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

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Transplanckian physics

Initial conditions from where?
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Initial conditions from where?

An information paradox?
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Initial conditions from where?

An information paradox?

Memories of things past
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Transplanckian physics
Scale

Time

Modulations due to new physics
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\[ P_\phi = \left( \frac{H}{2\pi} \right)^2 \left( 1 - \frac{H}{\Lambda} \sin \left( \frac{2\Lambda}{H} \right) \right) \]
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... a modulated spectrum!
Can it be seen?
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Can it be seen?

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Given

\[ \varepsilon = \frac{M_{\text{pl}}^2}{2} \left( \frac{V'}{V} \right)^2 \]

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

\[ \frac{H}{\Lambda} \sim 4 \cdot 10^{-4} \frac{\sqrt{\varepsilon}}{\gamma} \]

\[ \frac{\Delta k}{k} \sim 1.3 \cdot 10^{-3} \frac{1}{\gamma \sqrt{\varepsilon}} \]

... where \( \Lambda = \gamma M_{\text{pl}} \)
Example

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

\[
\frac{H}{\Lambda} \sim 10^{-2}
\]

\[
\frac{H}{\tilde{b}} \sim \mathcal{O}(1)
\]
Example

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This can be achieved with

\[ \frac{\sqrt{\varepsilon}}{\gamma} \sim 20 \quad \varepsilon \sim 10^{-2} \]
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Consistent with old fashioned heterotic string compactifications...
Another example...
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If really slow modulation we can allow a much larger amplitude...
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\[
\frac{H}{\Lambda} \sim 10^{-1}
\]

\[
\frac{\Delta k}{k} \sim O(10)
\]
Another example...

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

This can be achieved with

$$\frac{\sqrt{\varepsilon}}{\gamma} \sim 200$$

$$\varepsilon \sim 10^{-2}$$

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

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

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

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... 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?
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There are essentially two possible ways to introduce initial conditions for inflation...
Perhaps there are other space times that are easier to study than de Sitter space?
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Milne space
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\[ \rho = 0 \quad \text{and} \quad k = -1 \]
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... which gives

\[ H^2 = \frac{8\pi\rho}{3} - \frac{k}{a^2} \implies a \sim t \]
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Milne space is especially simple since it is related to flat Minkowsky space time through a change of coordinates...

\[ \tilde{t} = t \cosh r, \quad \tilde{r} = t \sinh r \]

\[ dt^2 = dr^2 + t^2 d\Omega^2 \]
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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

\[ ds^2 = dt^2 - t^2 (dr^2 + \sinh^2 r d^2\Omega) \]
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Hence one would not expect any transplanckian effects in Milne space...
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... and perhaps this conclusion carries over to other space times as well?
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... 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...
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The divergence of ingoing null geodesics is given by:

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

\[ \frac{d\mathcal{H}}{d\tau} \leq 0 \]
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\[ \frac{d\Omega}{d\tau} \leq 0 \]

Hence is...
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Hence is...

Normal

Anti trapped

... impossible!
A region with anti trapped surfaces cannot be embedded in normal space without breaking the weak energy condition or having a singularity...
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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?
\[ \frac{1}{T} \sim \frac{1}{H} \sim R \]

...is certainly too short...
\[ \frac{1}{T} \sim \frac{1}{H} \sim R \] ... is certainly too short...

Note that the emission rate is only:

\[ P \sim P - R \sim \frac{1}{1} \]
$1/T \sim 1/H \sim R$ ... is certainly too short...

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\[ \tau \sim \frac{R^2}{l_p^2} \cdot R \sim \frac{R^3}{l_p^2} \]
This is a VERY long time...
This is a **VERY** long time...

Actually, can anyone survive that long?
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Planck scale sized cells...
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\tau \Gamma \sim 1 \Rightarrow \tau \sim \frac{R^3}{l_{pl}^2}
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Same time scale!
Conjecture: \[ \frac{m_{pl}^2}{T^3} \]
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Weak... ... is the thermalization time for de Sitter space.
Conjecture: \[ \frac{m^2_{pl}}{T^3} \]

Weak... \[ \ldots \text{is the thermalization time for de Sitter space.} \]

Strong! \[ \ldots \text{is the thermalization time in general.} \]
If temperature redshifts...
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\[ \int dt \Gamma \sim \int dt \frac{T^3}{\Lambda^2} \sim \int dt \frac{1}{a^3 \Lambda^2} \]
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Need box to prevent temperature to redshift!
Just for amusement...
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**Room temperature**

$300K \quad \rightarrow \quad 10^{39} \quad \text{years}$
Room temperature

\[ 300K \quad \Rightarrow \quad 10^{39} \text{ years} \]

Core of sun

\[ 10^7 K \quad \Rightarrow \quad 10^{25} \text{ years} \]
Just for amusement...

Room temperature

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

Core of sun

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TeV-temperatures

$10^{17} K$ $\rightarrow$ hours
FUSION at ITER?
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To be compared with \( \frac{m_{pl}^2}{T^3} \sim 10^{20} \text{years} \)
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\( 10^4 \tau \) ... of running time would be enough for one event.
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10$^4 \tau$ ... of running time would be enough for one event.
Memories of things past
Memories of things past

What about the transplanckian problem?
Memories of things past

What about the transplanckian problem?

Recall...
Memories of things past

What about the transplanckian problem?

Recall...
Number of e-foldings before thermalization:
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\[ N \sim H \tau \sim \frac{1}{R} \cdot R^3/l_p^2 \sim R^2/l_p^2 \]
Number of e-foldings before thermalization:

\[ N \sim H\tau \sim \frac{1}{R} \cdot \frac{R^3}{l_p^2} \sim \frac{R^2}{l_p^2} \]

\[ R \sim 10^4 l_p \quad \rightarrow \quad N \sim 10^8 \]
The string landscape...
The string landscape...
The string landscape...
... how far back can one see?
Conclusions

\[ \frac{m^2_{pl}}{T^3} \]