Trans-Planckian Censorship

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Swampland
Renormalization & EFT

Energy scale

A low-energy effective field theory

LHC! Belle II!
Renormalization & EFT

energy scale

$\Lambda_{\text{cutoff}}$

$\Delta L \sim \frac{1}{\Lambda_{\text{cutoff}}}$

$\mathcal{O}_{\text{suppressed}}$

→ low-energy effective field theory

LHC! Belle II!
Renormalization & EFT

- Energy scale
  - $M_{\text{pe}}$
  - $\Lambda_{\text{cutoff}}$

- $QG, \text{string, ...}$

- $\Delta \mathcal{L} \sim \frac{1}{\Lambda_{\text{cutoff}}}$ $O_{\text{qq}}$
  - $\uparrow$ suppressed

- Low-energy effective field theory

- LHC! Belle II!
Renormalization & EFT

Energy scale

$M_{Pl}$: special!

Very constrained

$\Lambda_{cutoff}$

LEEFT
Renormalization & EFT

energy

Scale

very constrained

M_{pl}; special!

\Lambda_{cutoff}

Landscape

Swampland

LEEFT
Swampland Conjectures: Necessary Conditions for existence of UV completion
Swampland Conjectures: Necessary Conditions for existence of UV completion

- Semiclassical
- GR
- String theory
- Phenomenology experiments

Arrows indicate relationships between the concepts.
Murayama - Yanagida - Y 1809. 00478
Fukuda - Saito - Shirai - Y 1810. 06532
Ibe - Yanagida - Y 1811. 04664
Y 1904. 04976
Shirai - Y 1904. 10577
Kusenko - Takhistov - Yamada - Y 1908. 10930
Y 1910. 08691
1. Is Trans-Planckian Censorship a Swampland Conjecture?
IPMU-19-0170


References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service

Saito (Yamaguchi)  Shirai (IPMU)
Trans-Planckian

"Problem"
Figure from https://www.u-tokyo.ac.jp/content/400031453.jpg
tiny quantum fluctuation

macroscopic fluctuation

exponential expansion
$\log(\text{physical scale})$

$1 \propto a$

$H^{-1} \propto a^2$ (RP)

$H^{-1} \propto a^{1.5}$ (MD)

$\log a(t)$

horizon size $H^{-1}$
\[ \log (\text{physical scale}) \]

horizon crossing

\[ \lambda \propto a \]

horizon exit

horizon size

\[ \frac{\dot{a}}{a} = H^{-1} \]

inflation

\[ H^{-1} \propto a^2 \quad (\text{RD}) \]

\[ H^{-1} \propto a^{1.5} \quad (\text{MD}) \]
tiny quantum fluctuation

exponential expansion

macroscopic fluctuation

CMB
trans-Planckian mode \( l \leq l_{\mu} \)

tiny quantum fluctuation

exponential expansion

macroscopic fluctuation

CMB
Trans-Planckian "Problem":

Can we observe trans-Planckian modes?

If so, breakdown of EFT?

* Similar problem for BHS
Trans-Planckian Censorship
Trans-Planckian Censorship Conjecture
(TCC, [Bedroya-Vafa 19])

Horizon-crossing of trans-Planckian modes
never happens in QG landscape

\[ l_p \frac{a(t)}{a(t_i)} \lesssim \frac{1}{H} \]

\[ e^N \quad N \text{ e-folding} \]
TCC \Rightarrow \text{metastable } dS \text{ has lifetime}

T \leq H^{-1} \ln \left( \frac{M_{\text{pe}}}{H} \right)
$TCC \implies \text{metastable dS has lifetime} \quad T \leq H^{-1} \ln \left( \frac{M_{\text{Pl}}}{H} \right)$

cf. dS swampland conjecture [Obied–Ooguri–Spodyneiko–Vafa (’18)]

$\implies \text{no metastable dS}$
$$\text{TCC} \implies \frac{|V'|}{\sqrt{V}} \geq \frac{2}{\sqrt{(d-1)(d-2)}} \quad a+\infty$$
\[ \text{TCC} \Rightarrow \frac{|V'|}{V} \geq \frac{2}{\sqrt{(d-1)(d-2)}} \text{ at } \infty \]

cf. dS swampland conjecture [Obied-Ooguri-Spodyneiko - Vafa ('18)] everywhere

\[ \frac{|V'|}{V} \geq c \]

\(O(1)\) number
$TCC \Rightarrow \frac{|V'|}{V} \geq \frac{2}{\sqrt{(d-1)(d-2)}} \quad \text{at } \infty$

cf. dS swampland conjecture

\[ \frac{|V'|}{V} \geq c \quad \text{O(1) number} \]

Problem with Higgs/pion/axion

[Penef-Hebecker-Wrase, Murayama-Yangida-MY]
[Choi-Chwoy-Shin, Hamaguchi-Ibe-Moroi ('18)]
1. Trans-Planckian Censorship and Inflationary Cosmology

2. Trans-Planckian Censorship and the Swampland

\[ \frac{P_t}{P_s} \lesssim 10^{-30} \]
Questions Raised on TCC:

* Implications if true? e.g., $r \lesssim 10^{-8}$, $r \lesssim 10^{-3}$

* Checks, Derivations?
Questions Raised on TCC:

* Implications if true? (e.g., $r \leq 10^{-8}$, $r \leq 10^{-3}$)
* Checks, Derivations?
* Is TCC a swampland conjecture?
Problems w/ TCC
Basic Problem w/ TCC: \[ \frac{a}{a_i} \sim \frac{M_{\text{pl}}}{H} \]
Basic Problem w/ TCC: \( \frac{a}{a_i} \sim \frac{M_{\text{pl}}}{H} \)

**Scenario 1**
- TCC: Yes

**Scenario 2**
- TCC: Yes

**Scenario 3**
- TCC: No

Theory
Basic Problem w/ TCC: \( \frac{a}{a_i} \lesssim \frac{M_{pl}}{H} \)

Scenario 1

TCC Yes

Scenario 2

TCC Yes

Scenario 3

TCC No

A swampland conjecture should apply to all scenarios in a given theory.
1. What happens if TCC indeed applies universally?

(universal TCC)
inflation

V(\phi)

\phi
inflation

\[ V(\phi) \]
inflation

\[ V(\phi) \]
Large quantum fluctuations can realize longer inflation, leading to violation of TCC (small but non-zero $p$).
2. If quantum fluctuations are problematic, why not only classical locus?

(classical TCC)
Higgs field will stay at top
\implies \text{exponential expansion}
\implies \text{violation of TCC}
3. We require that TCC is obeyed in our Universe,

(implicit in many follow-up papers)
3. We require that TCC is obeyed in our Universe, by requiring at least one TCC-consistent scenario for a given theory (observational TCC) (implicit in many follow-up papers)
This is fine (we are atypical)

However, the prediction \( T \leq H^{-1} \ln H \) is gone since decay is probabilistic

\[ p(t) \sim e^{-t/T} \]

\( t \to 0 \)
4. Allow TCC violation with "small" probabilities?

(probabilistic TCC)
4. Allow TCC violation with "small" probabilities?

- how small?
- why?

(probabilistic TCC)
4. Allow TCC violation with "Small" probabilities? 
   - How small? Why? 
   - Which probability? "Measure problem" 

(probabilistic TCC)
We ourselves can be very atypical/unlikely, while probabilistic prediction assumes typicality.

String landscape
We ourselves can be very atypical.

While probabilistic prediction assumes typicality.

**String landscape**

**Anthropic measure?**
Summary
* Non-trivial if TCC
  is a swampland conjecture

If not, resurrection of the trans-Planckion problem?
* Ideas on QG can be tested against observations
A swampland conjecture is a constraint on theory, not scenarios affecting observable predictions.

(General Lesson on QG ??)