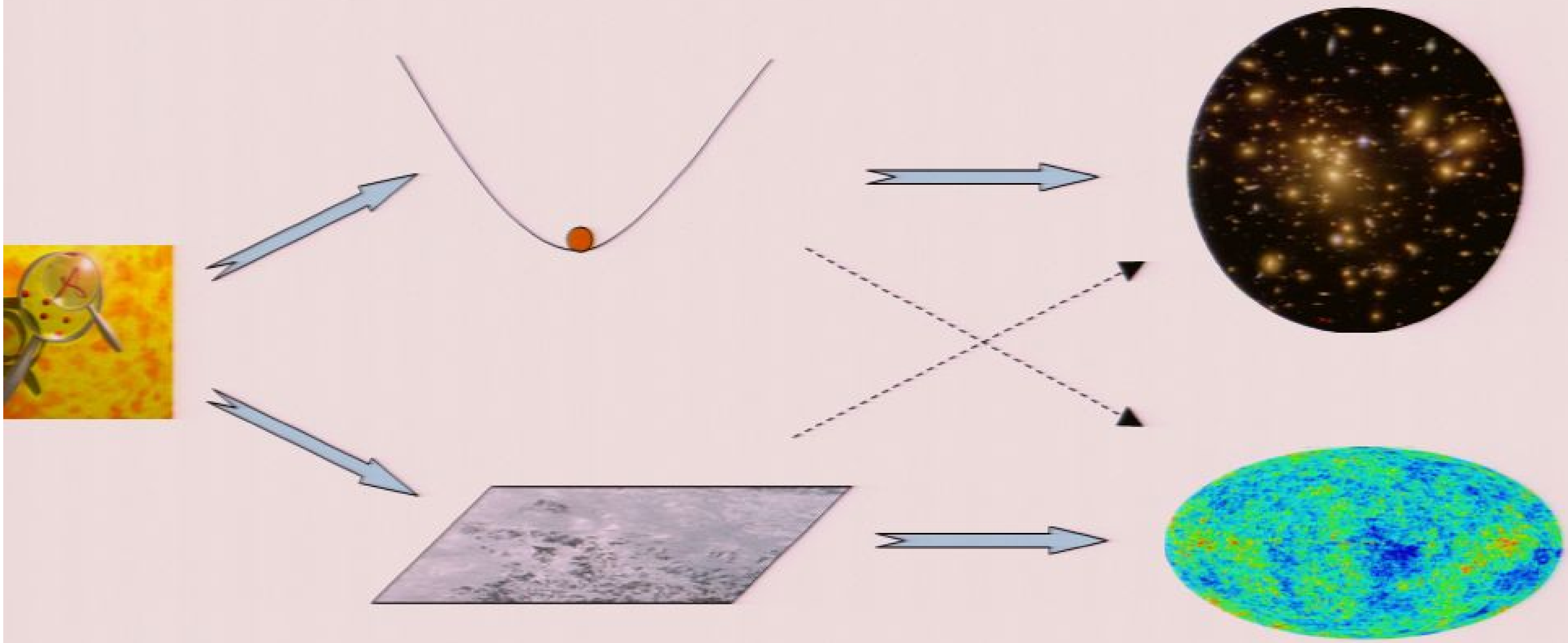
Transplanckian physics

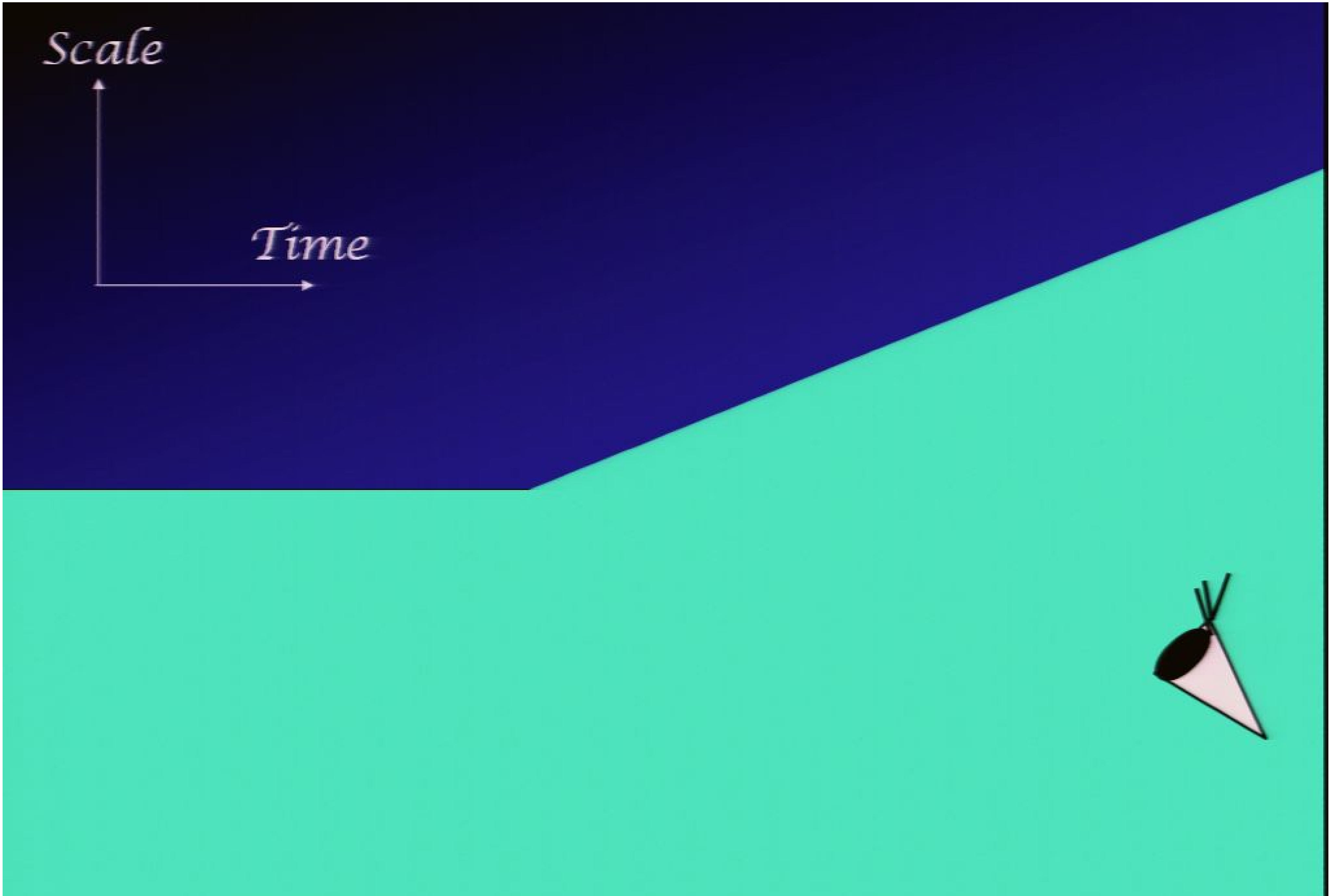


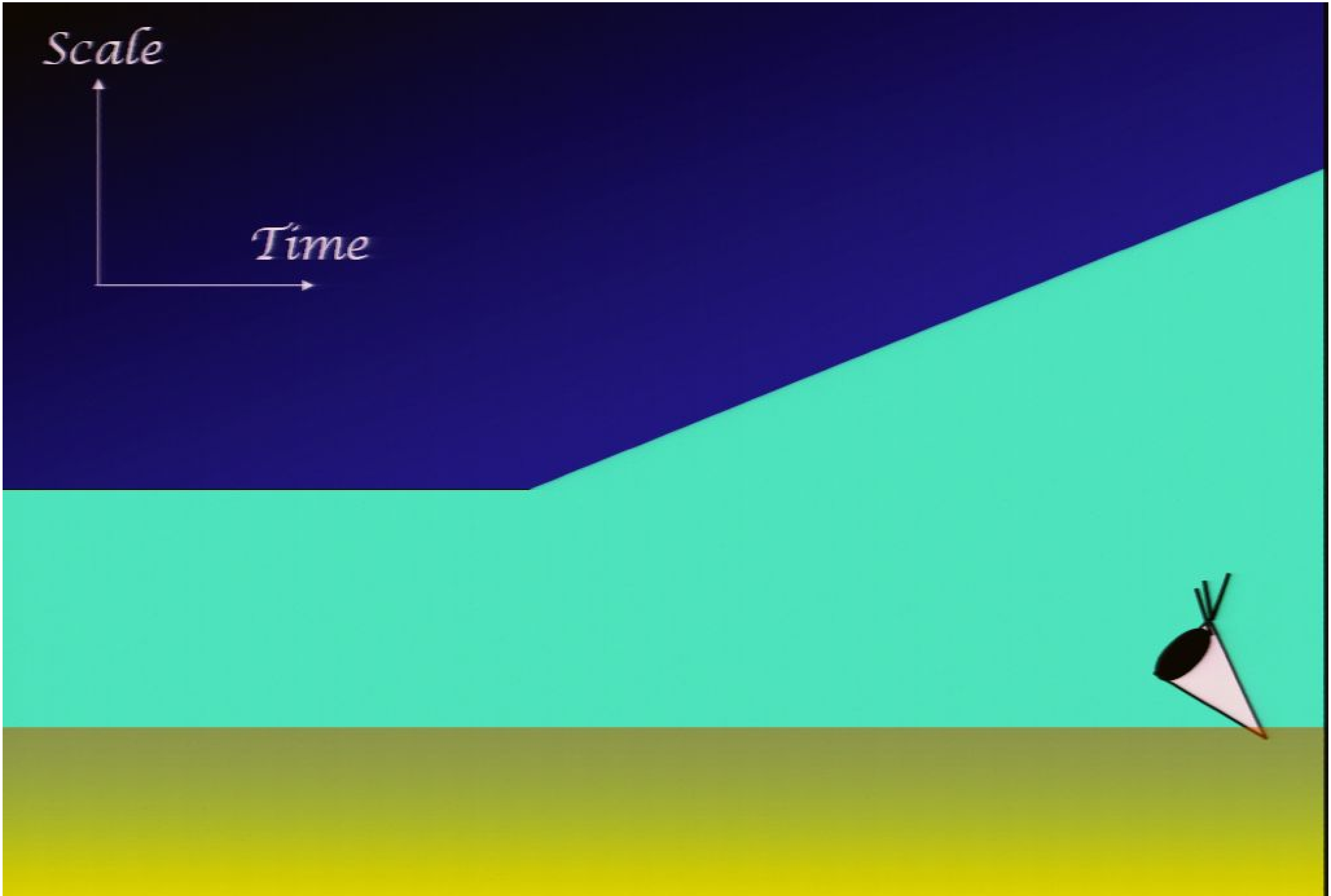
Transplanckian physics

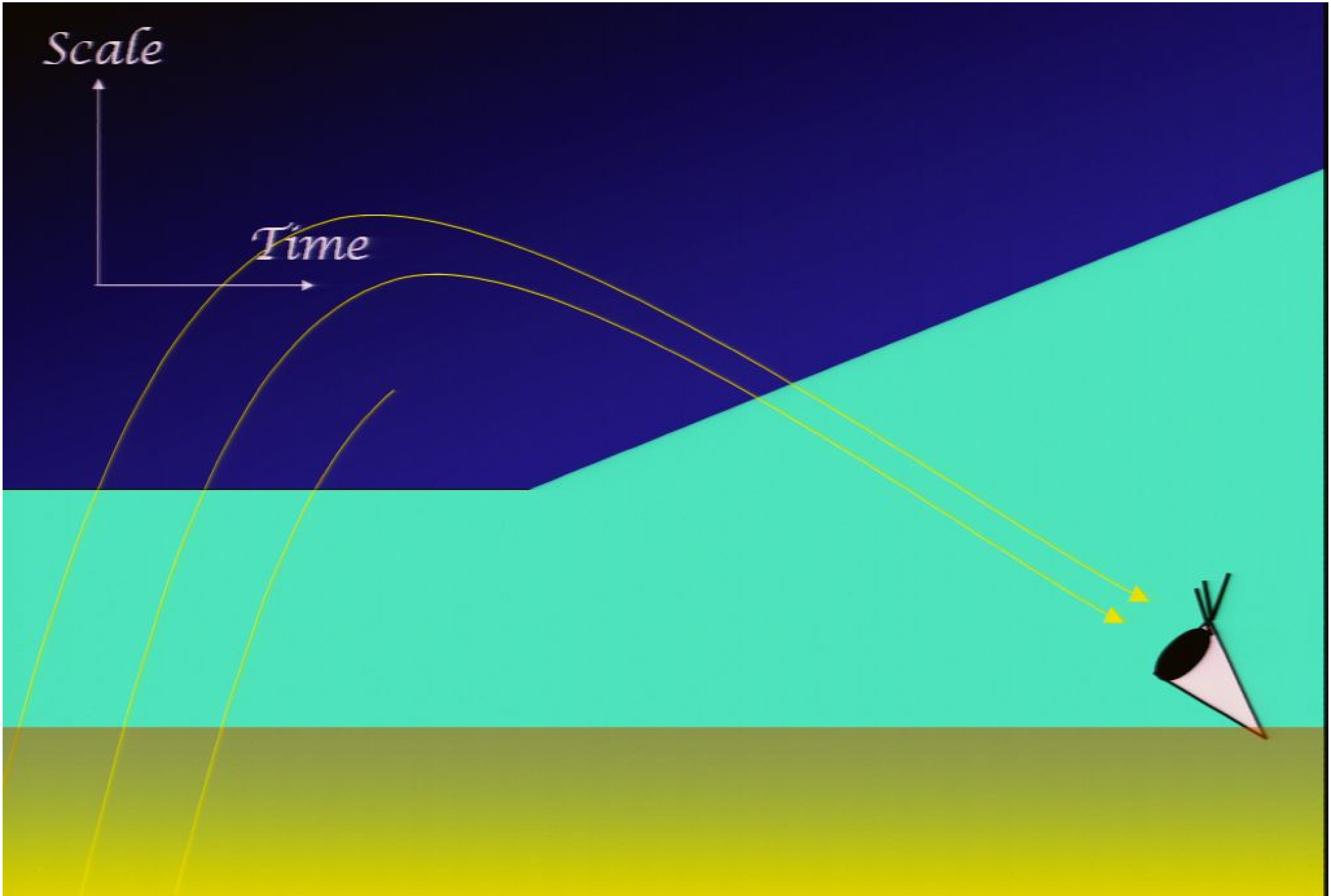


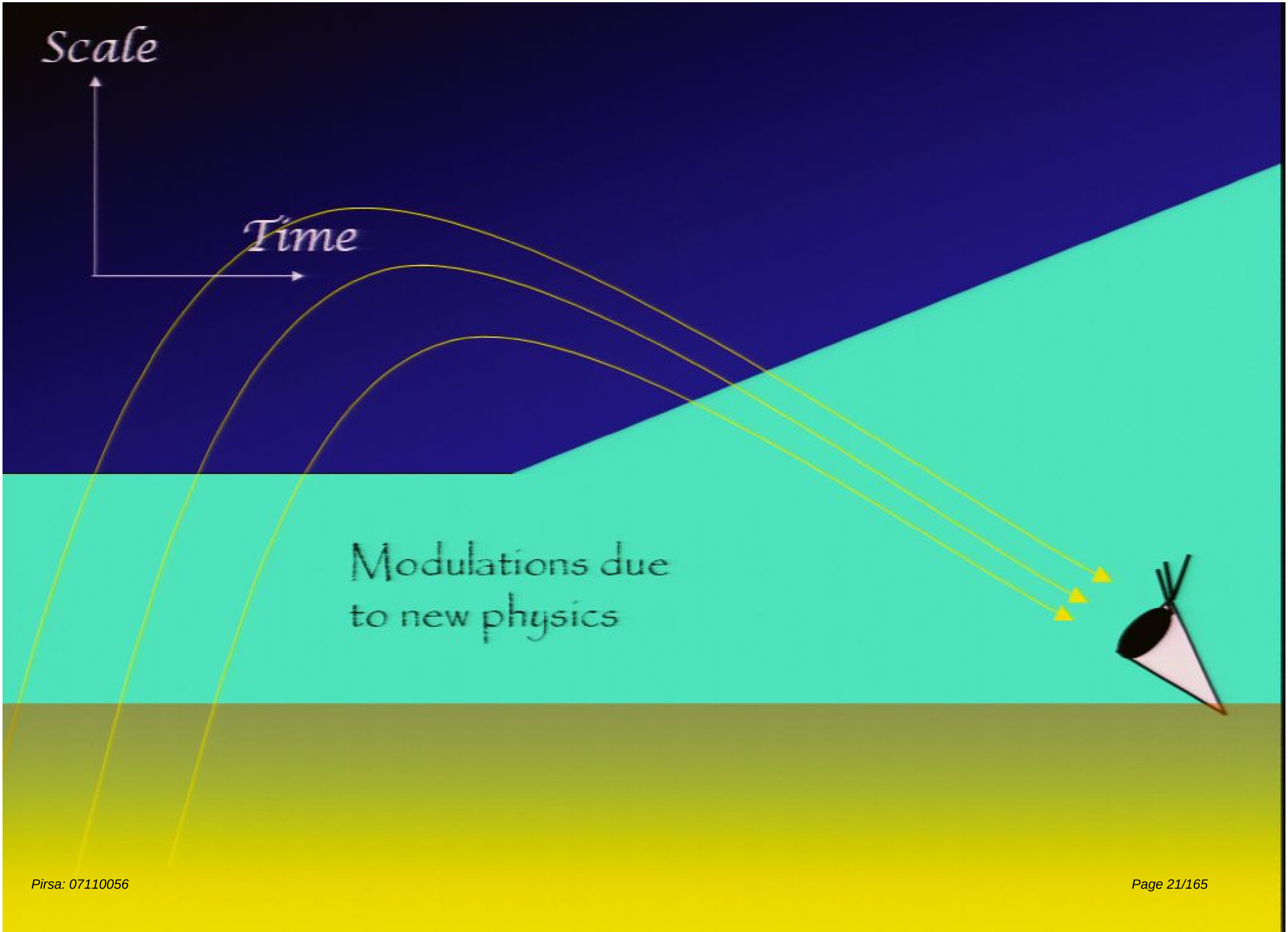
Transplanckian physics

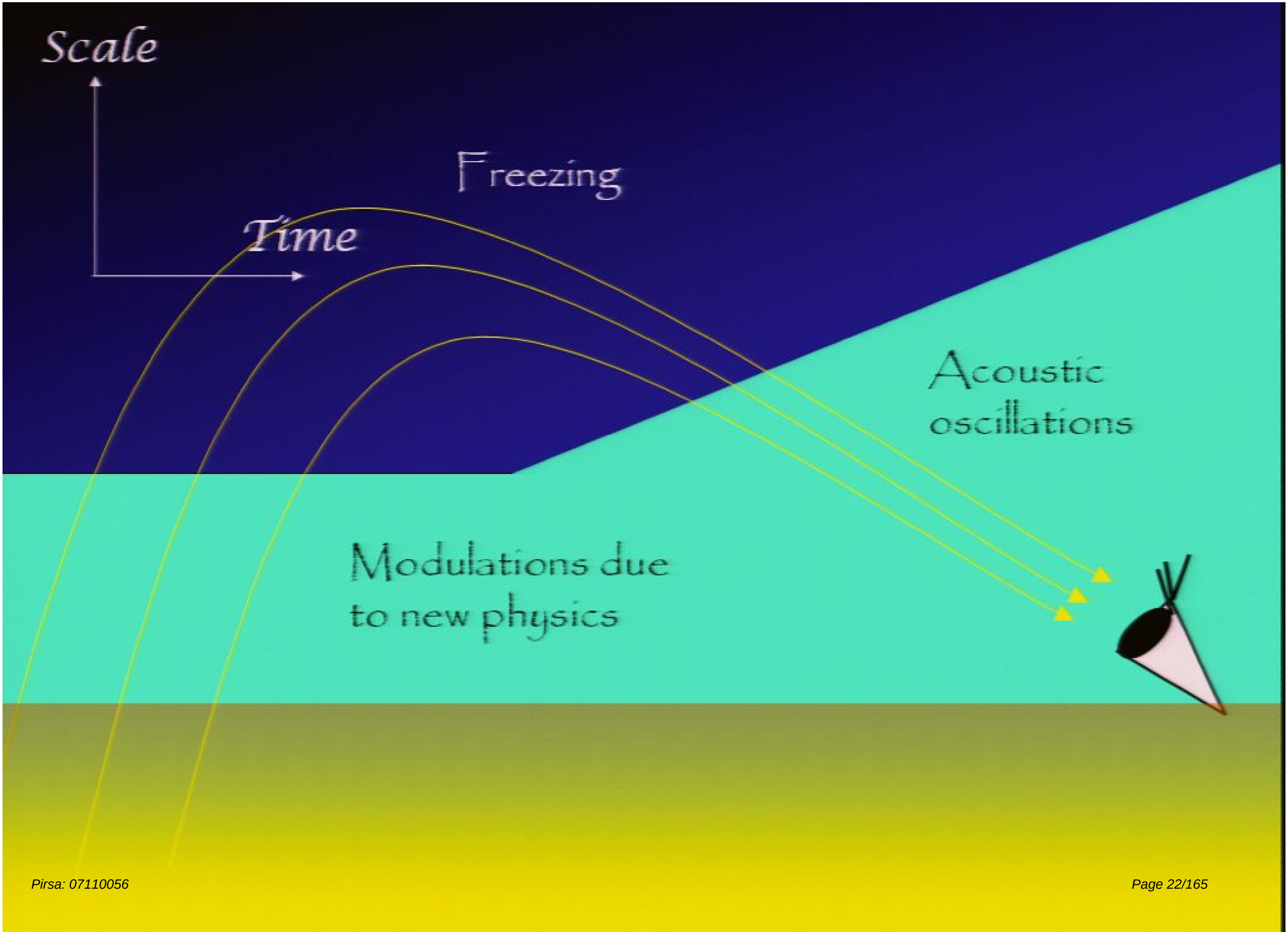



Scale
Time


Scale
Time


Scale
Time


Scale
Time
Modulations due
to new physics


Scale
Time
Freezing
Acoustic
oscillations
Modulations due
to new physics

The generic expectation is of the form:

The generic expectation is of the form:

$$P_\phi = \left(\frac{H}{2\pi}\right)^2 \left(1 - \frac{H}{\Lambda} \sin\left(\frac{2\Lambda}{H}\right)\right)$$

The generic expectation is of the form:

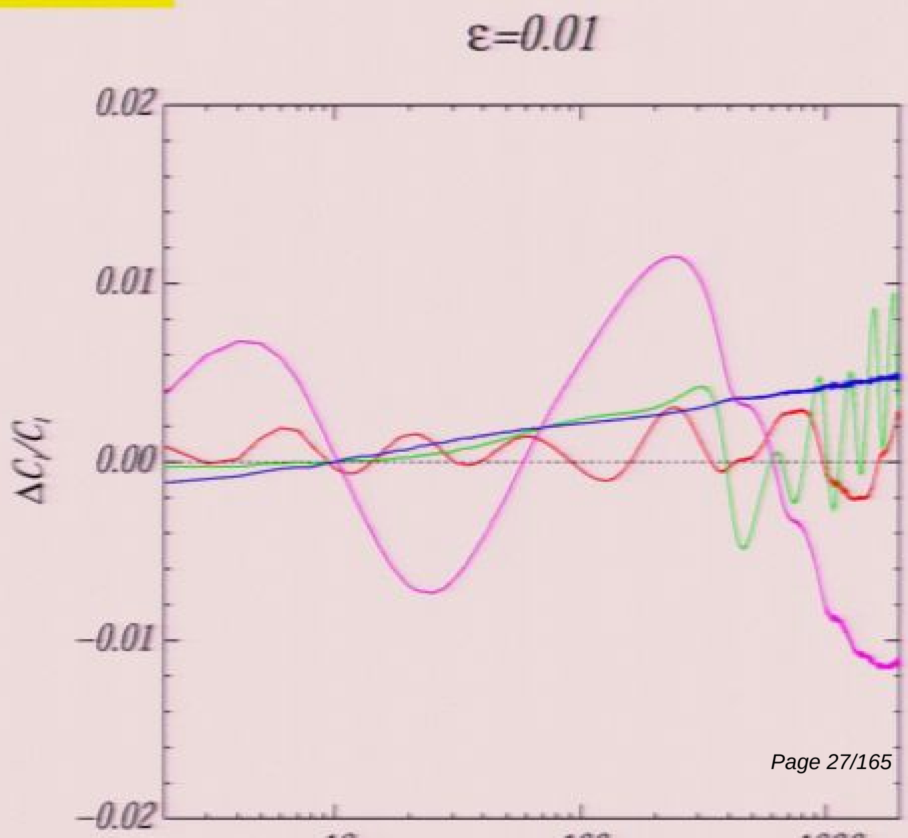
$$P_\phi = \left(\frac{H}{2\pi}\right)^2 \left(1 - \frac{H}{\Lambda}\sin\left(\frac{2\Lambda}{H}\right)\right)$$

... a modulated spectrum!

The generic expectation is of the form:

$$P_\phi = \left(\frac{H}{2\pi}\right)^2 \left(1 - \frac{H}{\Lambda}\sin\left(\frac{2\Lambda}{H}\right)\right)$$

... a modulated spectrum!



Can it be seen?

Can it be seen?

This depends on having a large enough amplitude and the right wavelength.

Can it be seen?

This depends on having a large enough amplitude and the right wavelength.

Given $$\varepsilon = \frac{M_{pl}^2}{2}\left(\frac{V'}{V}\right)^2$$

Can it be seen?

This depends on having a large enough amplitude and the right wavelength.

Given $$\varepsilon = \frac{M_{pl}^2}{2}\left(\frac{V'}{V}\right)^2$$

... one can show that the amplitude and wavelength are given according to

Can it be seen?

This depends on having a large enough amplitude and the right wavelength.

Given $$\varepsilon = \frac{M_{pl}^2}{2}\left(\frac{V'}{V}\right)^2$$

... one can show that the amplitude and wavelength are given according to

$$\boxed{\begin{aligned} \frac{H}{\Lambda} &\sim 4 \cdot 10^{-4}\,\frac{\sqrt{\varepsilon}}{\gamma} \\ \frac{\Delta k}{k} &\sim 1.3 \cdot 10^{-3}\,\frac{1}{\gamma\sqrt{\varepsilon}} \end{aligned}}$$

... where $\Lambda = \gamma M_{pl}$

Example

In order to beat cosmic variance and have modulations within the scales relevant for the CMBR we need...

$$\frac{H}{\Lambda} \sim 10^{-2}$$

$$[illegible] \sim \mathcal{O}(1)$$

Example

In order to beat cosmic variance and have modulations within the scales relevant for the CMBR we need...

$$\frac{H}{\Lambda} \sim 10^{-2}$$

$$\frac{\Delta k}{k} \sim \mathcal{O}(1)$$

Example

In order to beat cosmic variance and have modulations within the scales relevant for the CMBR we need...

$$\boxed{\begin{array}{c}\frac{H}{\Lambda} \sim 10^{-2} \\[2ex] \frac{\Delta k}{k} \sim \mathcal{O}(1)\end{array}}$$

This can be achieved with

$$\frac{\sqrt{\varepsilon}}{\gamma} \sim 20 \qquad \varepsilon \sim 10^{-2}$$

Example

In order to beat cosmic variance and have modulations within the scales relevant for the CMBR we need...

$$\boxed{\begin{aligned} \frac{H}{\Lambda} &\sim 10^{-2} \\ \frac{\Delta k}{k} &\sim \mathcal{O}(1) \end{aligned}}$$

This can be achieved with

$$\frac{\sqrt{\varepsilon}}{\gamma} \sim 20 \qquad \varepsilon \sim 10^{-2}$$

Consistent with old fashioned heterotic string compactifications...

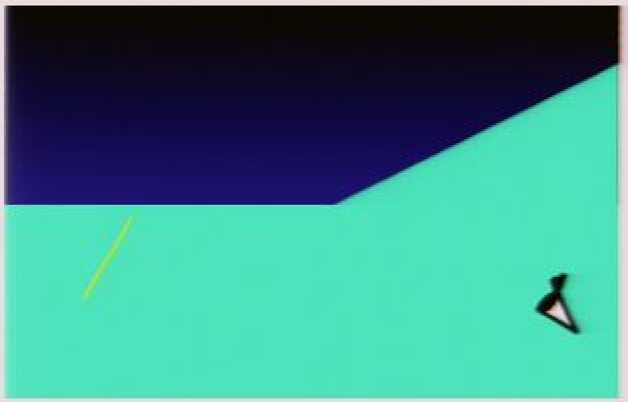
Another example...

Another example...

If really slow modulation we can allow a much larger amplitude...

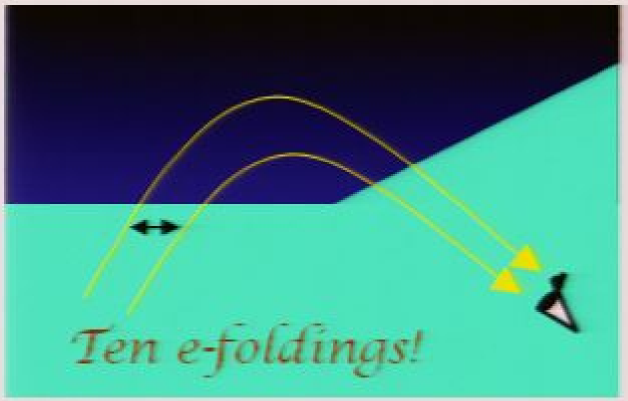
Another example…

If really slow modulation we can allow a much larger amplitude…



Another example...

If really slow modulation we can allow a much larger amplitude...

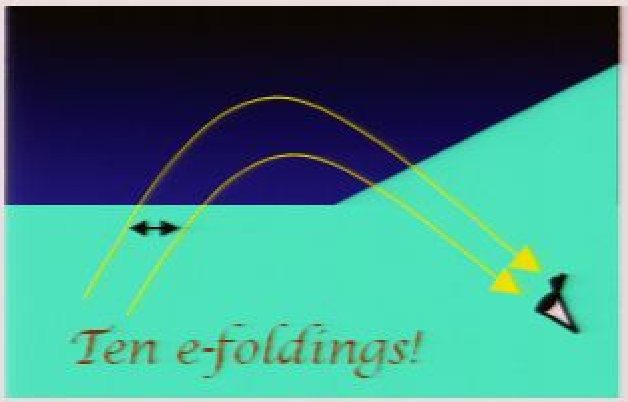


$$\frac{H}{\Lambda} \sim 10^{-1}$$

$$\frac{\Delta k}{k} \sim \mathcal{O}(10)$$

Another example...

If really slow modulation we can allow a much larger amplitude...



$$\frac{H}{\Lambda} \sim 10^{-1}$$

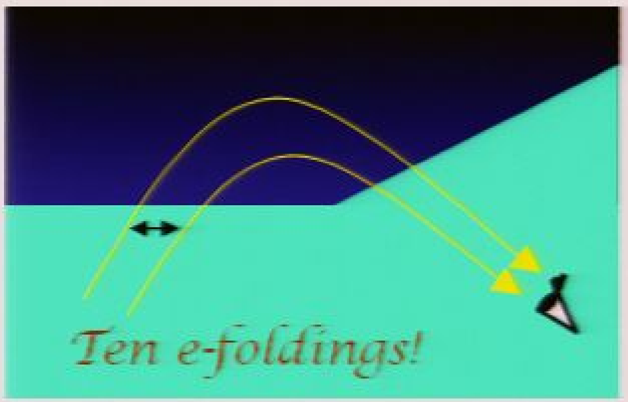
$$\frac{\Delta k}{k} \sim \mathcal{O}(10)$$

This can be achieved with

$$\frac{\sqrt{\varepsilon}}{\gamma} \sim 200 \qquad \varepsilon \sim 10^{-2}$$

Another example...

If really slow modulation we can allow a much larger amplitude...



$$\frac{H}{\Lambda} \sim 10^{-1}$$

$$\frac{\Delta k}{k} \sim \mathcal{O}(10)$$

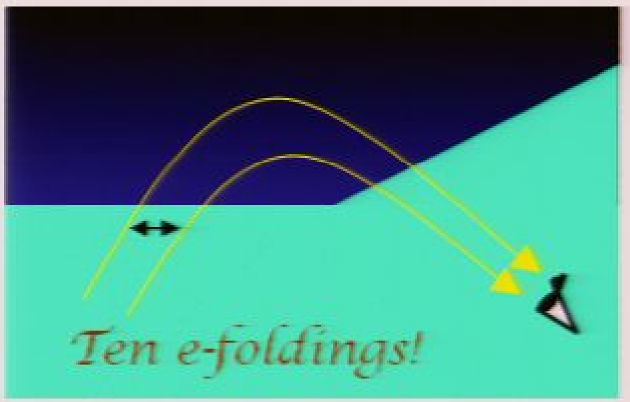
This can be achieved with

$$\frac{\sqrt{\varepsilon}}{\gamma} \sim 200 \qquad \varepsilon \sim 10^{-2}$$

... implying a string scale lowered by an order of magnitude.

Another example...

If really slow modulation we can allow a much larger amplitude...



$$\frac{H}{\Lambda} \sim 10^{-1}$$

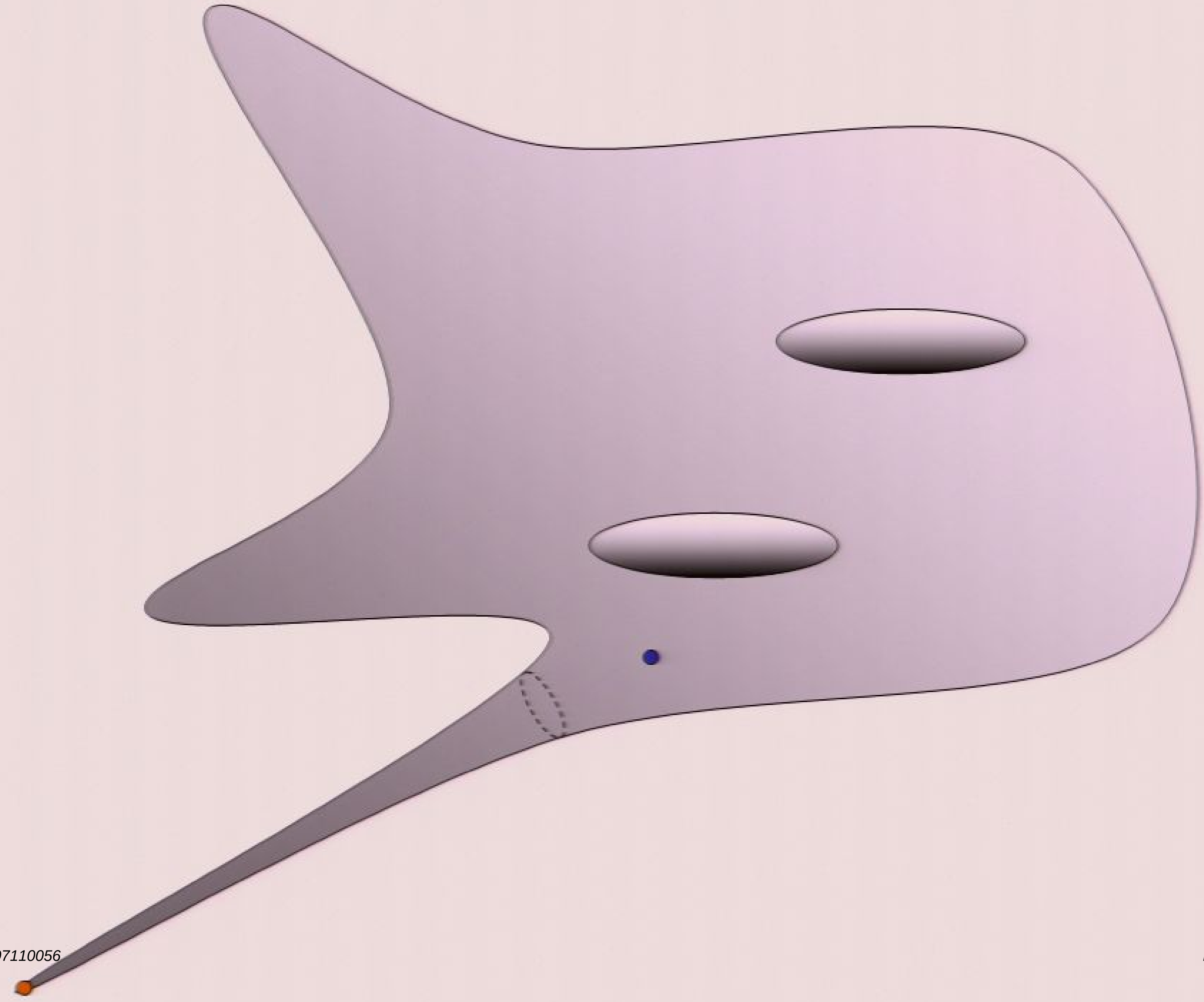
$$\frac{\Delta k}{k} \sim \mathcal{O}(10)$$

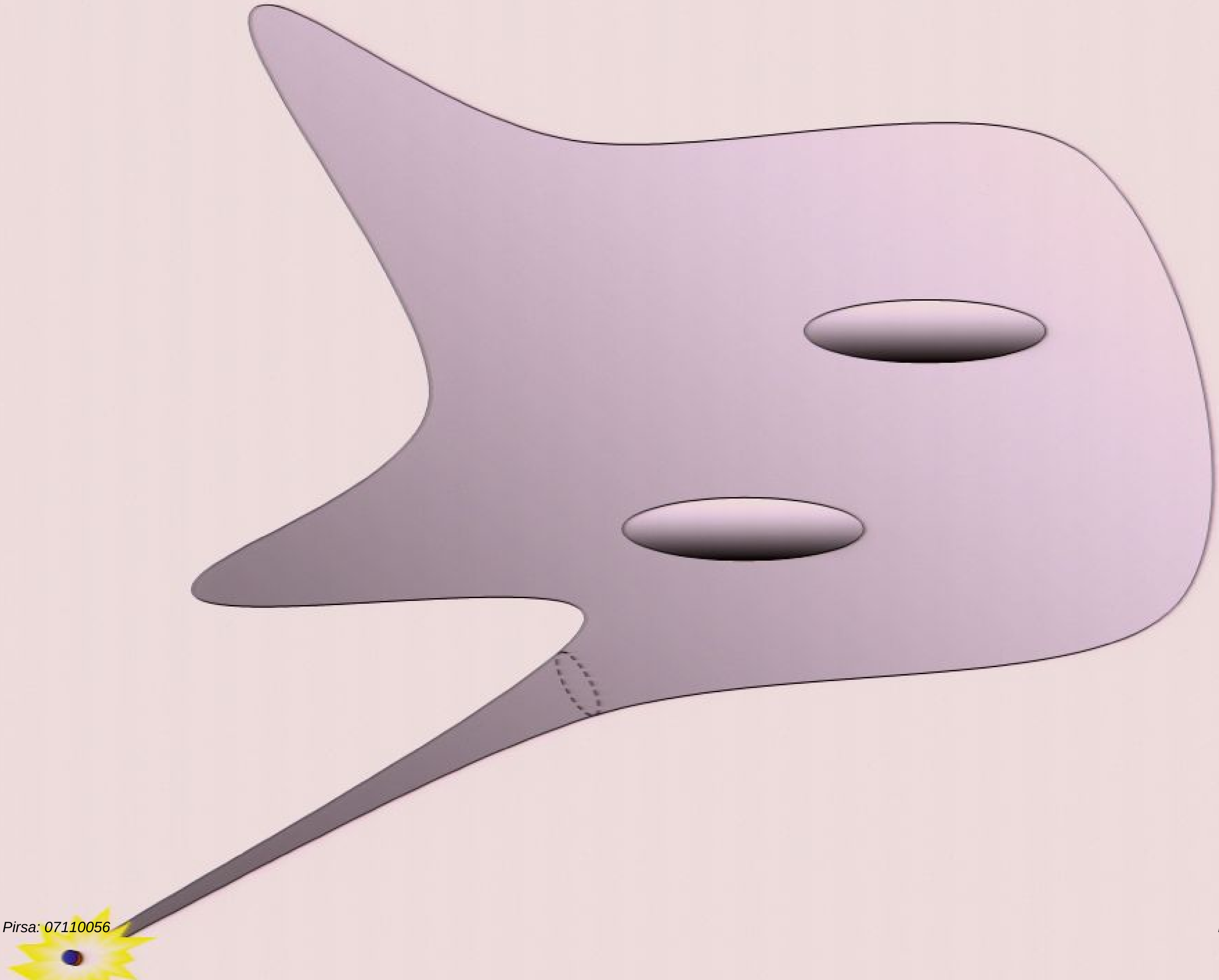
This can be achieved with

$$\frac{\sqrt{\varepsilon}}{\gamma} \sim 200 \qquad \varepsilon \sim 10^{-2}$$

... implying a string scale lowered by an order of magnitude.

Observable signature is running of the spectral parameter between CMBR and large scale structure





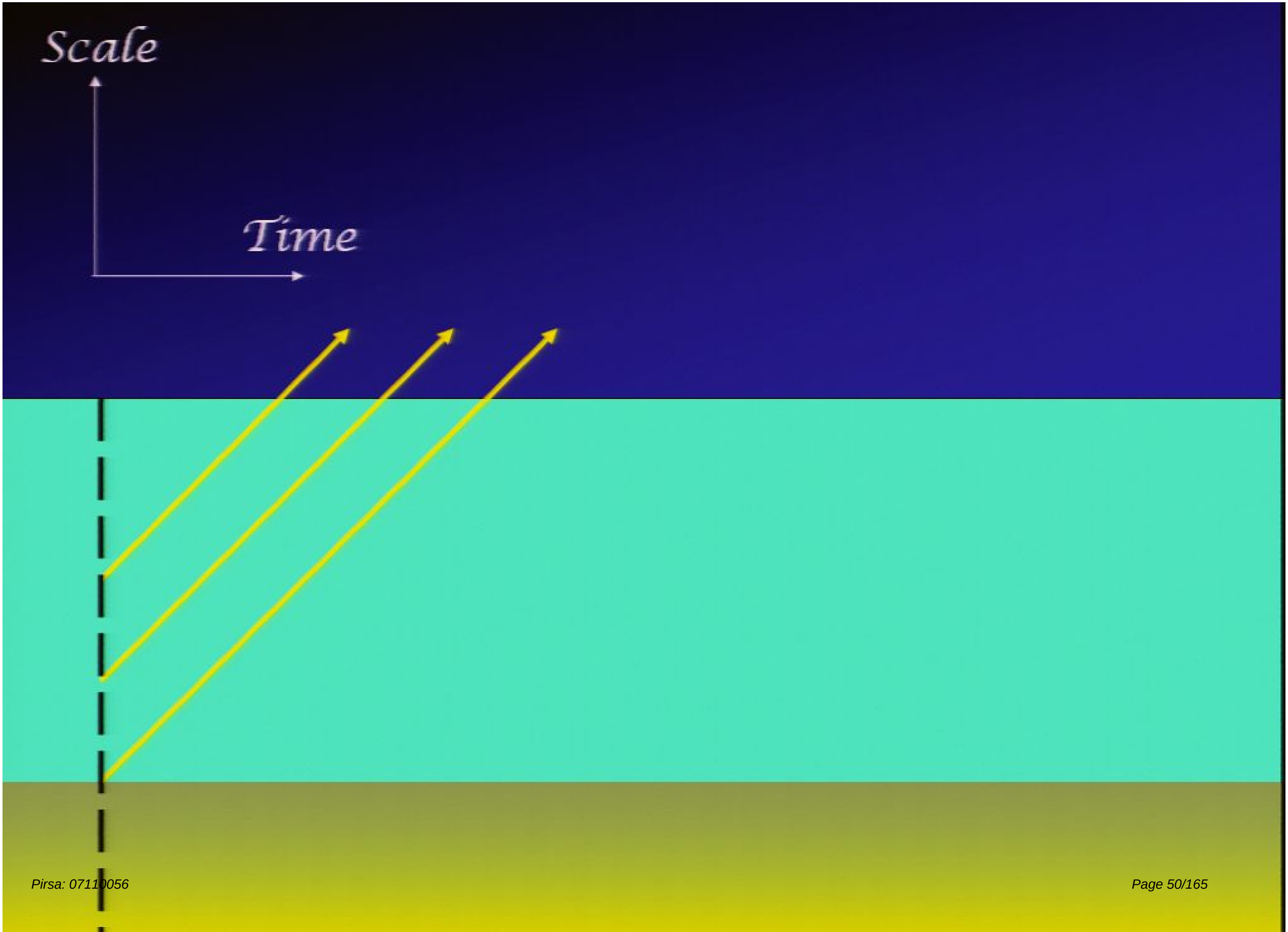
Initial conditions from where?

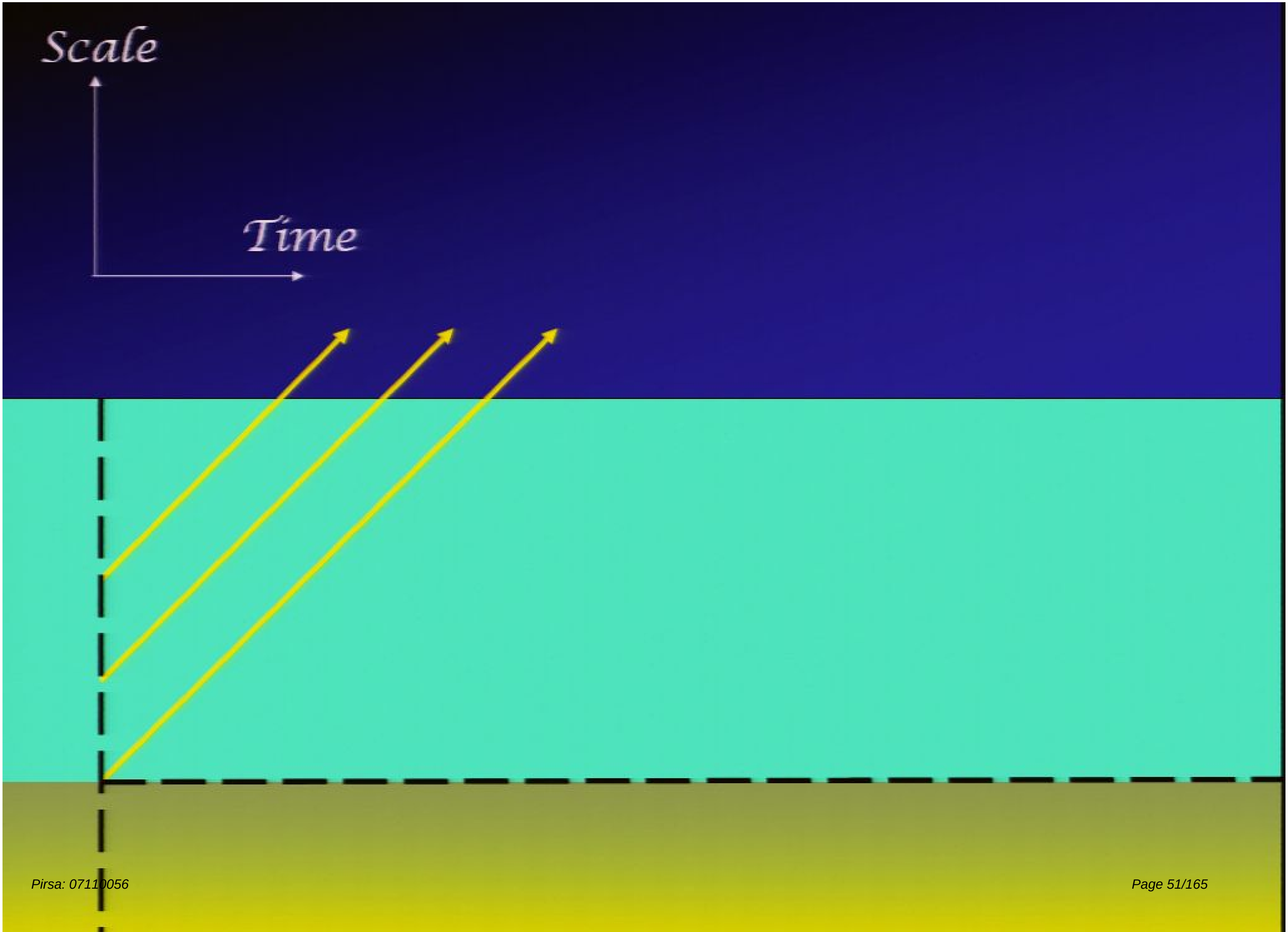
Initial conditions from where?

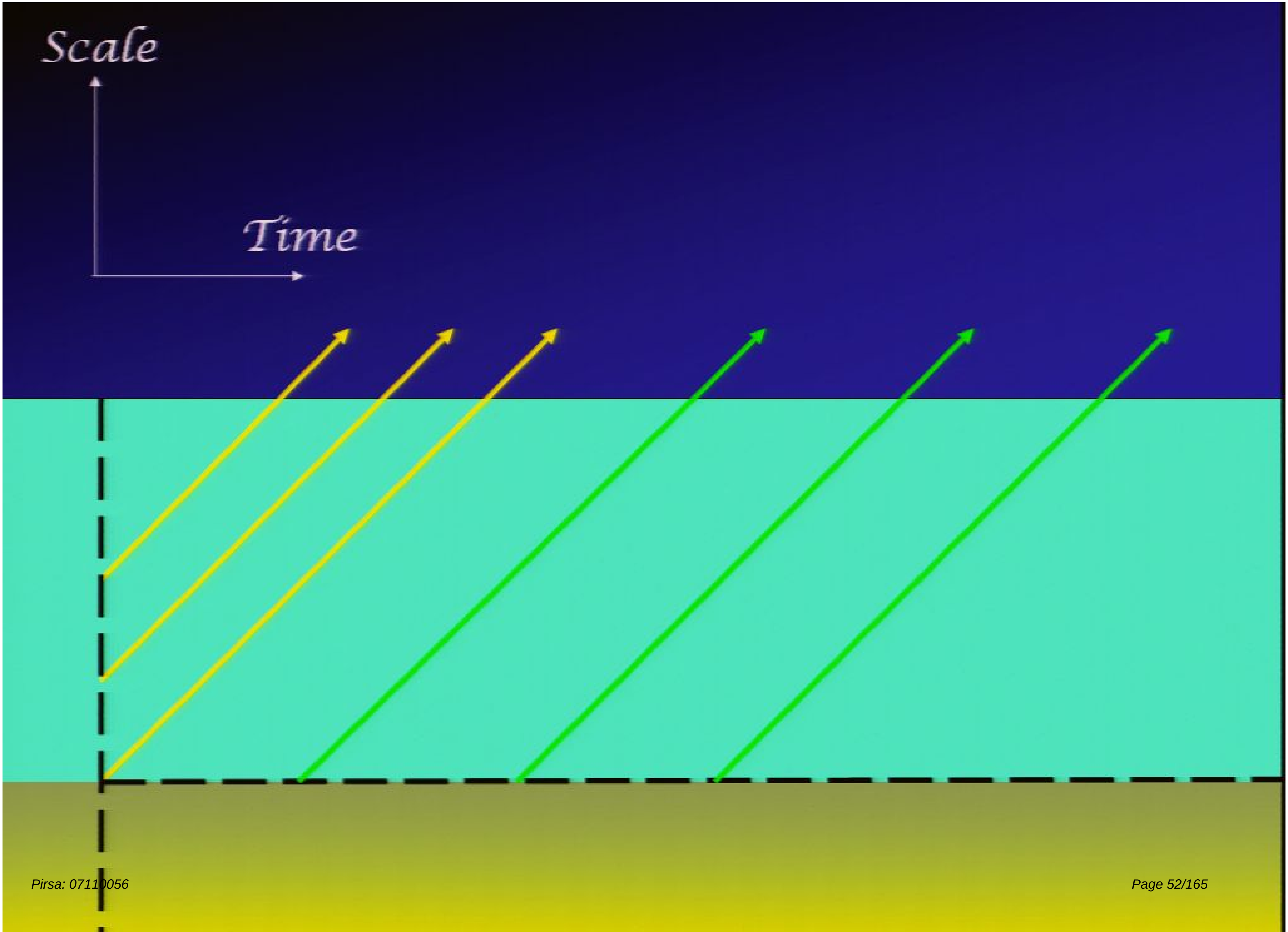
There are essentially two possible ways to introduce initial conditions for inflation...

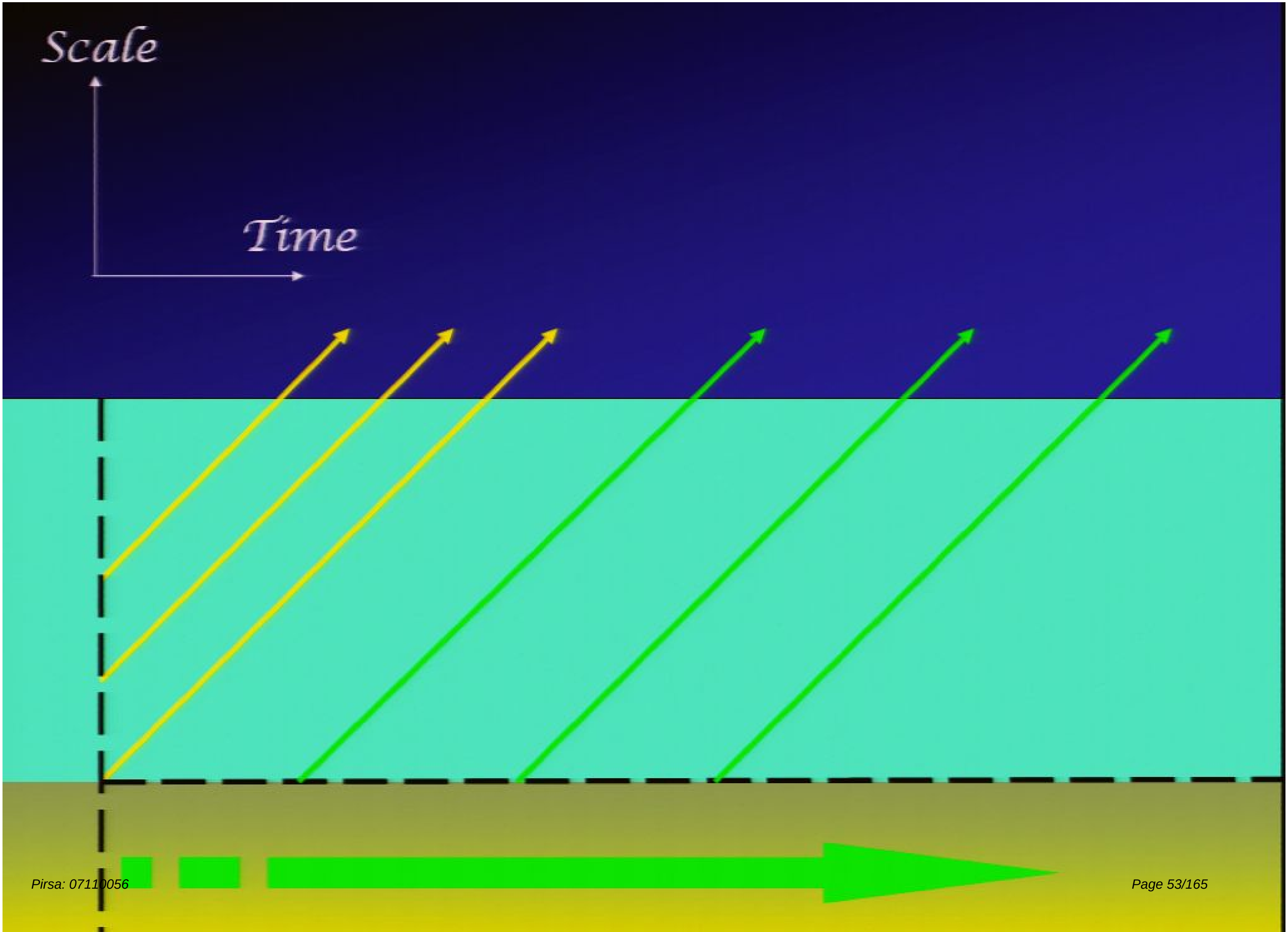

Scale
Time

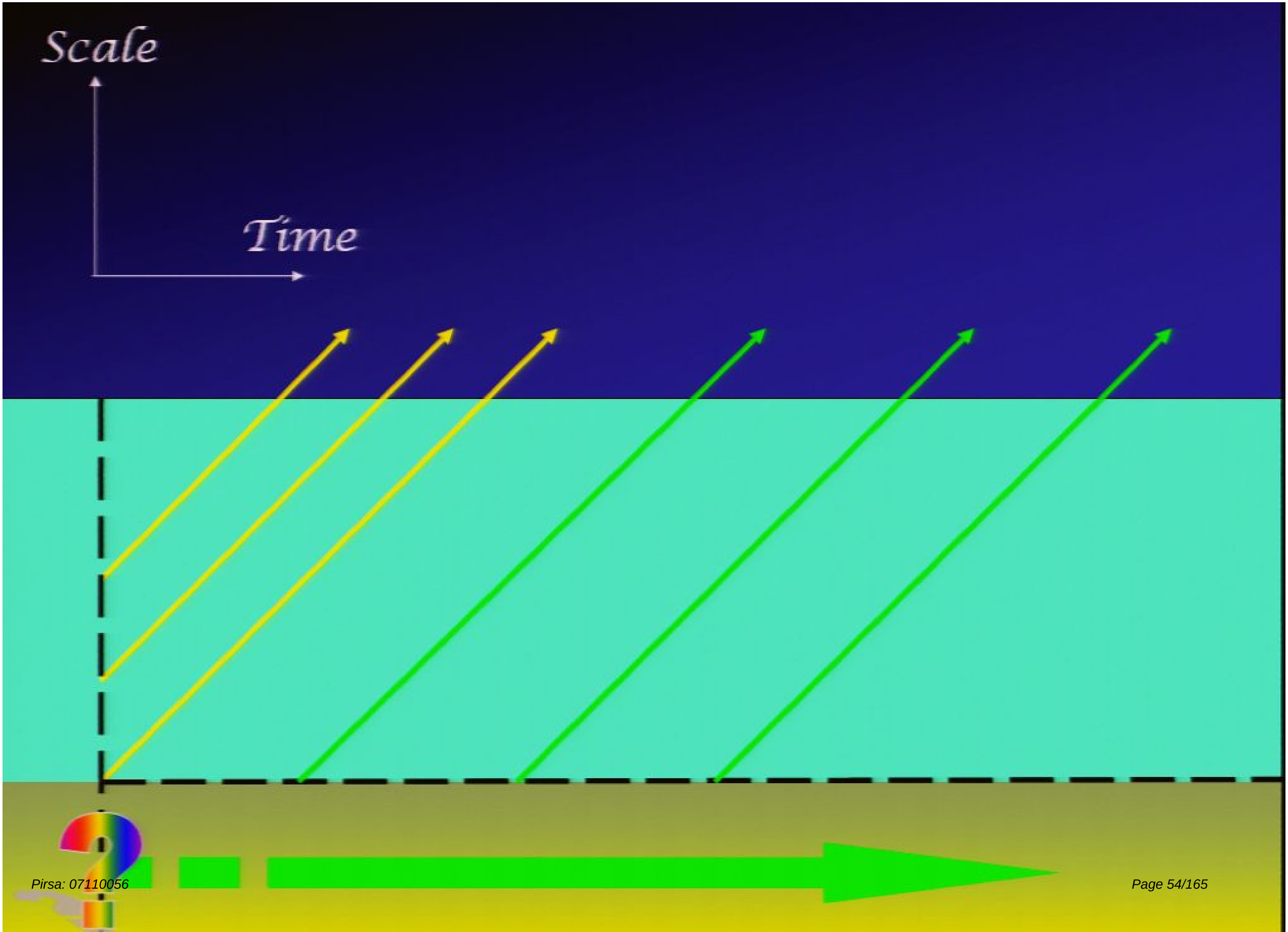

Scale
Time


Scale
Time


Scale
Time


Scale
Time


Scale
Time


Scale
Time

Perhaps there are other space times that are easier to study than de Sitter space?

Perhaps there are other space times that are easier to study than de Sitter space?

One interesting possiblity is:

Milne space

Perhaps there are other space times that are easier to study than de Sitter space?

One interesting possiblity is:

Milne space

Milne space has:

$$\rho = 0 \quad \text{and} \quad k = -1$$

Milne space has:

$$\rho = 0 \quad \text{and} \quad k = -1$$

... which gives

$$H^2 = \frac{8\pi\rho}{3} - \frac{k}{a^2} \Rightarrow a \sim t$$

Naively one would expect the transplanckian effects to be present in any expanding cosmology, Milne space not excluded.

Naively one would expect the transplanckian effects to be present in any expanding cosmology, Milne space not excluded.

Milne space is especially simple since it is related to flat Minkowsky space time through a change of coordinates...

Just put $\tilde{t} = t\cosh r, \;\; \tilde{r} = t\sinh r$

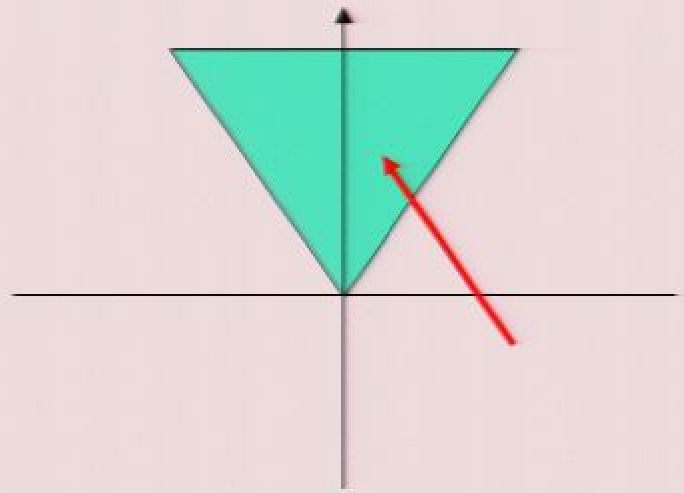
Naively one would expect the transplanckian effects to be present in any expanding cosmology, Milne space not excluded.

Milne space is especially simple since it is related to flat Minkowsky space time through a change of coordinates...

Just put $$\tilde{t} = t\cosh r, \quad \tilde{r} = t\sinh r$$

... in $$ds^2 = d\tilde{t}^2 - d\tilde{r}^2 - \tilde{r}^2 d^2\Omega$$

... to obtain $$ds^2 = dt^2 - t^2(dr^2 + \sinh^2 r d^2\Omega)$$



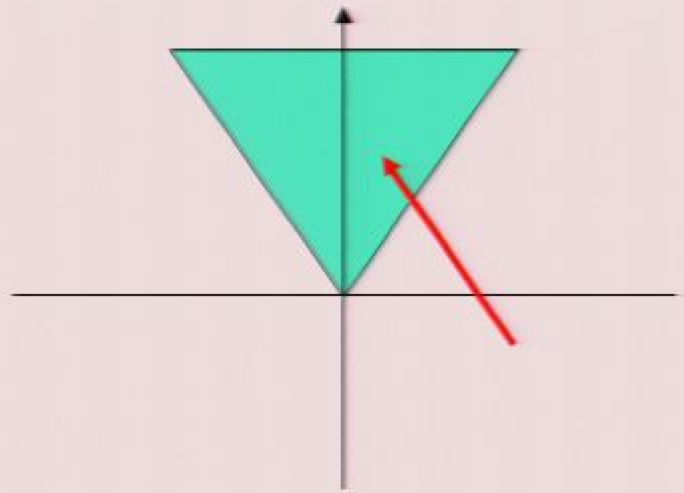
Naively one would expect the transplanckian effects to be present in any expanding cosmology, Milne space not excluded.

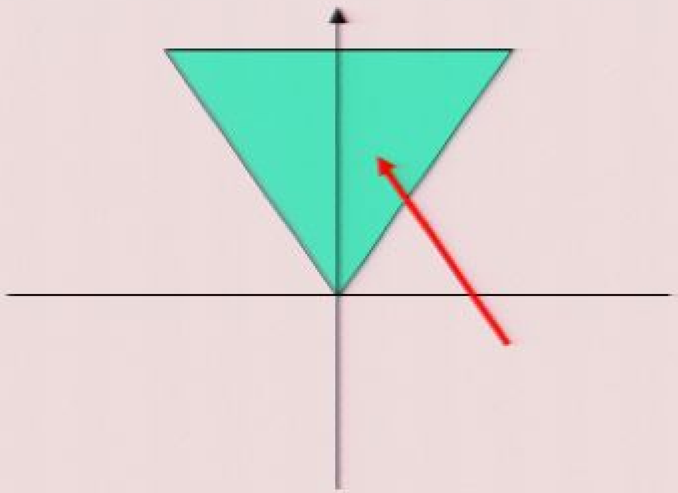
Milne space is especially simple since it is related to flat Minkowsky space time through a change of coordinates...

Just put $$\tilde{t} = t\cosh r, \quad \tilde{r} = t\sinh r$$

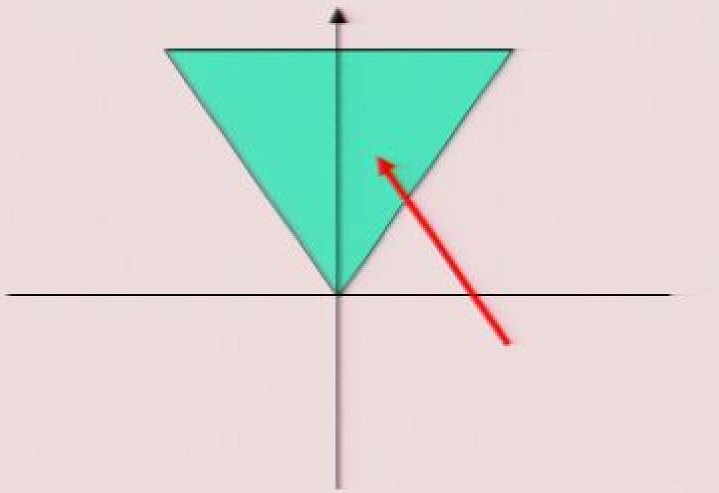
... in $$ds^2 = d\tilde{t}^2 - d\tilde{r}^2 - \tilde{r}^2 d^2\Omega$$

... to obtain $$ds^2 = dt^2 - t^2(dr^2 + \sinh^2 r d^2\Omega)$$



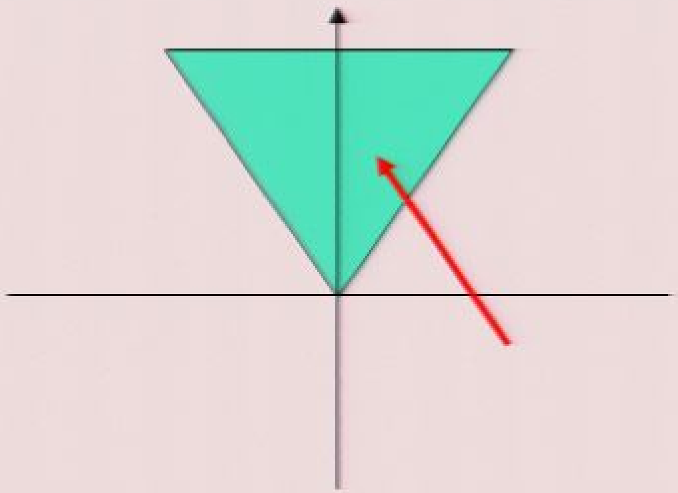


Hence one would not expect any transplanckian effects in Milne space...



Hence one would not expect any transplanckian effects in Milne space...

... and perhaps this conclusion carries over to other space times as well?



Hence one would not expect any transplanckian effects
in Milne space...

... and perhaps this conclusion carries over to other space times as well?

I will argue that it does not...

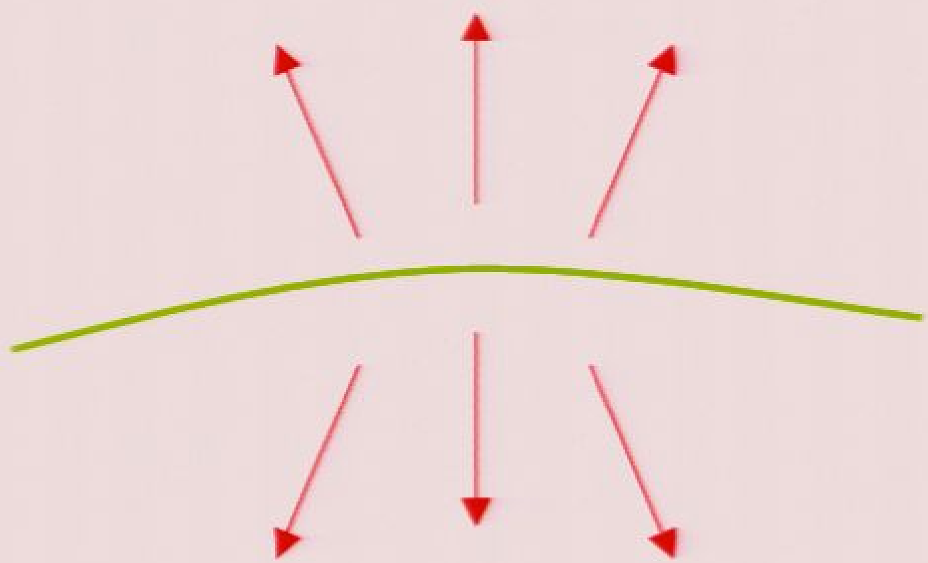
The reason has to do with the existence of anti trapped surfaces...

The reason has to do with the existence of anti trapped surfaces...

An anti trapped surface is a two-sphere where both ingoing and outgoing normal null geodesics diverge.

The reason has to do with the existence of anti trapped surfaces...

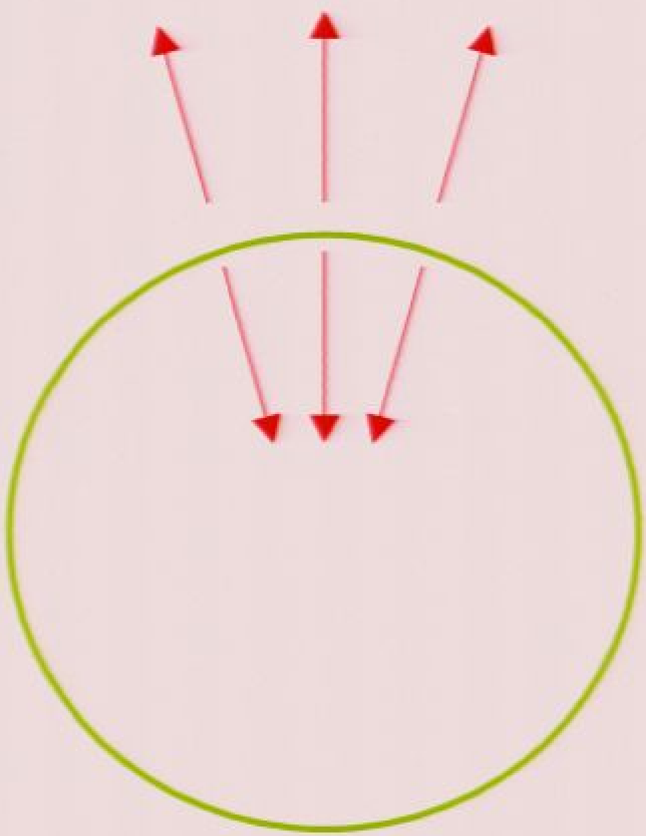
An anti trapped surface is a two-sphere where both ingoing and outgoing normal null geodesics diverge.



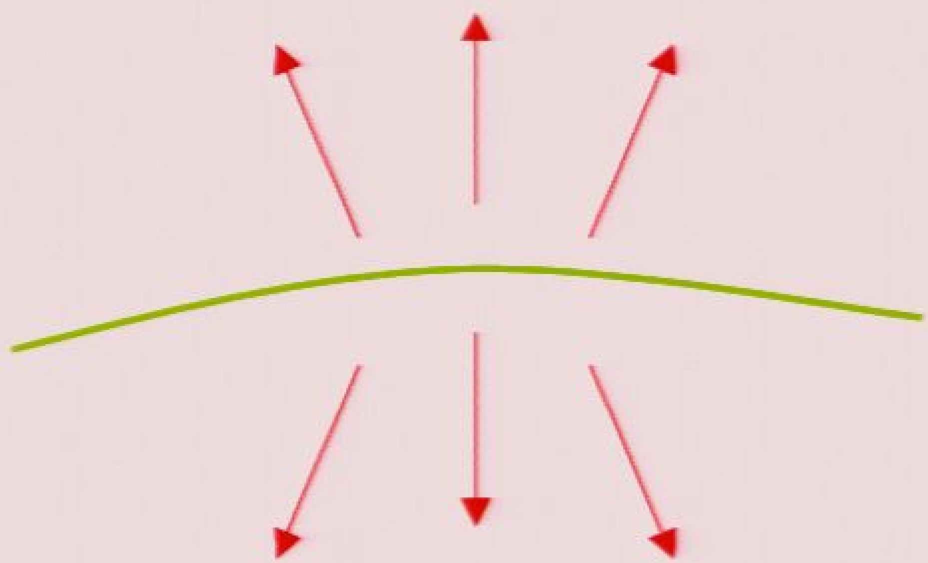
Anti trapped

The reason has to do with the existence of anti trapped surfaces...

An anti trapped surface is a two-sphere where both ingoing and outgoing normal null geodesics diverge.



Normal



Anti trapped

The divergence of ingoing null geodesics is given by:

$$\Theta = \frac{2}{a}\left(H - \frac{\sqrt{1-kr^2}}{ar}\right)$$

The divergence of ingoing null geodesics is given by:

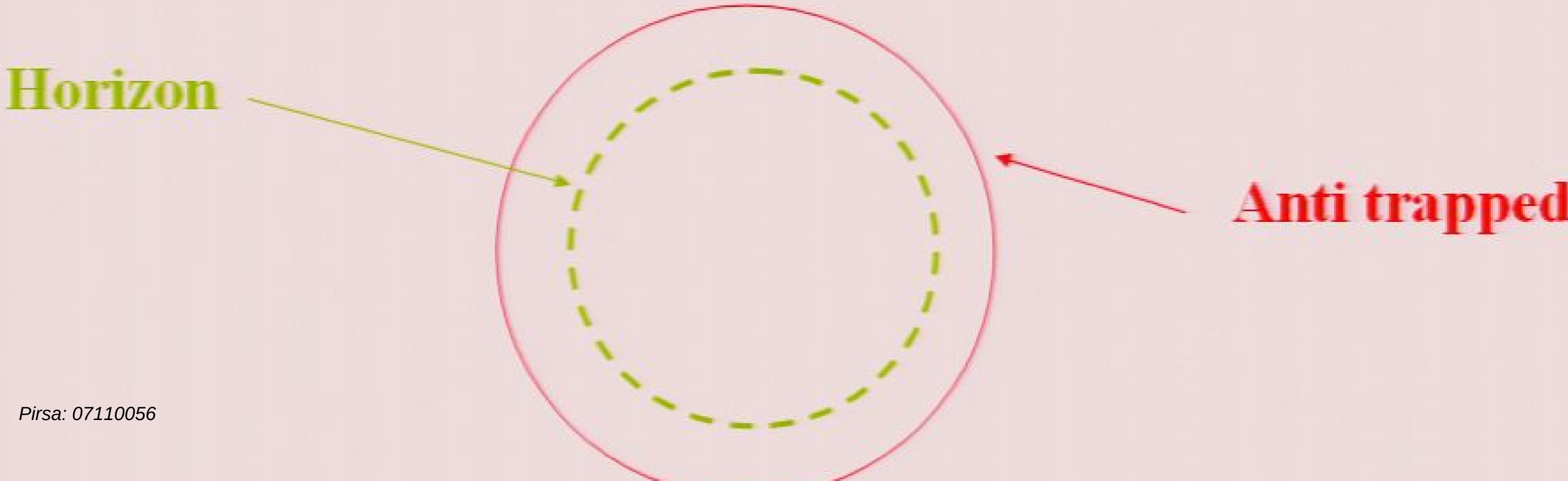
$$\Theta = \frac{2}{a}\left(H - \frac{\sqrt{1-kr^2}}{ar} \right)$$

With $k = 0$ we find $\Theta > 0$ for $ar > H^{-1}$

The divergence of ingoing null geodesics is given by:

$$\Theta = \frac{2}{a}\left(H - \frac{\sqrt{1-kr^2}}{ar} \right)$$

With $k = 0$ we find $\Theta > 0$ for $ar > H^{-1}$



With $k = -1$ we find

With $k = -1$ we find

$$\Theta = \frac{2}{a^2}\left(1 - \frac{\sqrt{1+r^2}}{r}\right) < 0$$

With $k = -1$ we find

$$\Theta = \frac{2}{a^2}\left(1 - \frac{\sqrt{1+r^2}}{r}\right) < 0$$

That is, no anti trapped surfaces in Milne space. This is obvious since Milne space is really just Minkowsky space...

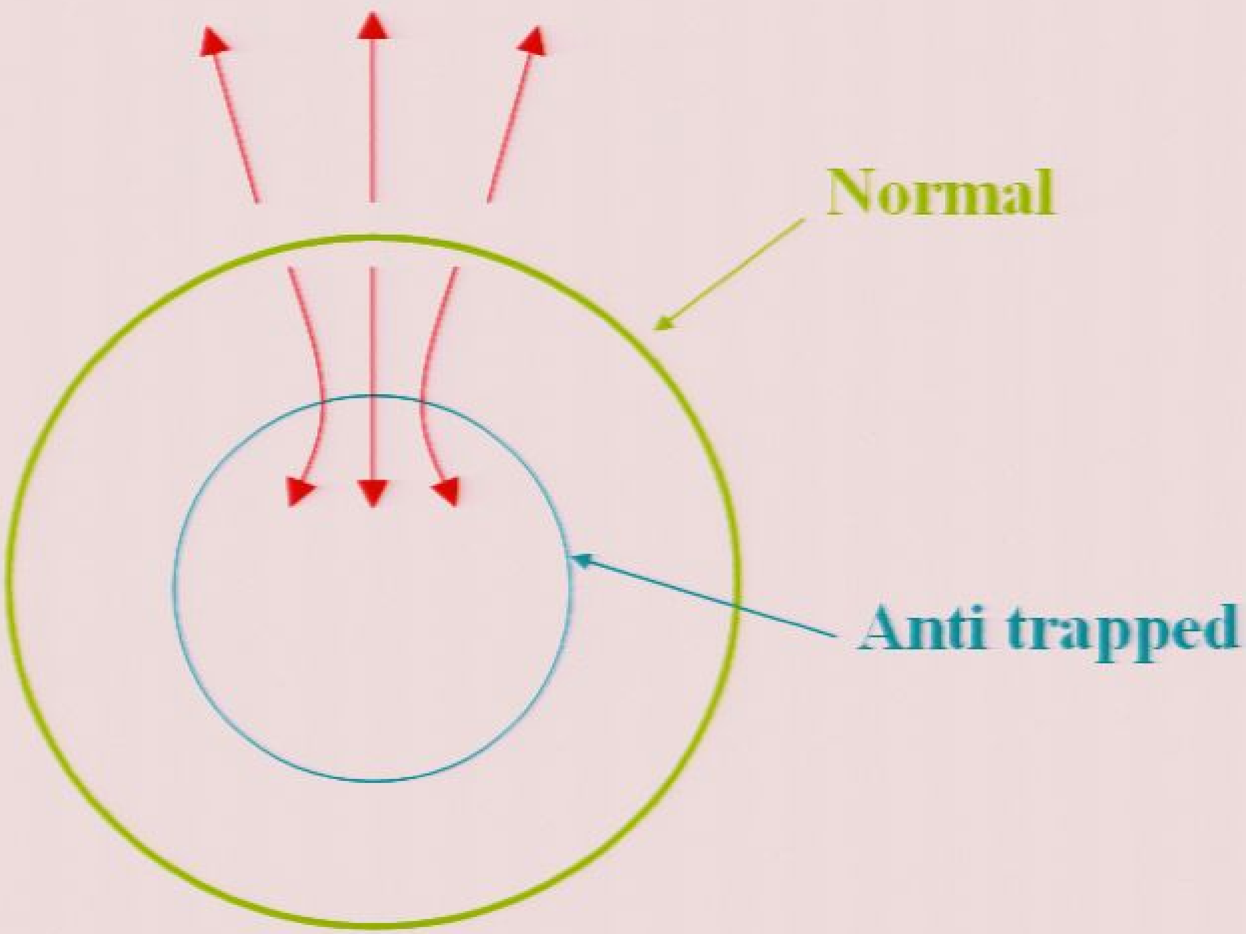
The Raychaudhuri equation tells us that matter obeying the weak energy condition has:

$$\frac{d\Theta}{d\tau} \leq 0$$

The Raychaudhuri equation tells us that matter obeying the weak energy condition has:

$$\frac{d\Theta}{d\tau} \leq 0$$

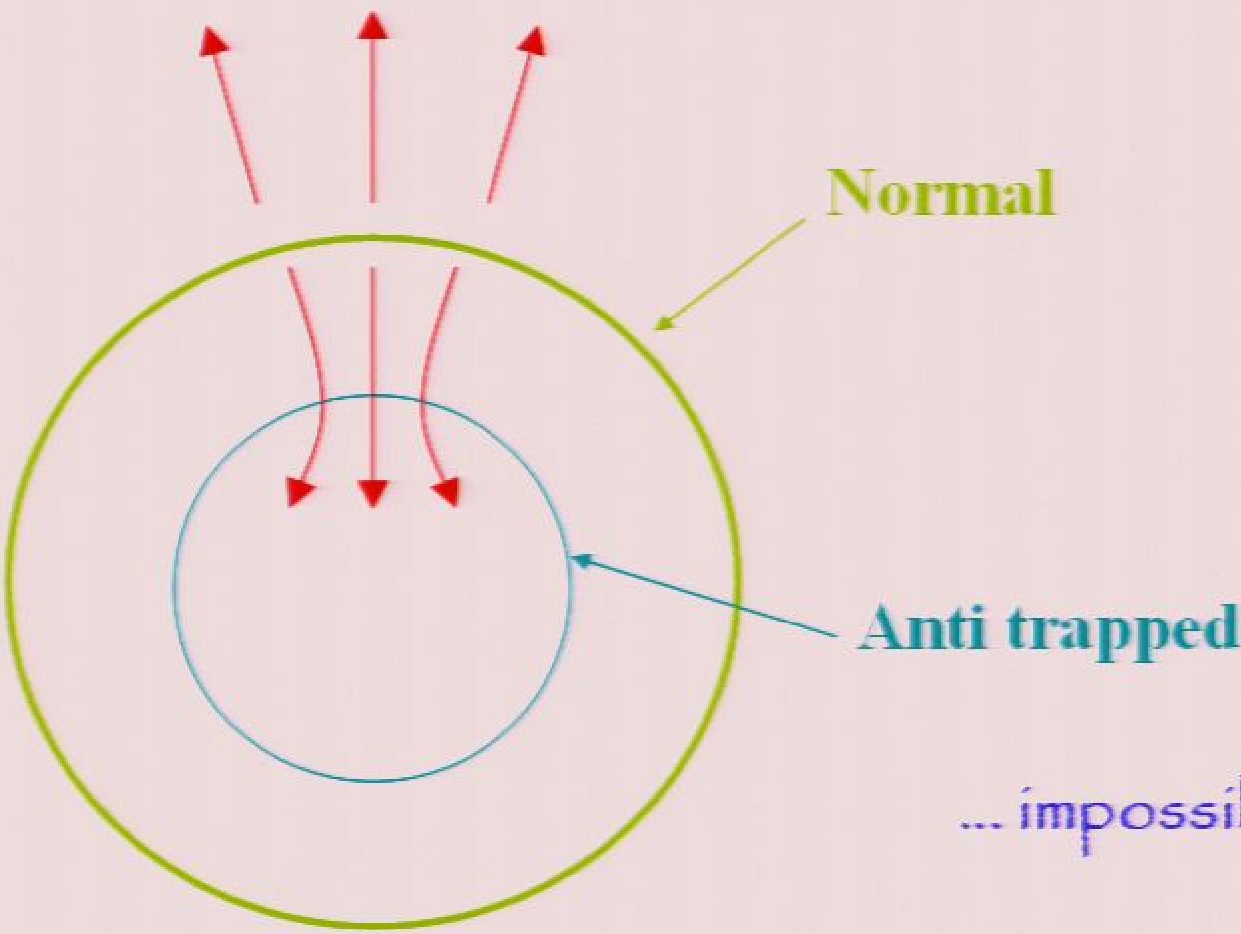
Hence is...



The Raychaudhuri equation tells us that matter obeying the weak energy condition has:

$$\frac{d\Theta}{d\tau} \leq 0$$

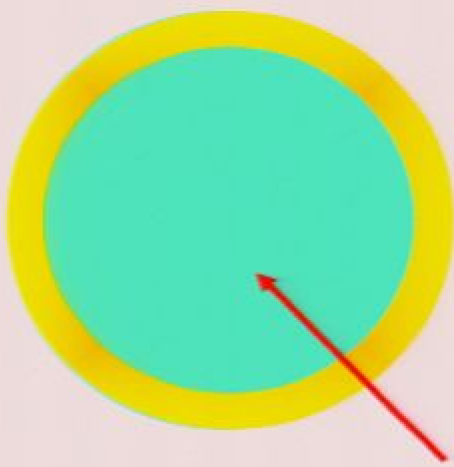
Hence is...

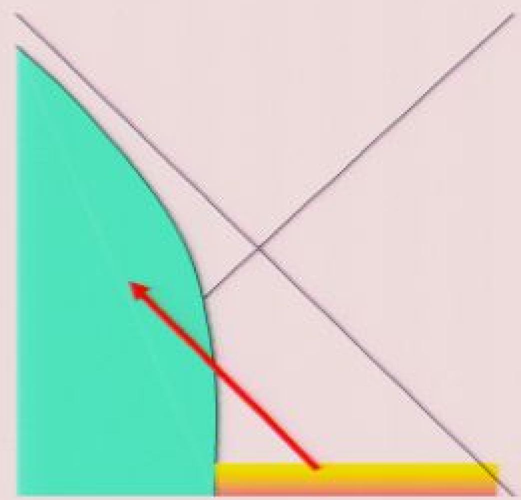


... impossible!

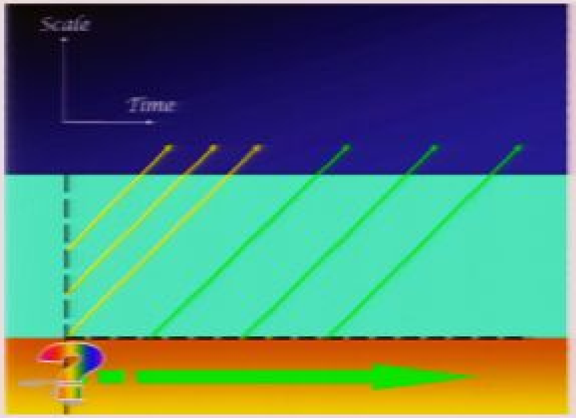
A region with anti trapped surfaces cannot be embedded in normal space without breaking the weak energy condition or having a singularity...

A region with anti trapped surfaces cannot be embedded in normal space without breaking the weak energy condition or having a singularity...

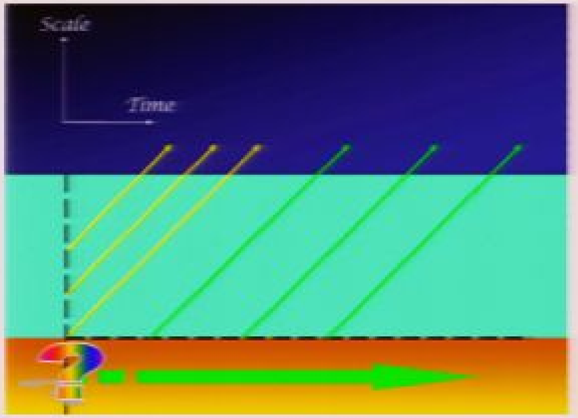




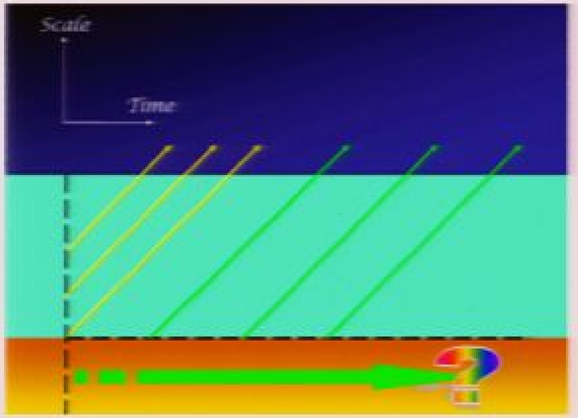
That was...



That was...



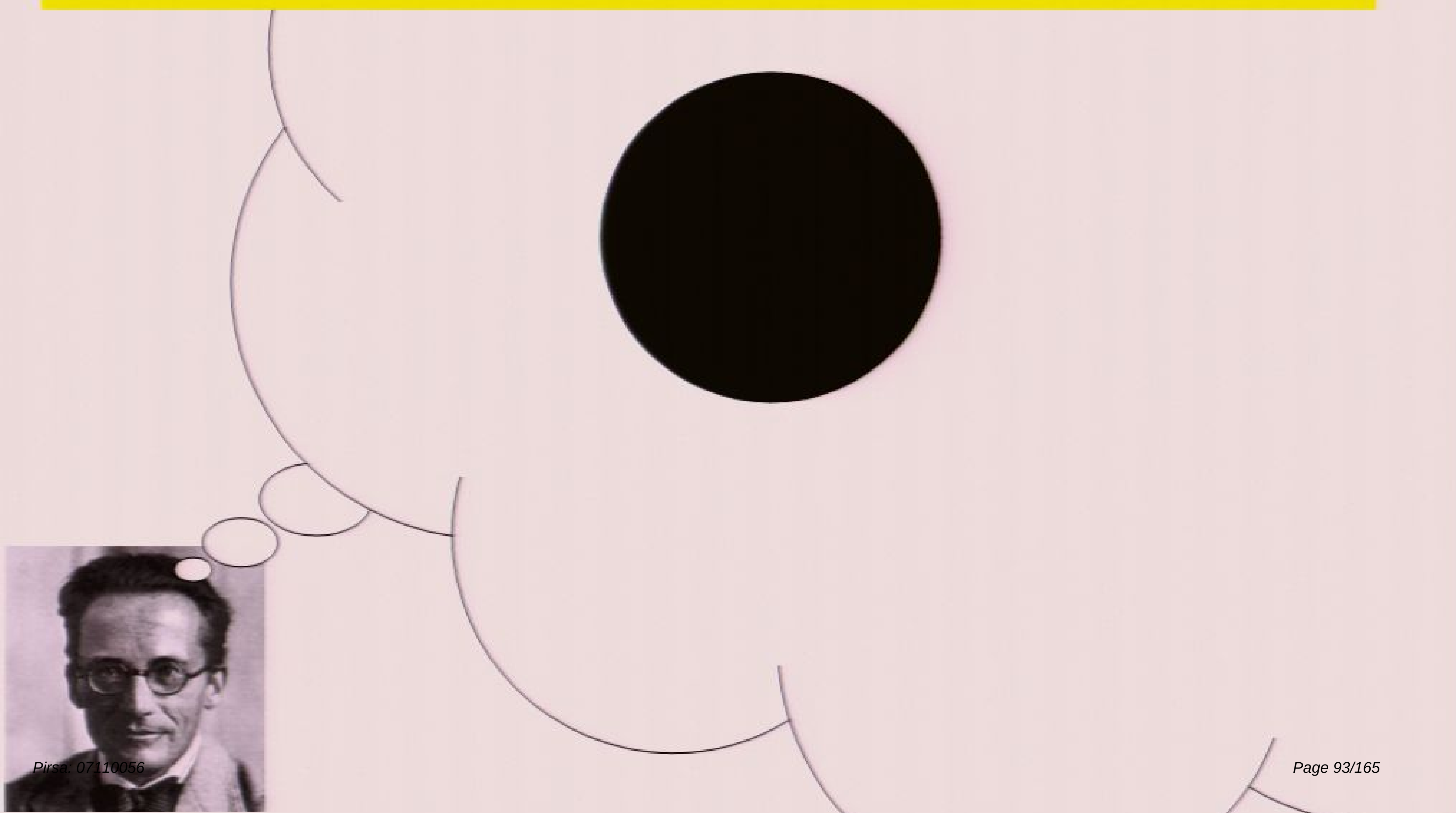
... now it is time for



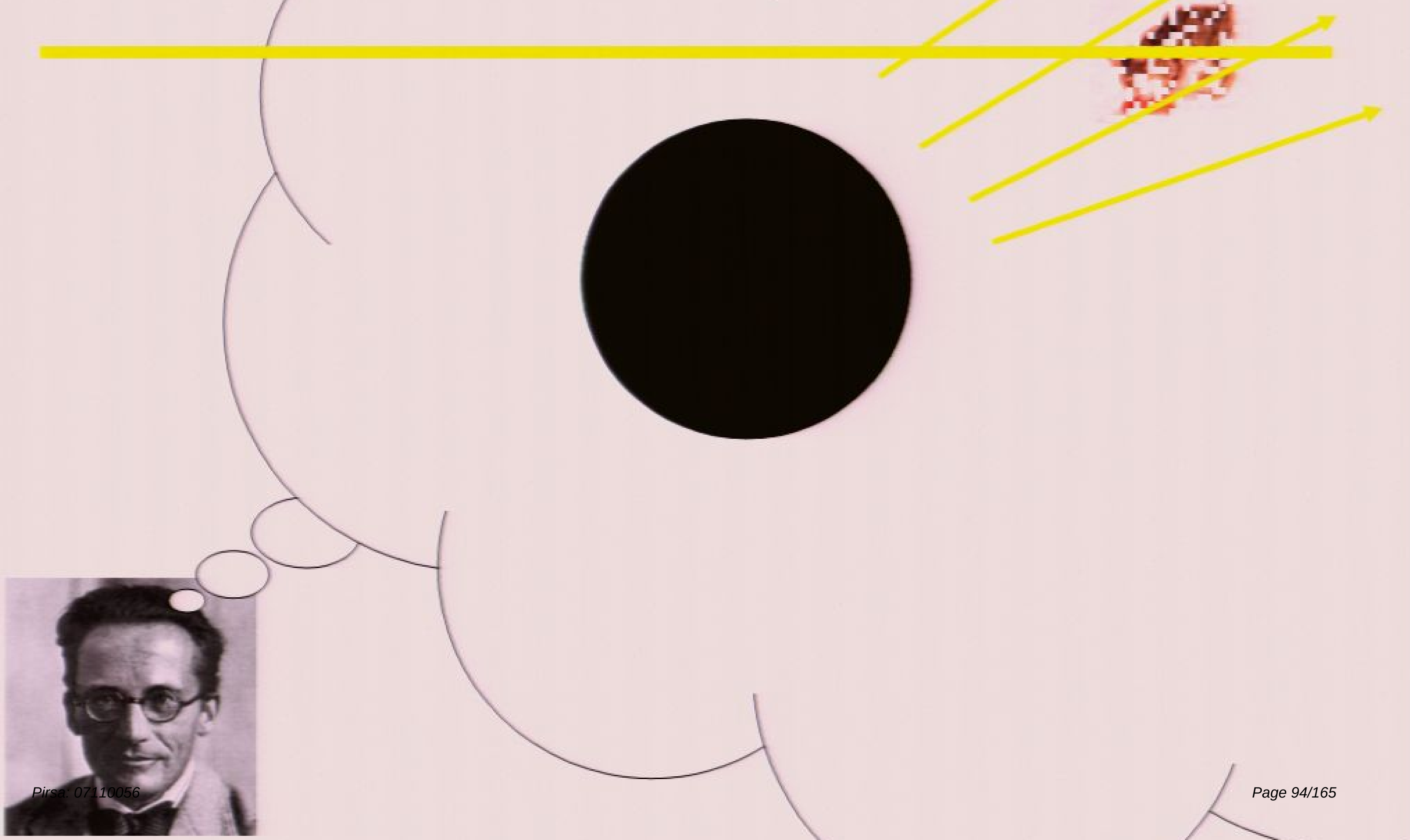
An information paradox?

An information paradox?

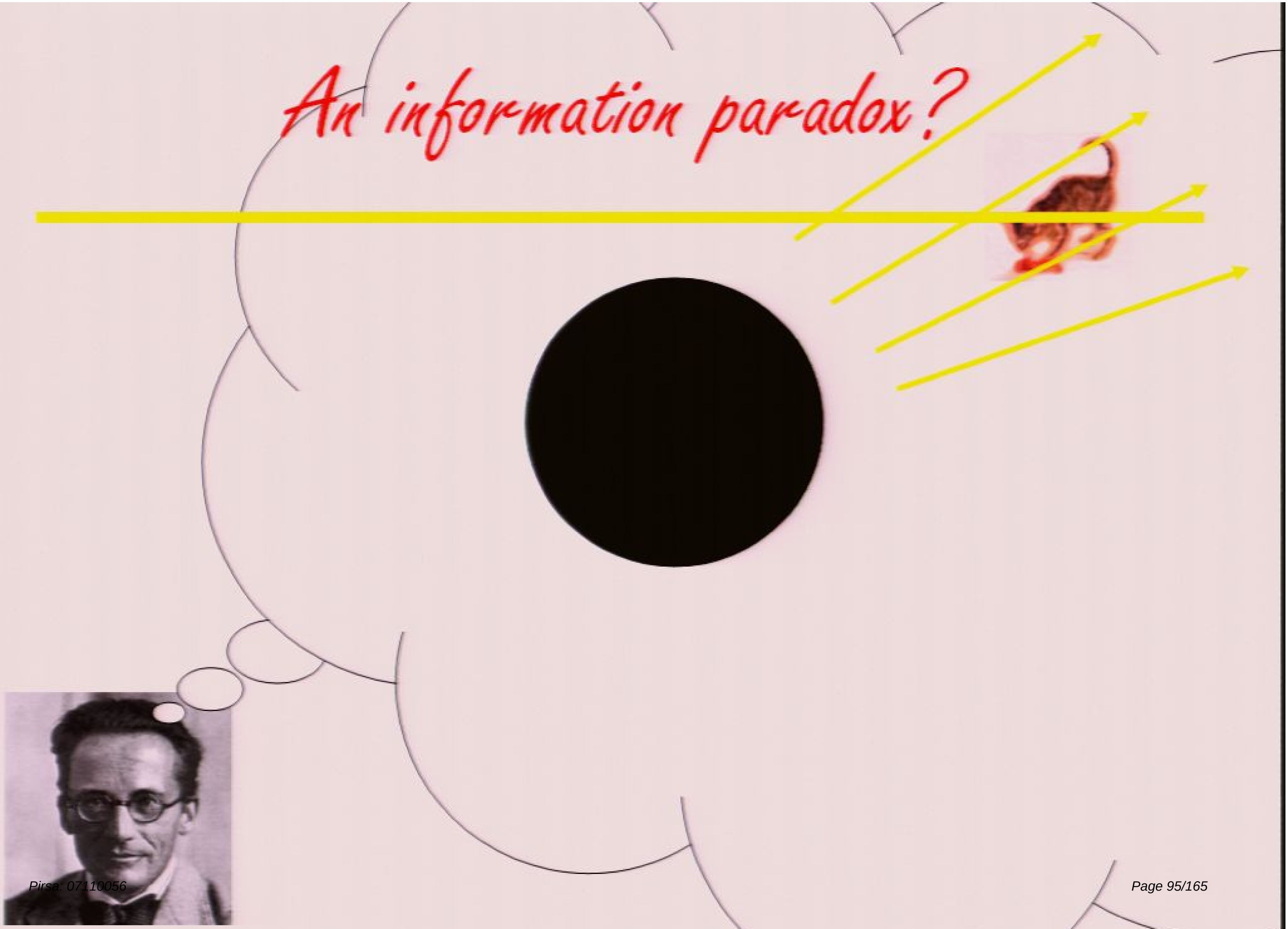
An information paradox?



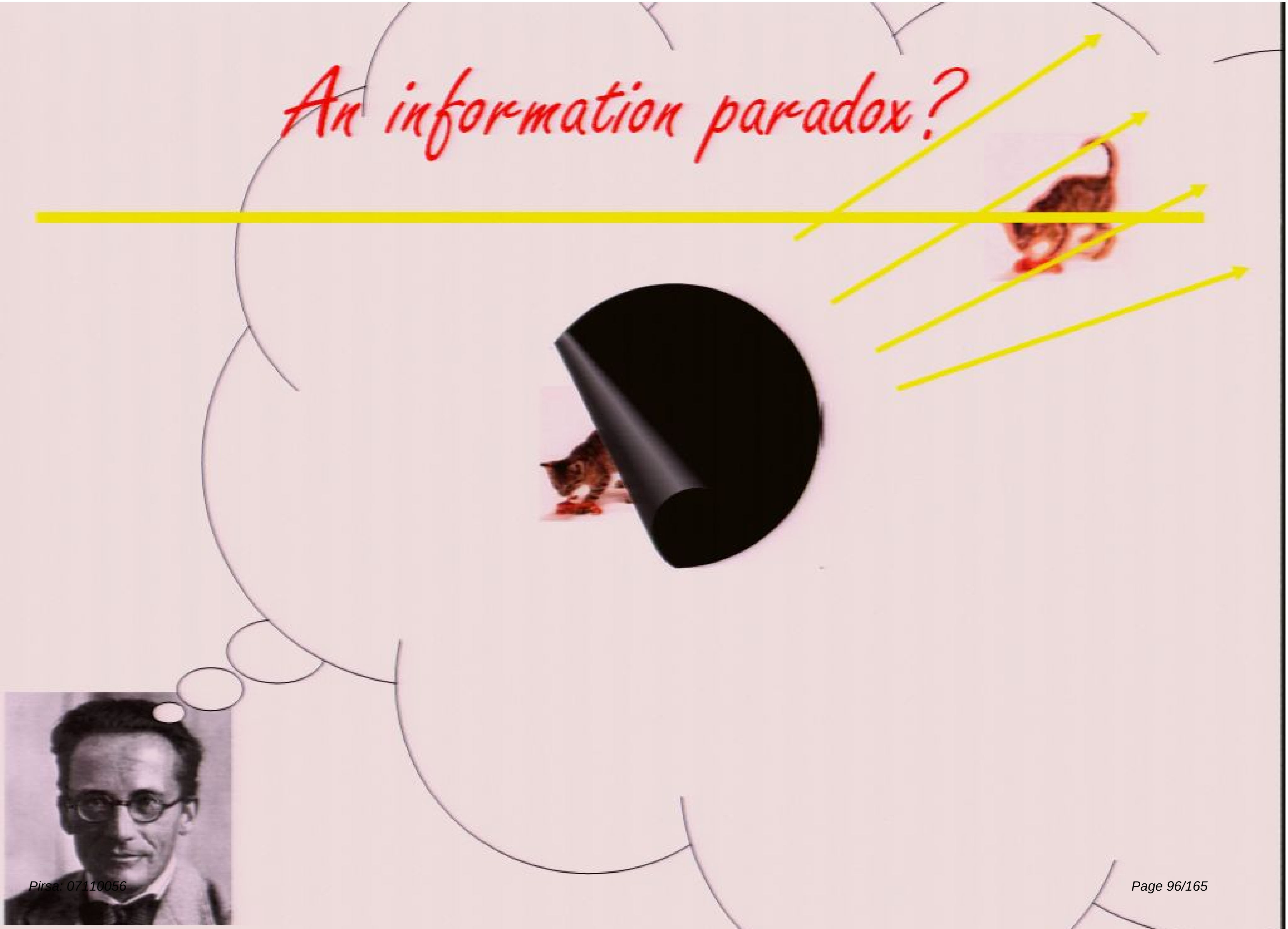
An information paradox?



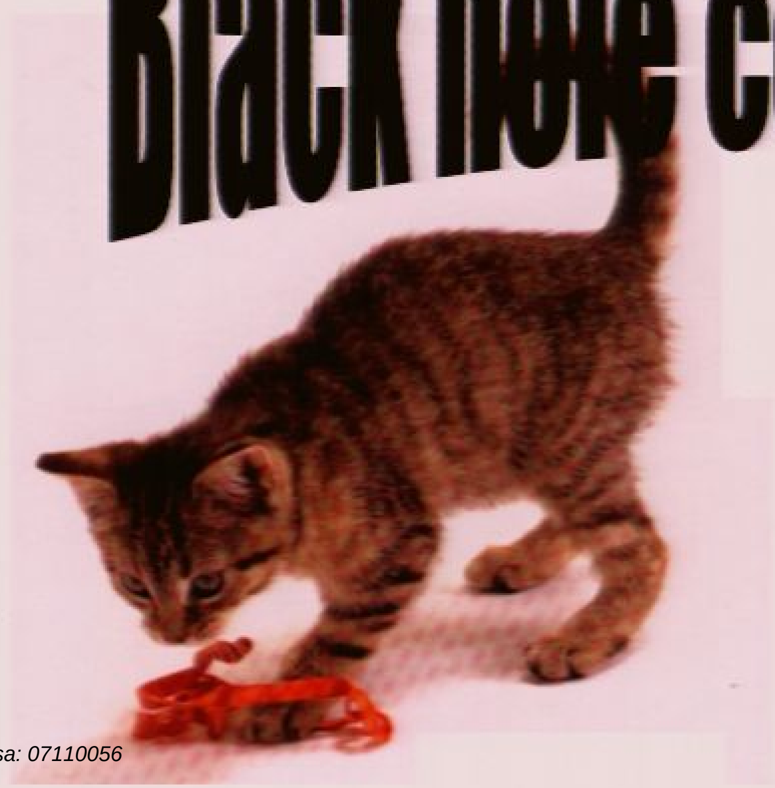
An information paradox?

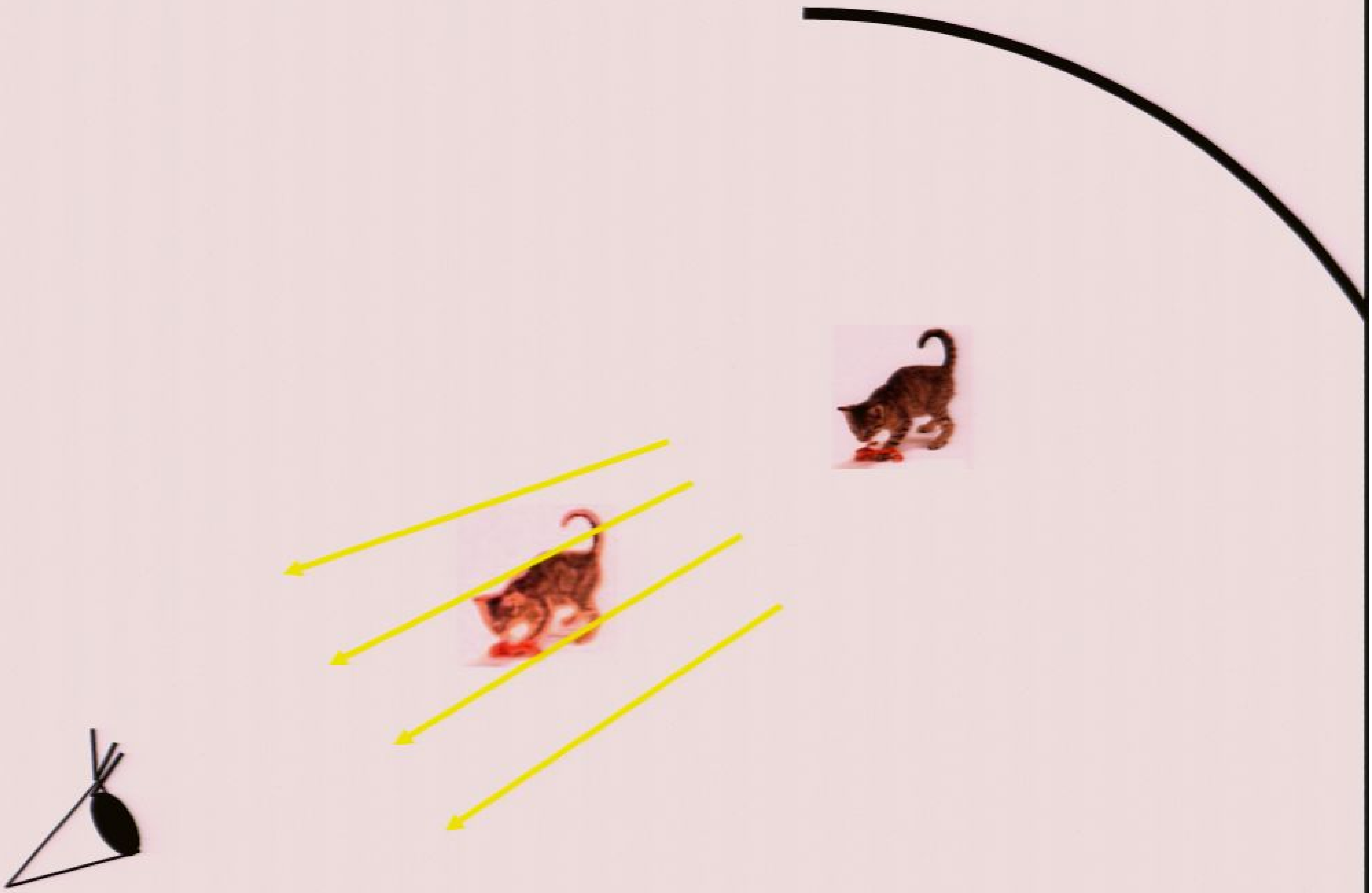


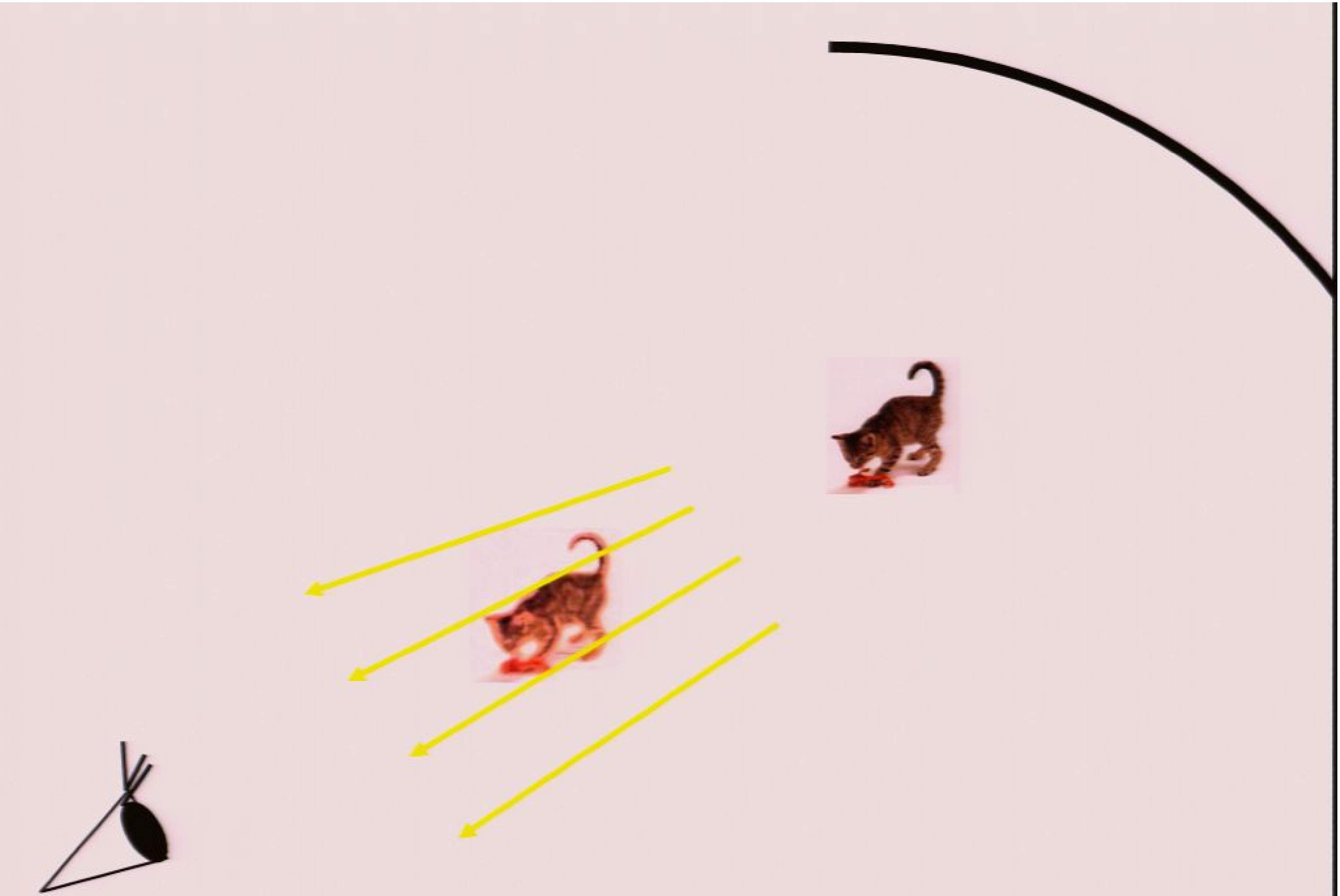
An information paradox?

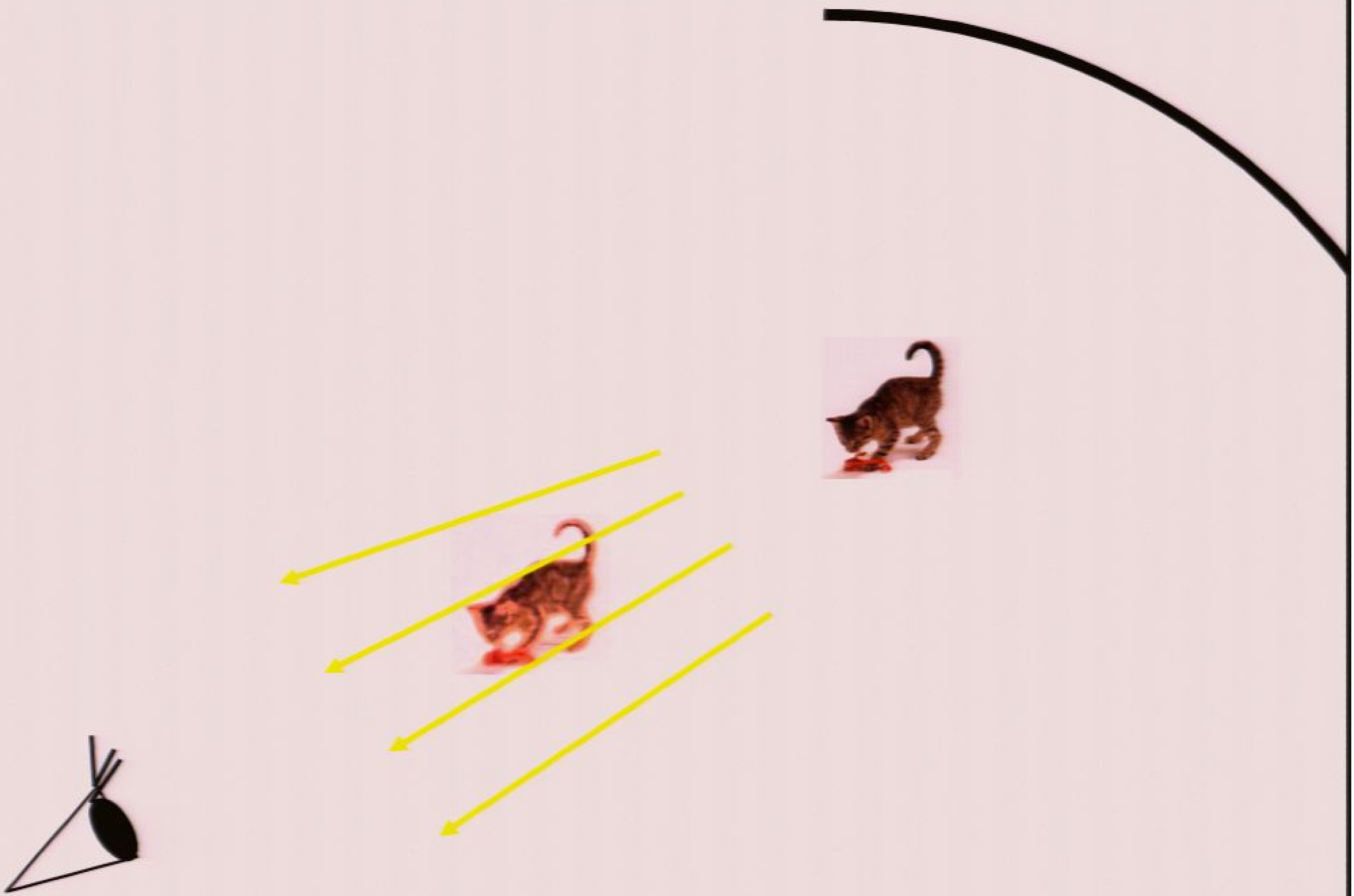


Black hole complementarity









What is the time it takes to actually see the cat evaporate?

$1/T \sim 1/H \sim R$ ... is certainly too short...

$1/T \sim 1/H \sim R$ ... is certainly too short...

Note that the emission rate is only:

[illegible]

$$1/T \sim 1/H \sim R$$ ... is certainly too short...

Note that the emission rate is only:

$$T^3 \cdot A \sim T^3 \cdot R^2 \sim T \sim 1/R$$

$$1/T \sim 1/H \sim R$$ ... is certainly too short...

Note that the emission rate is only:

$$T^3 \cdot A \sim T^3 \cdot R^2 \sim T \sim 1/R$$

$$1/T \sim 1/H \sim R$$ ... is certainly too short...

Note that the emission rate is only:

$$T^3 \cdot A \sim T^3 \cdot R^2 \sim T \sim 1/R$$

$$\Longrightarrow \quad \tau \sim R^2/l_p^2 \cdot R \sim R^3/l_p^2$$

$$1/T \sim 1/H \sim R$$ ... is certainly too short...

Note that the emission rate is only:

$$T^3 \cdot A \sim T^3 \cdot R^2 \sim T \sim 1/R$$

$$\tau \sim R^2/l_p^2 \cdot R \sim R^3/l_p^2$$

$$\tau \sim R^2/l_p^2 \cdot R \sim R^3/l_p^2$$

This is a VERY long time...

This is a VERY long time...

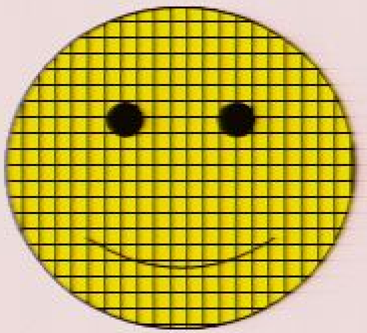
Actually, can anyone survive that long?

This is a VERY long time...

Actually, can anyone survive that long?

This is a VERY long time...

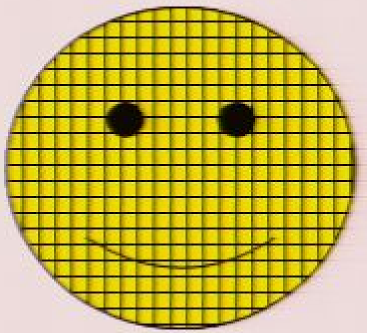
Actually, can anyone survive that long?



Planck scale sized cells...

This is a VERY long time...

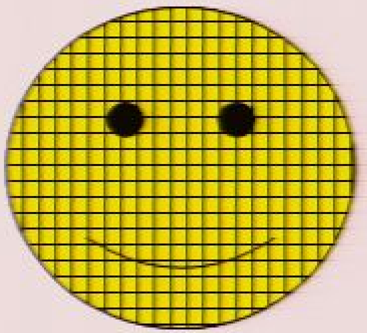
Actually, can anyone survive that long?



Planck scale sized cells...

This is a VERY long time...

Actually, can anyone survive that long?

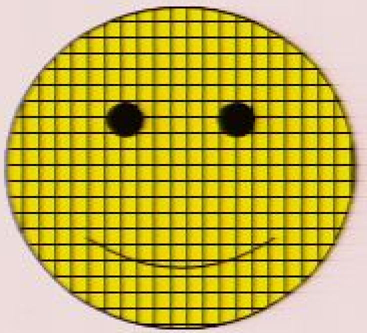


Planck scale sized cells...

$$\Gamma \sim \sigma n v \sim l_{pl}^2 \cdot T^3 \cdot 1 \sim l_{pl}^2 \cdot 1/R^3$$

This is a VERY long time...

Actually, can anyone survive that long?



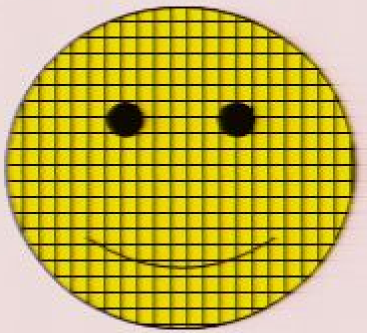
Planck scale sized cells...

$$\Gamma \sim \sigma n v \sim l_{pl}^2 \cdot T^3 \cdot 1 \sim l_{pl}^2 \cdot 1/R^3$$

$$\tau\Gamma \sim 1 \Rightarrow \tau \sim \frac{R^3}{l_{pl}^2}$$

This is a VERY long time...

Actually, can anyone survive that long?



Planck scale sized cells...

$$\Gamma \sim \sigma n v \sim l_{pl}^2 \cdot T^3 \cdot 1 \sim l_{pl}^2 \cdot 1/R^3$$

$$\tau\Gamma \sim 1 \Rightarrow \tau \sim \frac{R^3}{l_{pl}^2}$$

Same time scale!

Conjecture:

$$\frac{m_{pl}^2}{T^3}$$

Conjecture: $$\frac{m_{pl}^2}{T^3}$$

Weak...

... is the thermalization time for de Sitter space.

Conjecture: $$\frac{m_{pl}^2}{T^3}$$

Weak...

... is the thermalization time for de Sitter space.

Strong!

... is the thermalization time in general.

If temperature redshifts...

If temperature redshifts...

$$\int dt\Gamma \sim \int dt\frac{T^3}{\Lambda^2} \sim \int dt\frac{1}{a^3\Lambda^2}$$

If temperature redshifts...

$$\int dt\Gamma \sim \int dt \frac{T^3}{\Lambda^2} \sim \int dt \frac{1}{a^3\Lambda^2}$$

... diverges only if scale factors grows slower than

If temperature redshifts...

$$\int dt\Gamma \sim \int dt \frac{T^3}{\Lambda^2} \sim \int dt \frac{1}{a^3\Lambda^2}$$

... diverges only if scale factors grows slower than

$$t^{1/3} \Rightarrow p = w\rho \qquad \text{with} \qquad w > 1$$

If temperature redshifts...

$$\int dt\Gamma \sim \int dt \frac{T^3}{\Lambda^2} \sim \int dt \frac{1}{a^3 \Lambda^2}$$

... diverges only if scale factors grows slower than

$$t^{1/3} \Rightarrow p = w\rho \qquad \text{with} \qquad w \cancel{>} 1$$

Need box to prevent temperature to redshift!

Just for amusement...

Just for amusement...

Room temperature

$$300K \Rightarrow 10^{39} \text{ years}$$

Just for amusement...

Room temperature

$300K \Rightarrow 10^{39}$ years

Core of sun

$10^7 K \Rightarrow 10^{25}$ years

Just for amusement...

Room temperature

$300K \rightarrow 10^{39}$ years

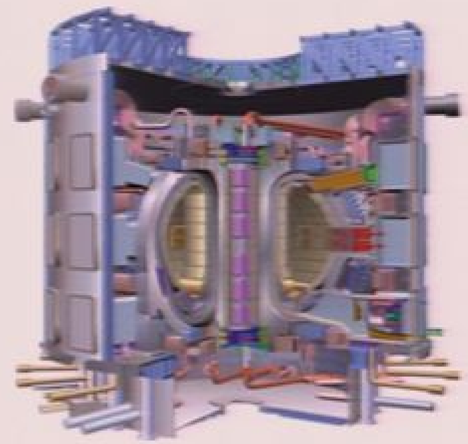
Core of sun

$10^{7} K \rightarrow 10^{25}$ years

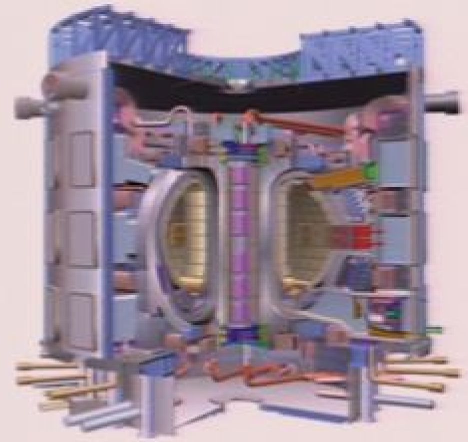
TeV- temperatures

$10^{17} K \rightarrow$ hours

FUSION at ITER?

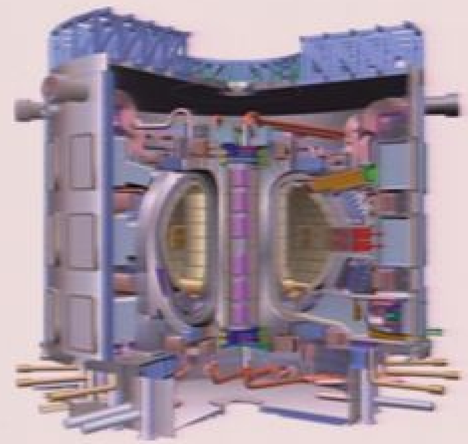


FUSION at ITER?



Useful fusion occurs if $$n\tau T \gtrsim 10^{21} skeV/m^3$$

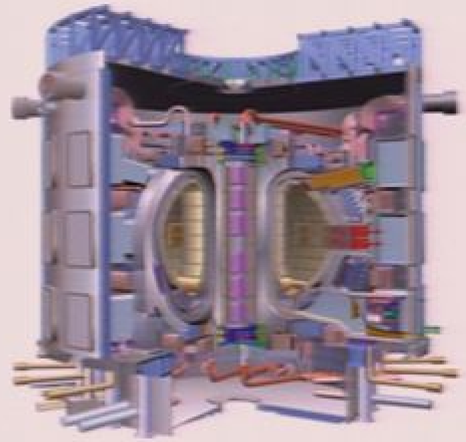
FUSION at ITER?



Useful fusion occurs if $n\tau T \gtrsim 10^{21} skeV/m^3$

With a volume of $10^3 m^3$

FUSION at ITER?

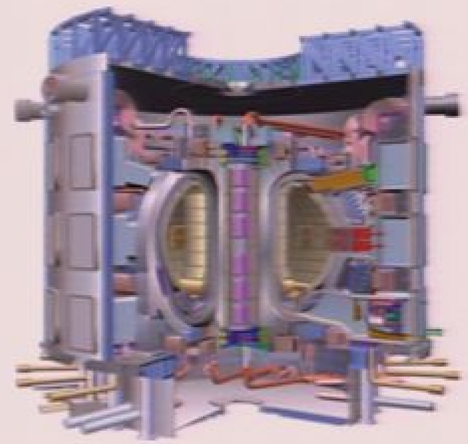


Useful fusion occurs if $n\tau T \gtrsim 10^{21} skeV/m^3$

With a volume of $10^3 m^3$

... we find $N\tau \sim 10^{23} s \sim 10^{16}$ years

FUSION at ITER?



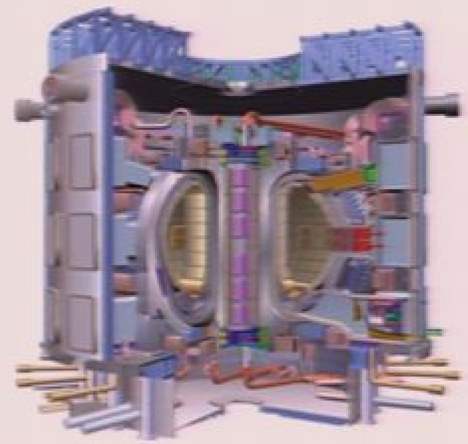
Useful fusion occurs if $n\tau T \gtrsim 10^{21} skeV/m^3$

With a volume of $10^3 m^3$

... we find $N\tau \sim 10^{23} s \sim 10^{16}$ years

To be compared with $\frac{m_{pl}^2}{T^3} \sim 10^{20}$years

FUSION at ITER?



Useful fusion occurs if $n\tau T \gtrsim 10^{21} skeV/m^3$

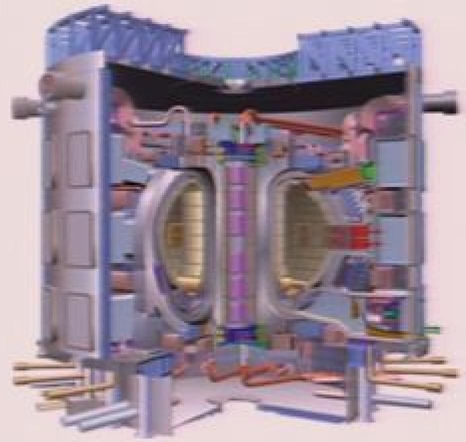
With a volume of $10^3 m^3$

... we find $N\tau \sim 10^{23} s \sim 10^{16}$ years

To be compared with $\frac{m_{pl}^2}{T^3} \sim 10^{20}$years

$10^4 \tau$ ... of running time would be enough for one event.

FUSION at ITER?



Useful fusion occurs if $n\tau T \gtrsim 10^{21} skeV/m^3$

With a volume of $10^3 m^3$

... we find $N\tau \sim 10^{23} s \sim 10^{16}$ years

To be compared with $\frac{m_{pl}^2}{T^3} \sim 10^{20}$years

$10^4 \tau$ ... of running time would be enough for one event.

Memories of tbings past

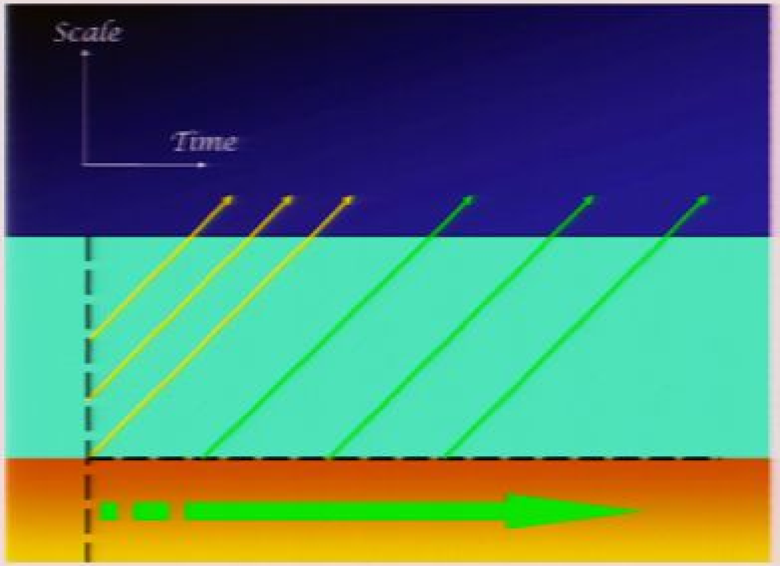
Memories of tbings past

What about the transplanckian problem?

Memories of tbings past

What about the transplanckian problem?

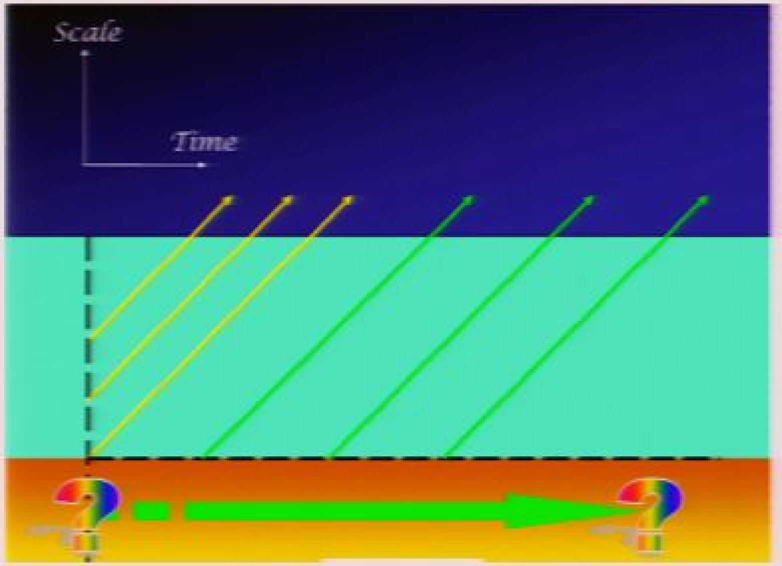
Recall...



Memories of tbings past

What about the transplanckian problem?

Recall...



$$\frac{m_{pl}^2}{T^3}$$

Number of e-foldings before thermalization:

Number of e-foldings before thermalization:

$$N \sim H\tau \sim 1/R \cdot R^3/l_p^2 \sim R^2/l_p^2$$

Number of e-foldings before thermalization:

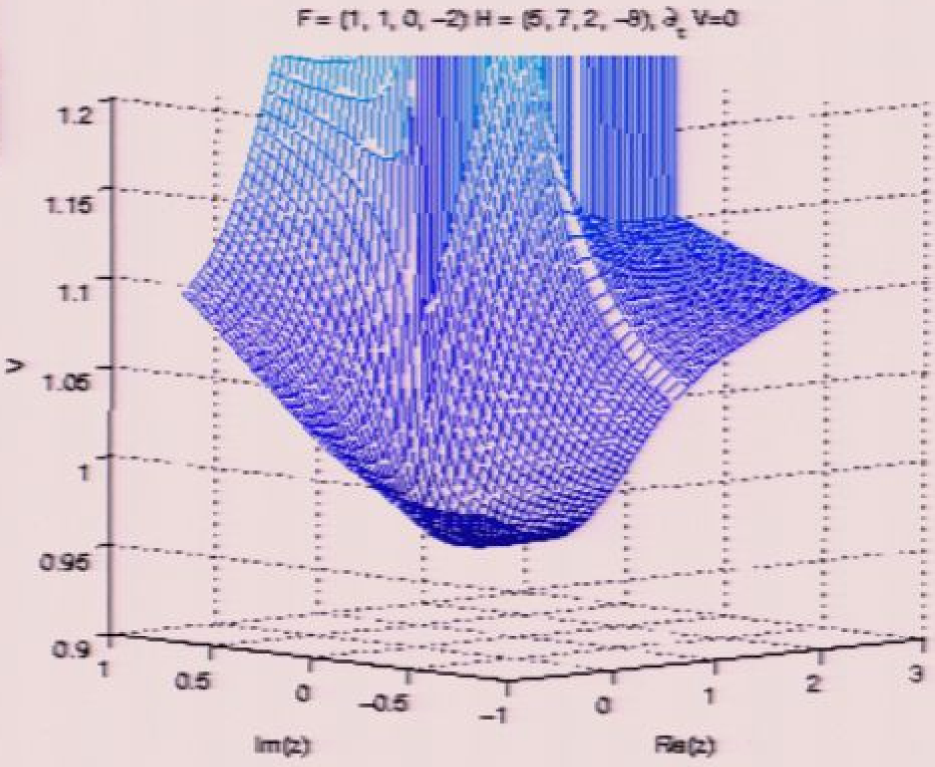
$$N \sim H\tau \sim 1/R \bullet R^3/l_p^2 \sim R^2/l_p^2$$

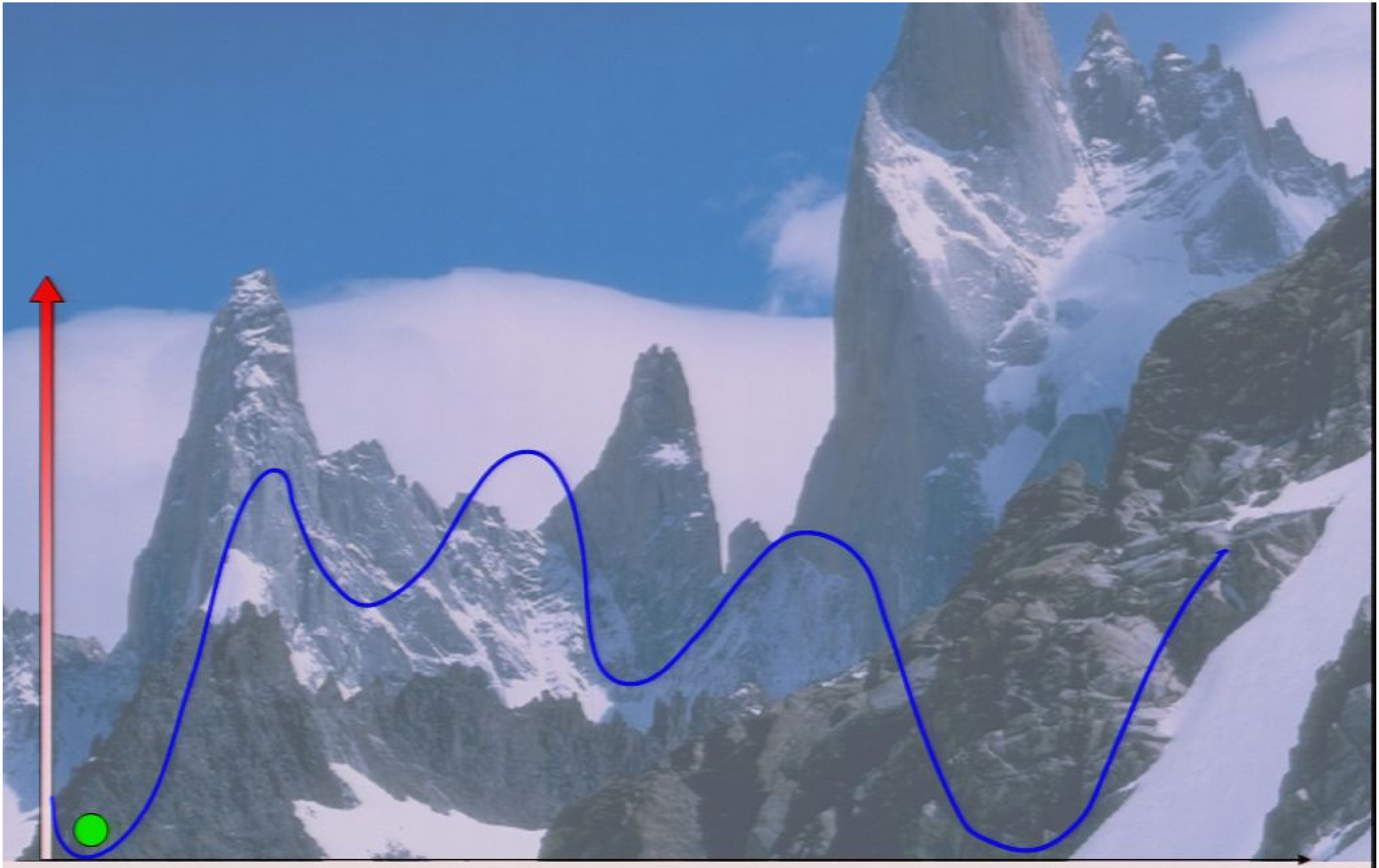
$$R \sim 10^4 l_p \quad \Longrightarrow \quad N \sim 10^8$$

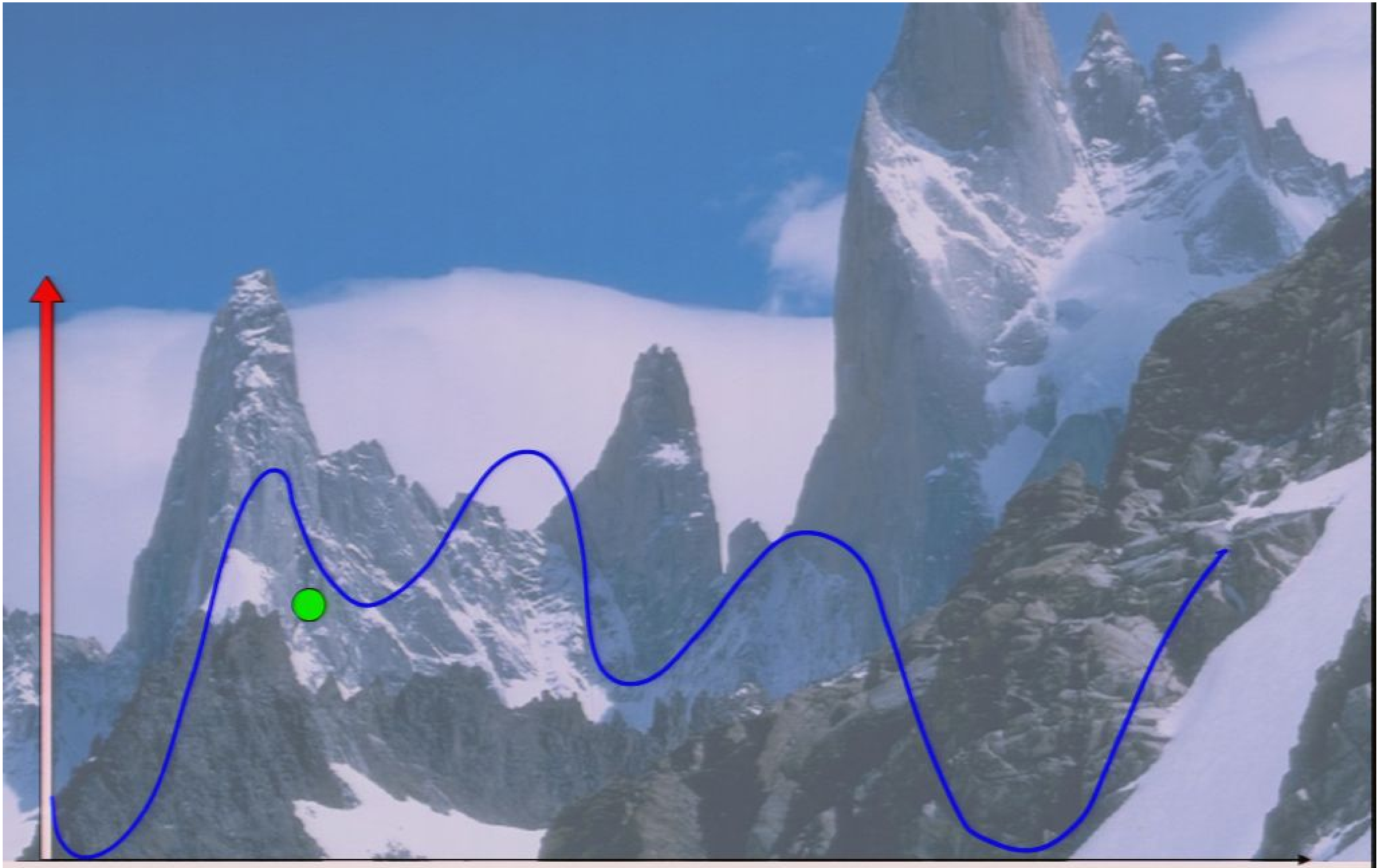
The string landscape...

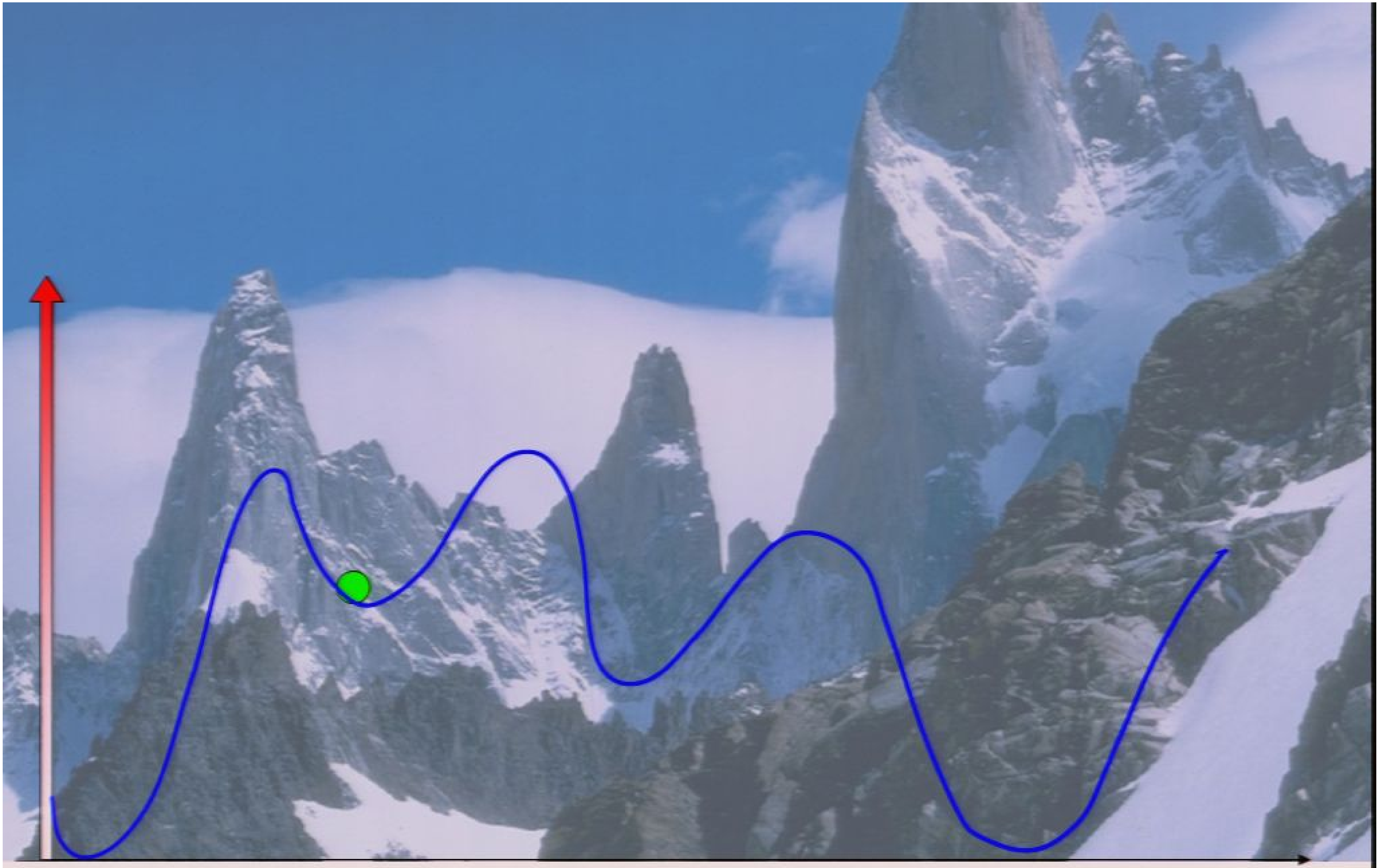
The string landscape...

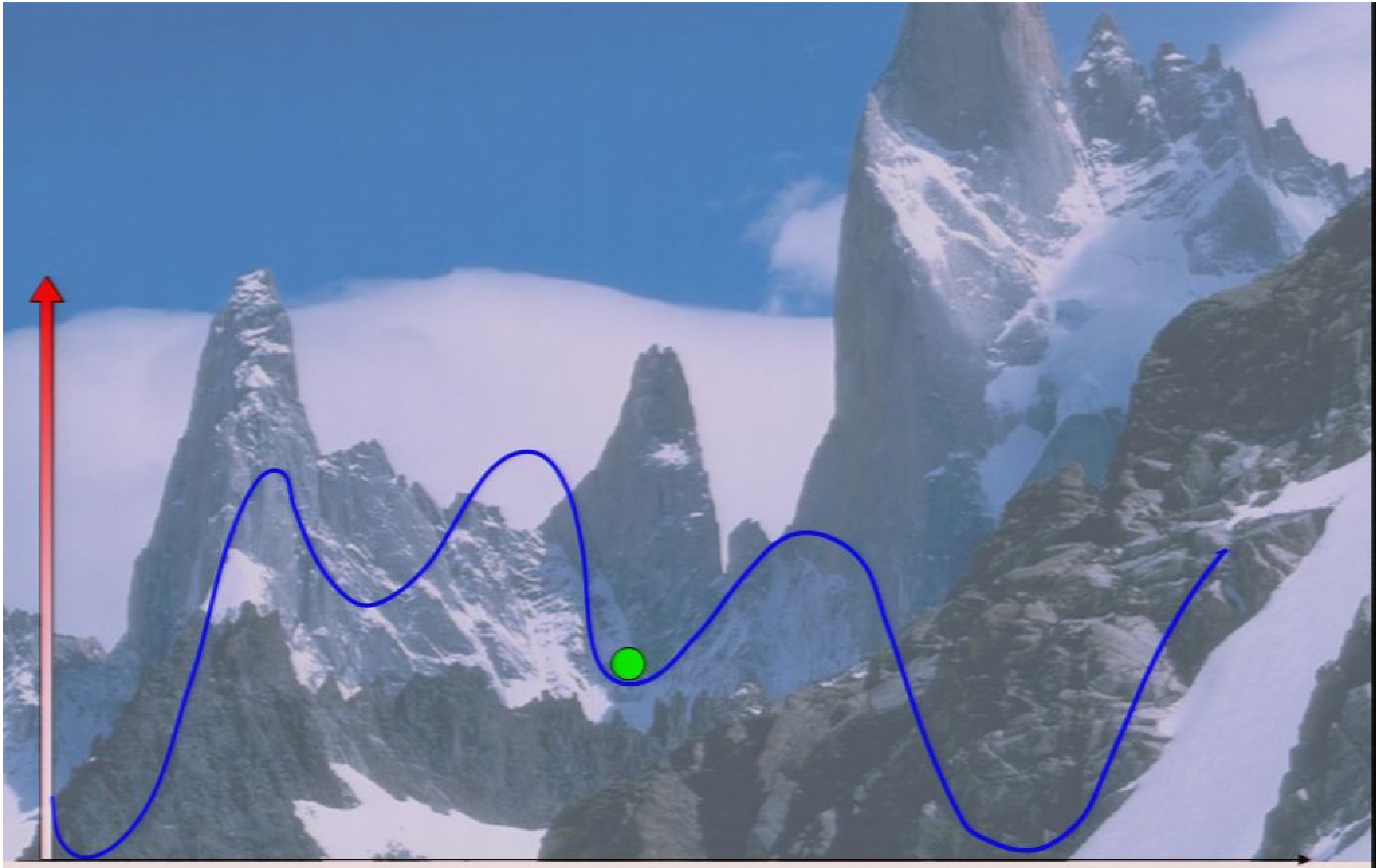
The string landscape...

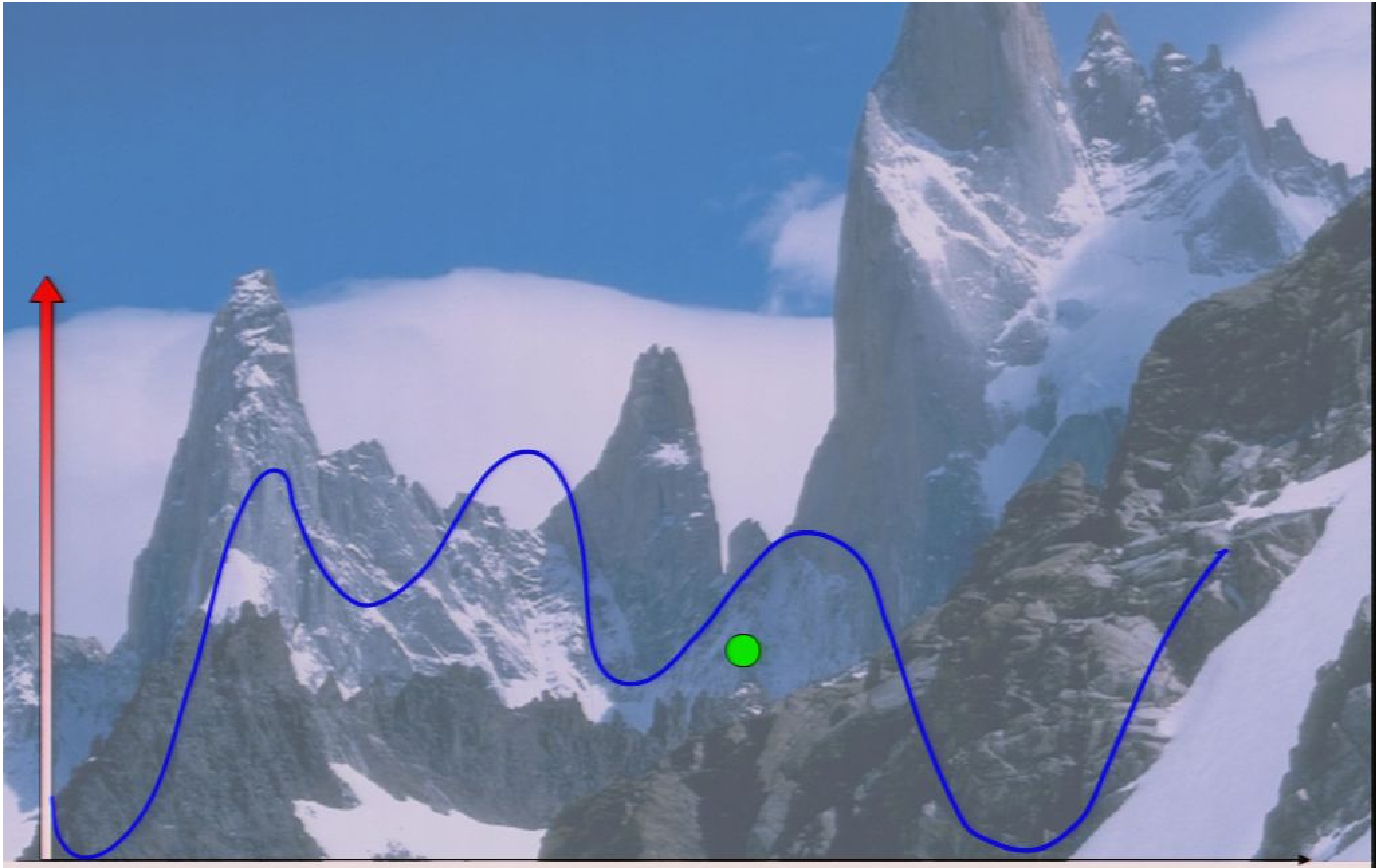


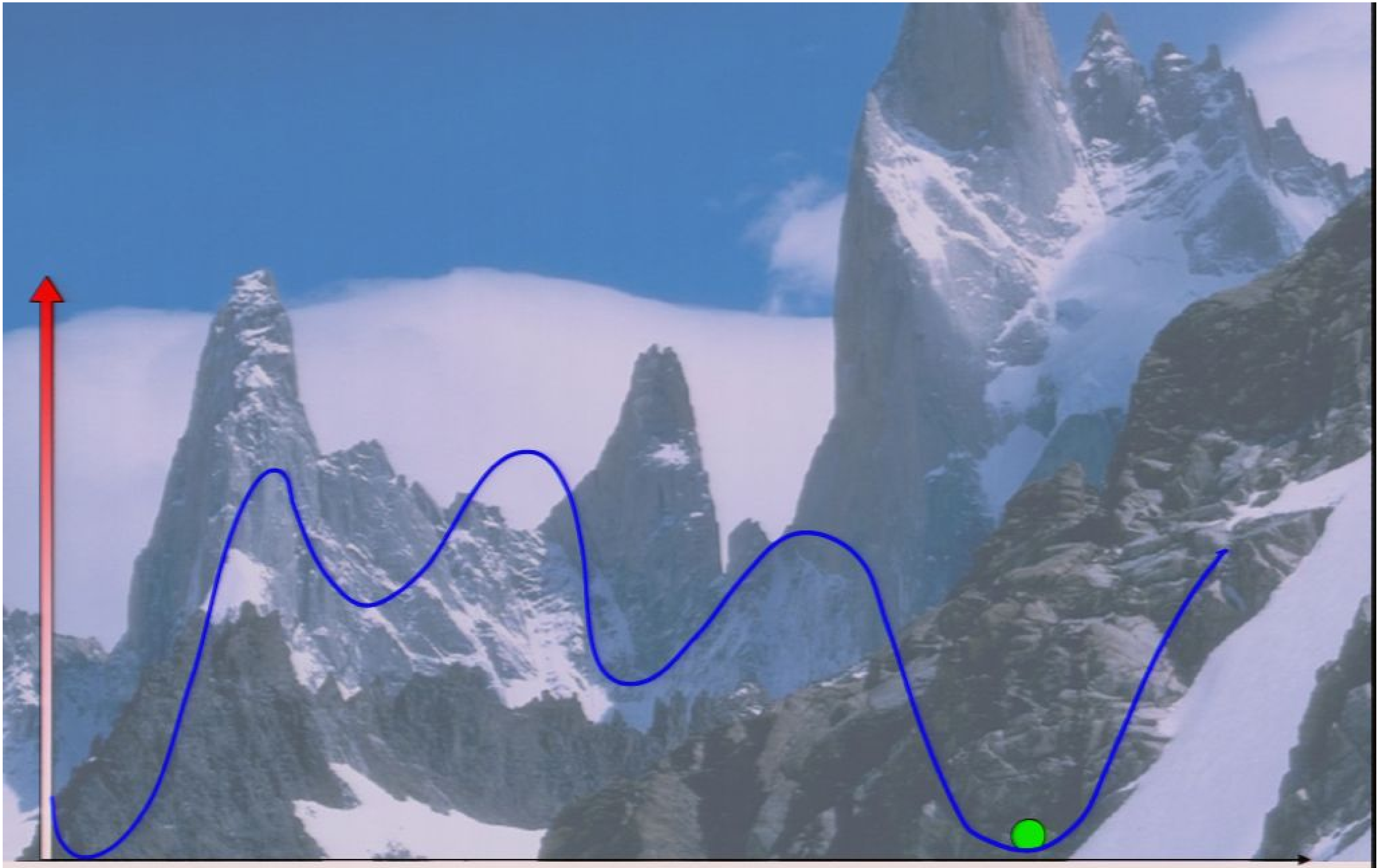


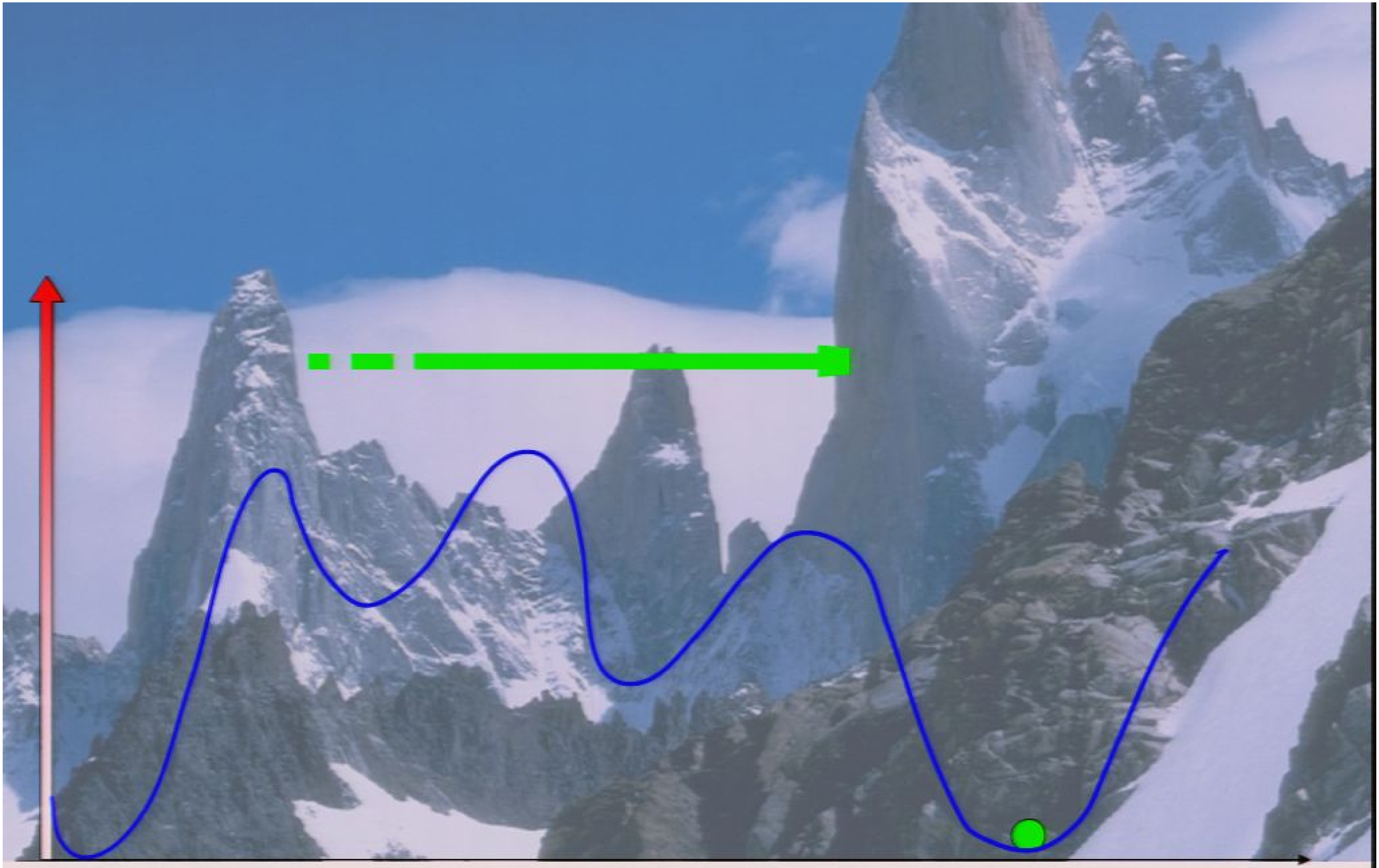


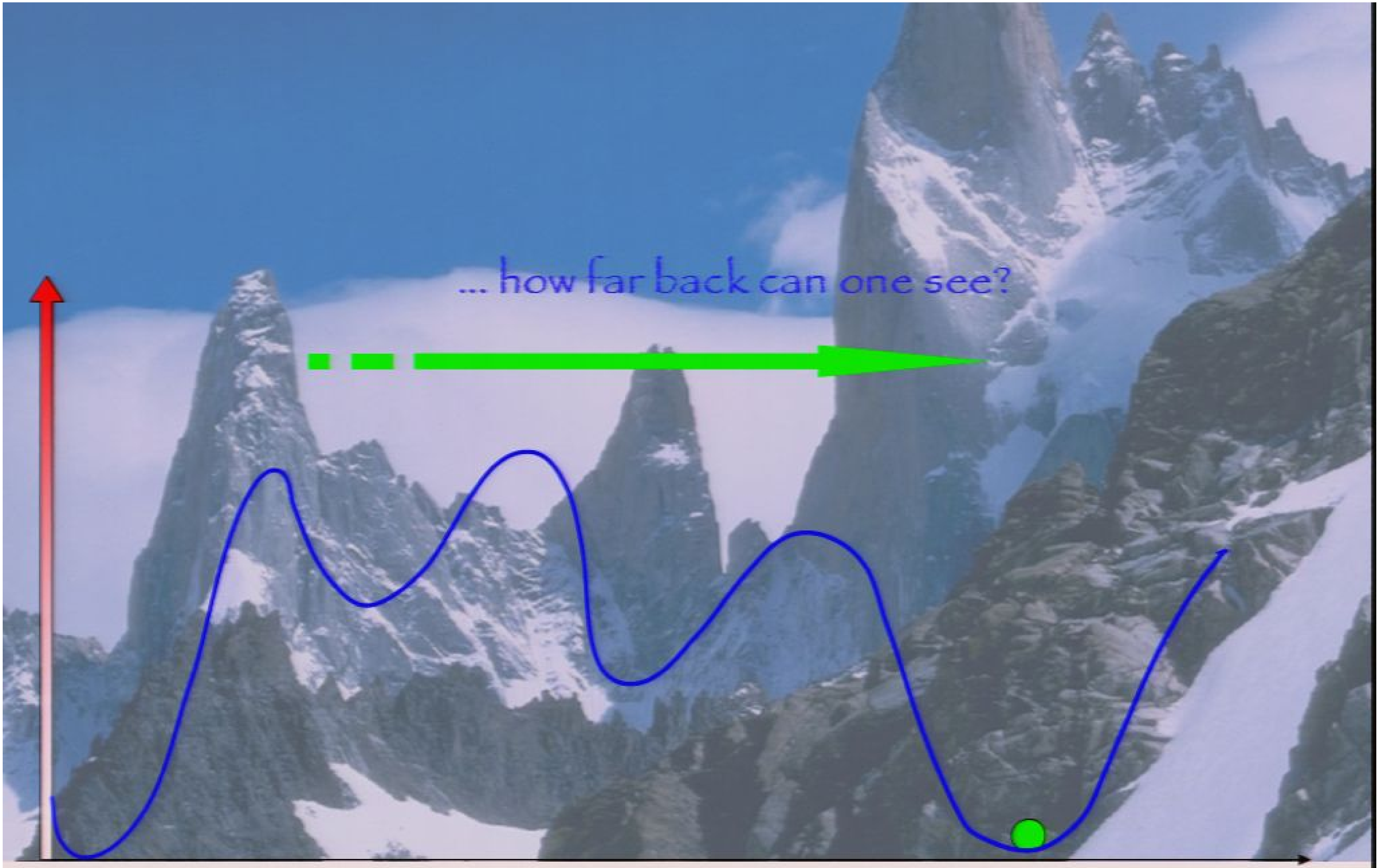




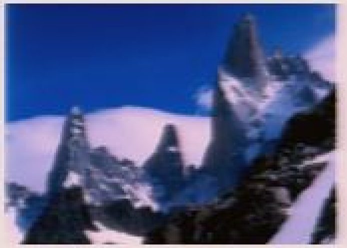


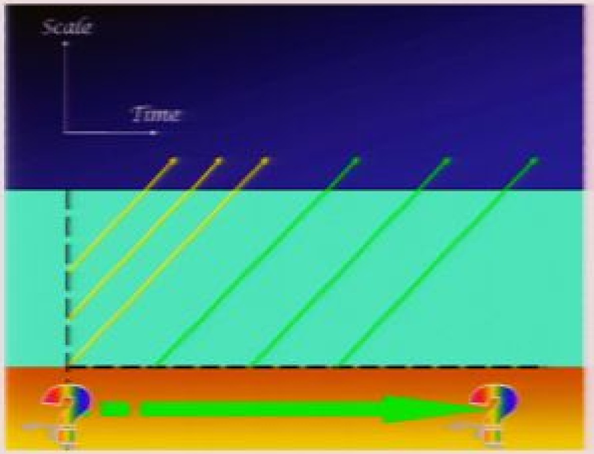


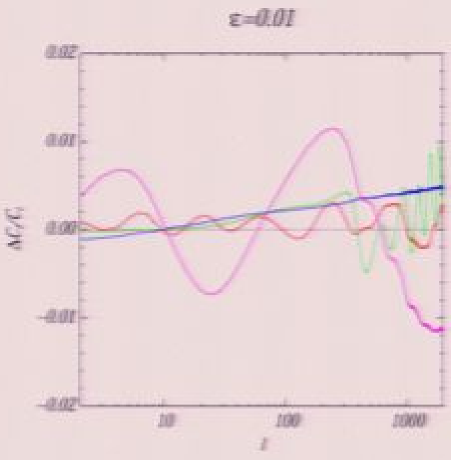



... how far back can one see?

Conclusions







$$\frac{m_{pl}^2}{T^3}$$