

CONSISTENCY OF TACHYACOUSTIC COSMOLOGY WITH DE SITTER SWAMPLAND CONJECTURES

<https://arxiv.org/abs/1812.04447>

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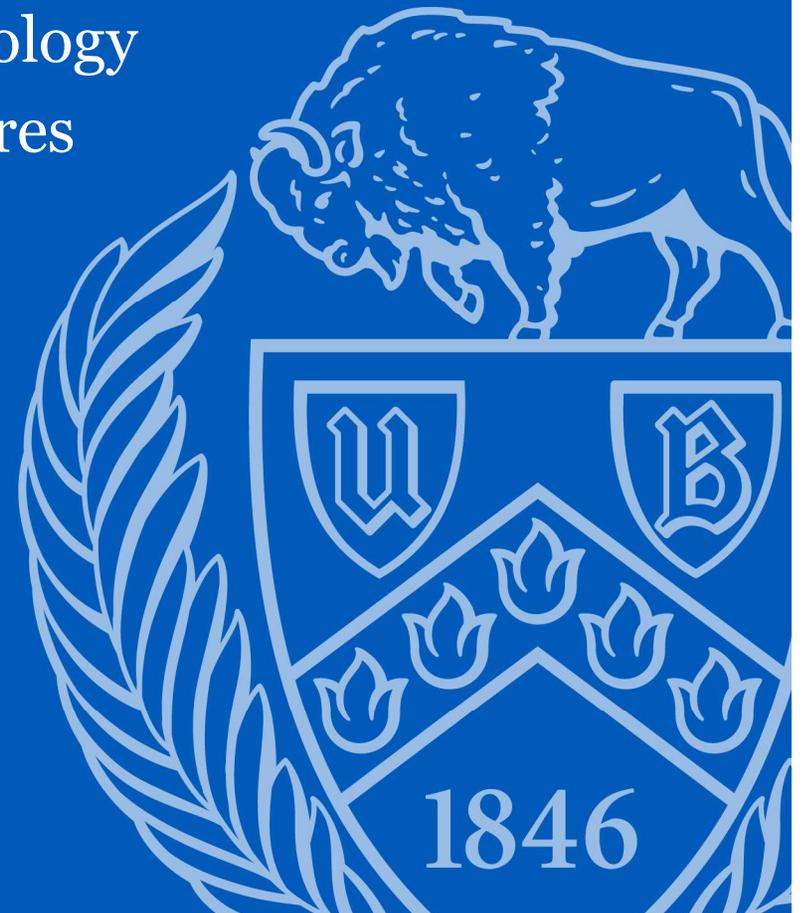
PHENO 2019 May 7, 2019

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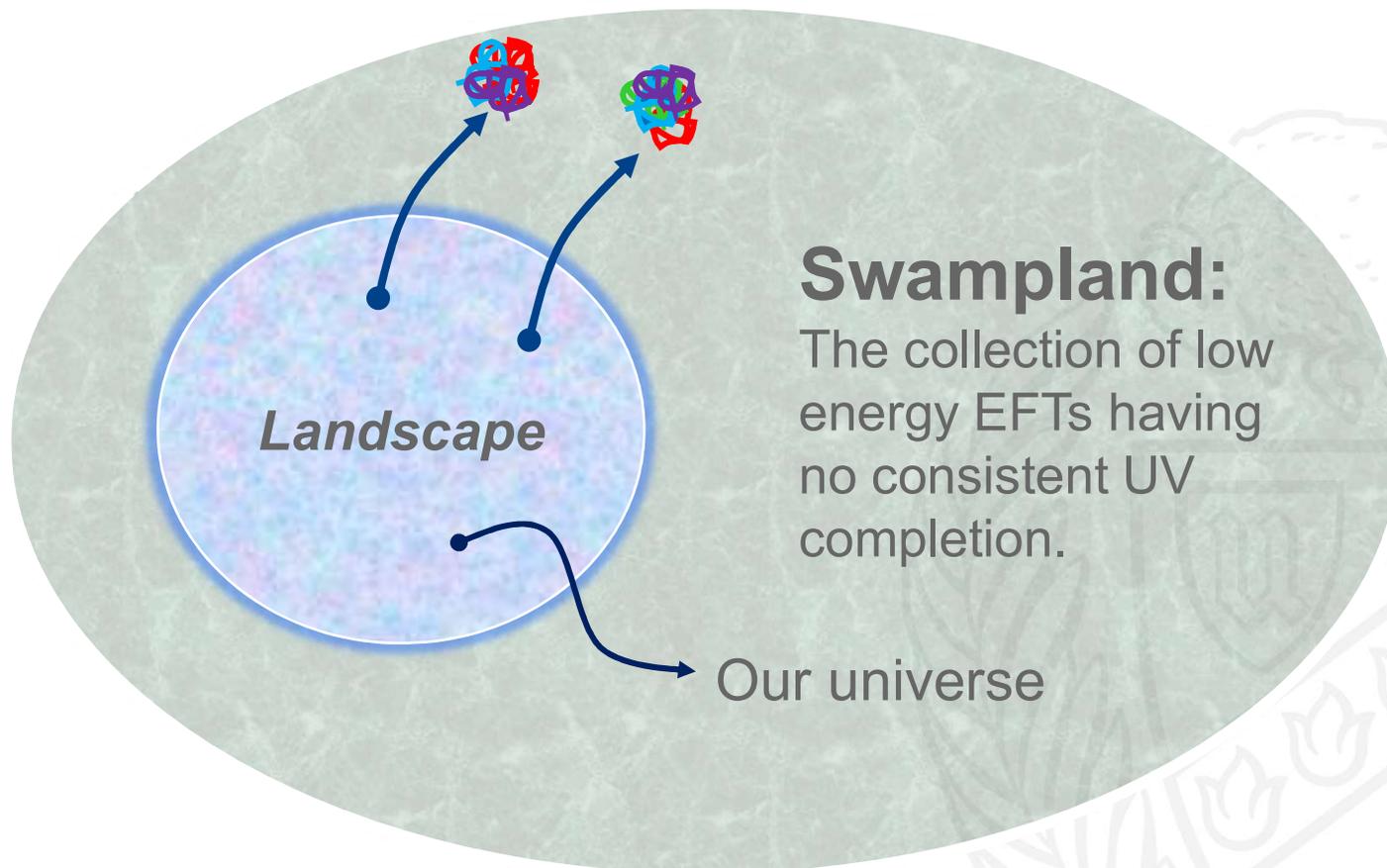


OUTLINE

1. de Sitter Swampland conjectures
2. Tachyacoustic cosmology
3. Consistency of Tachyacoustic Cosmology with de Sitter Swampland Conjectures



Swampland conjectures



The first conjecture is that there is an upper bound on the range traversed by scalar fields in field space

$$\frac{|\Delta\phi|}{M_P} \lesssim \Delta \sim \mathcal{O}(1)$$

The second conjecture is that there is a lower bound on the logarithmic gradient of the scalar field potential $V(\phi)$

$$M_P \frac{|V'(\phi)|}{V} \gtrsim c \sim \mathcal{O}(1)$$

[1]C. Vafa, (2005), arXiv:hep-th/0509212 [hep-th].

[2]G. Obied, H. Ooguri, L. Spodyneiko, and C. Vafa, (2018), arXiv:1806.08362 [hep-th].

[3]P. Agrawal, G. Obied, P. J. Steinhardt, and C. Vafa, Phys. Lett. B784, 271 (2018), arXiv:1806.09718 [hep-th].

For the single-field slow-roll inflation with a concave potential, $V''(\phi) < 0$:

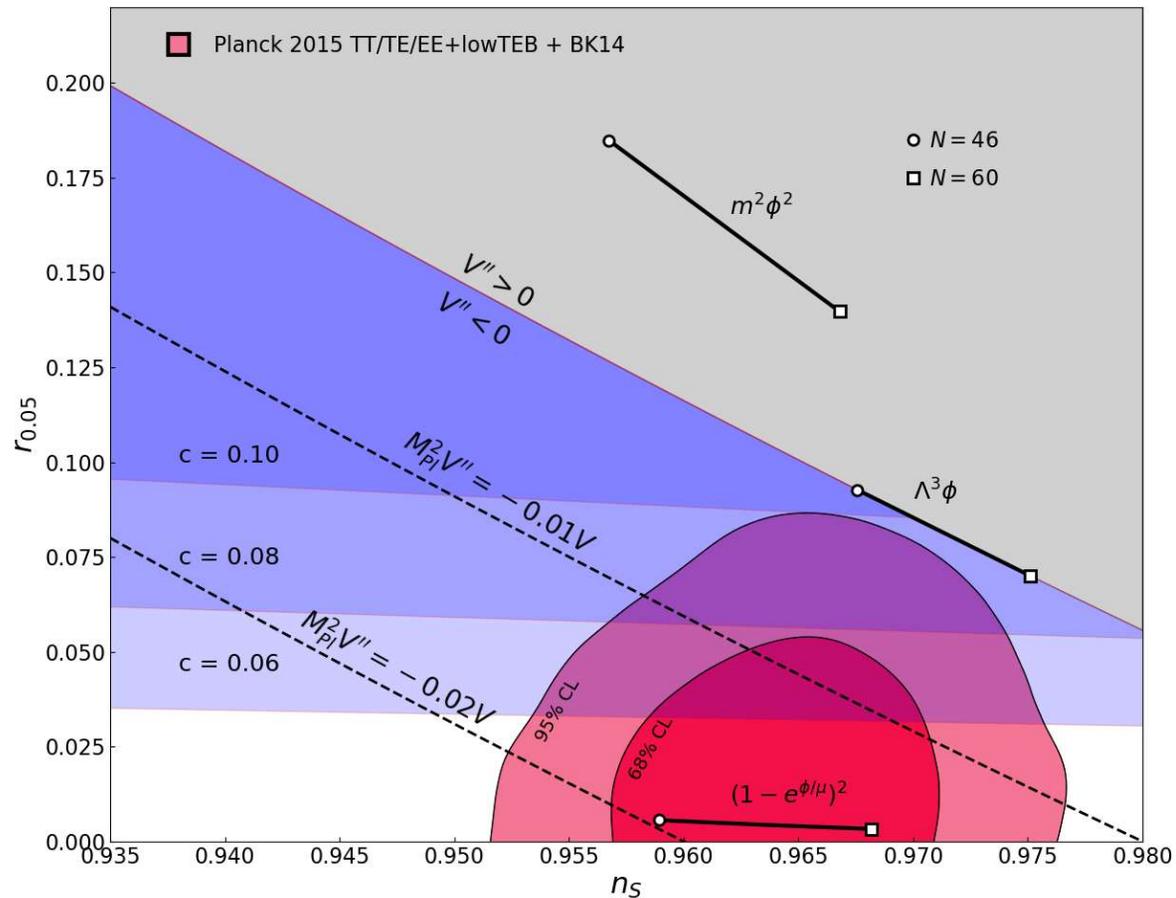
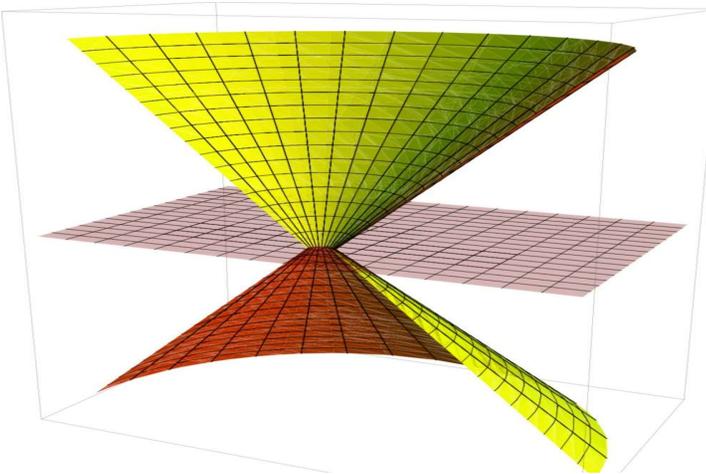


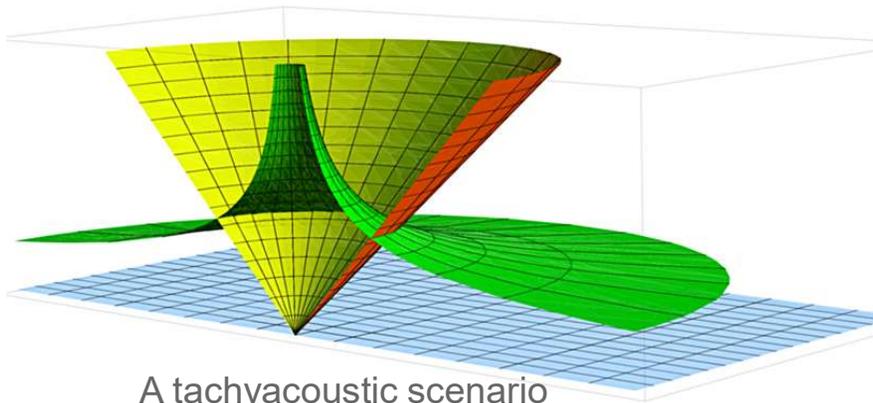
Figure 1 from [1]. Regions in the $n_s - r$ plane allowed by data (red) and the swampland conjectures (blue) for various values of the parameter c and c'

[1] W. H. Kinney, S. Vagnozzi, and L. Visinelli, (2018), arXiv:1808.06424 [astro-ph.CO]

Tachyacoustic cosmology



An inflationary scenario



A tachyacoustic scenario

The curvature perturbation is generated at the acoustic horizon c_S/aH , which is larger than the Hubble horizon $(aH)^{-1}$ when $c_S > 1$.

$$\mathcal{L} = \mathcal{L}[X, \phi]$$

$$X = \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi$$

$$c_S^2 \equiv \frac{p_X}{\rho_X} = \left(1 + 2X \frac{\mathcal{L}_{XX}}{\mathcal{L}_X}\right)^{-1}$$

$$H = H_0 e^{\epsilon N} \quad \mathcal{L}_X = A e^{\tilde{s}N}$$

$$c_S = e^{-sN} \quad \frac{\phi}{\phi_0} = e^{-\tilde{s}N/2}$$

$$a(t) \propto \exp\left[\int_{t_0}^t H dt\right] \equiv e^{-N}$$

The Cuscuton-like and Dirac-Born-Infeld(DBI)-like models

the Cuscuton-like model: $\tilde{s} = -2s$

$$\mathcal{L}(X, \phi) = 2f(\phi)\sqrt{X} + CX - V(\phi)$$

$$f(\phi) = \frac{\sqrt{2}M_P^2 H(\phi)\epsilon}{s\phi_0 c_S(\phi)} [c_S^2(\phi) - 1]$$

$$V(\phi) = M_P^2 H^2(\phi) \left[3 - \frac{\epsilon}{c_S^2(\phi)} \right]$$

$$H(\phi) = H_0 \left(\frac{\phi}{\phi_0} \right)^{\epsilon/s}$$

$$c_S(\phi) = \left(\frac{\phi_0}{\phi} \right)$$

the DBI-like model: $\tilde{s} = s$

$$\mathcal{L}(X, \phi) = -f^{-1}(\phi)\sqrt{1 - 2f(\phi)X} + f^{-1}(\phi) - V(\phi)$$

$$f(\phi) = \left(\frac{1}{2M_P^2 \epsilon} \right) \frac{1 - c_S^2(\phi)}{H^2(\phi) c_S(\phi)}$$

$$V(\phi) = 3M_P^2 H^2(\phi) \left[1 - \left(\frac{2\epsilon}{3} \right) \frac{1}{1 + c_S(\phi)} \right]$$

$$H(\phi) = H_0 \left(\frac{\phi}{\phi_0} \right)^{-2\epsilon/s}$$

$$c_S(\phi) = \left(\frac{\phi}{\phi_0} \right)^2$$

The first swampland criterion: there is an upper bound on the range traversed by scalar fields in field space

$$\frac{|\Delta\phi|}{M_P} \lesssim \Delta \sim \mathcal{O}(1)$$

We found a general scaling rule for the field excursion

$$\frac{\Delta\phi}{M_P} \sim \pm \sqrt{2\epsilon} (c_S)^{1/\beta} \Delta N$$

where $\beta \equiv 2s/\tilde{s}$, which shows that $\beta < 0$ is the condition to pass the first swampland criterion with $c_S \gg 1$.

$$\frac{\Delta\phi}{M_P} \sim -\frac{\sqrt{2\epsilon}}{c_S} \Delta N$$

The Cuscuton-like model: $\beta = -1$

$$\frac{\Delta\phi}{M_P} \sim \sqrt{2\epsilon c_S} \Delta N$$

The DBI-like model: $\beta = 2$

The second swampland criterion: there is a lower bound on the logarithmic gradient of the scalar field potential $V(\phi)$

$$M_P \frac{|V'(\phi)|}{V} \gtrsim c \sim \mathcal{O}(1)$$

We found that if **the leading-order behavior of the potential is a power law in c_S** , then the potential scales as

$$M_P \frac{|V'(\phi)|}{V} \sim c_S^{-1/\beta}$$

the condition to pass the second swampland criterion is also to have $\beta = 2s/\tilde{s} < 0$.

For any potential having the leading order behavior of a power law in c_S , the condition to satisfy **both** swampland conjectures is

$$\beta = 2s/\tilde{s} < 0.$$

The Cuscuton-like model, having $\beta = -1$, passes both of the swampland criteria but the DBI-like model, having $\beta = 2$, does not.

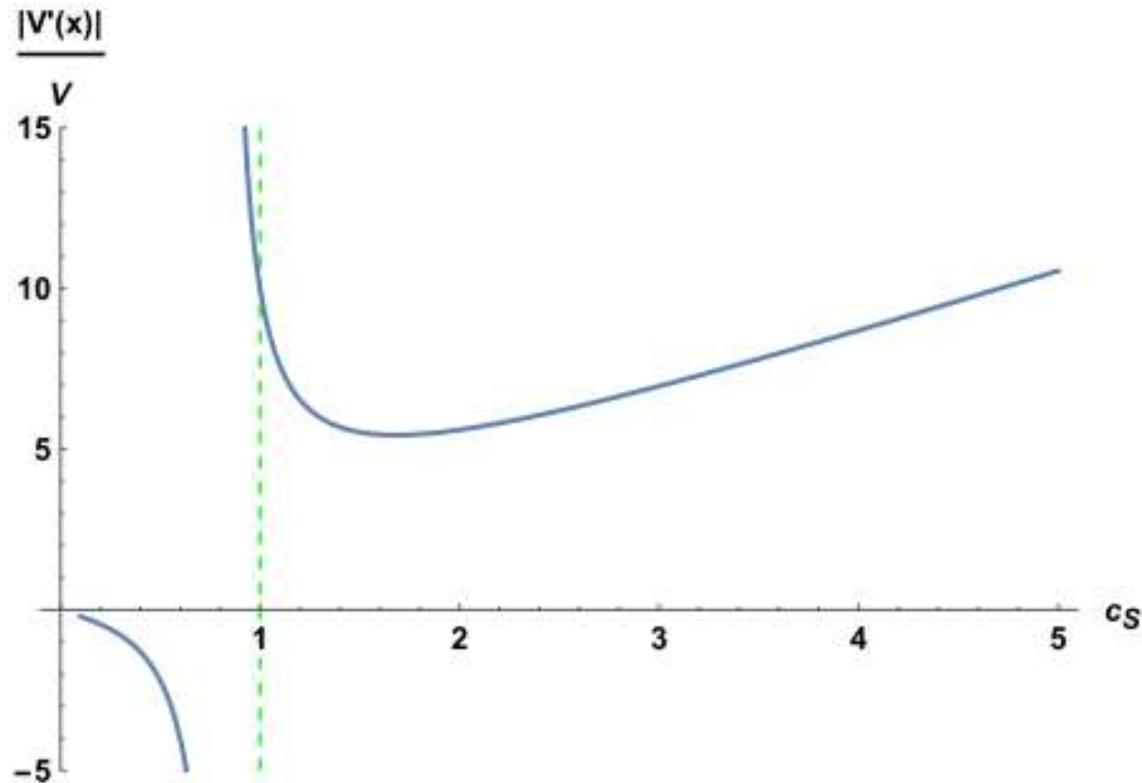


FIG. 1. In the Cuscuton-like model, if the region traversed by the scalar field is restricted to $c_S > 1$, the second swampland conjectures is satisfied, $\frac{|V'(x)|}{V} \gtrsim \mathcal{O}(1)$. This figure also shows that the potential quickly becomes negative when $c_S < 1$. The dashed (green) line indicates $c_S = 1$.



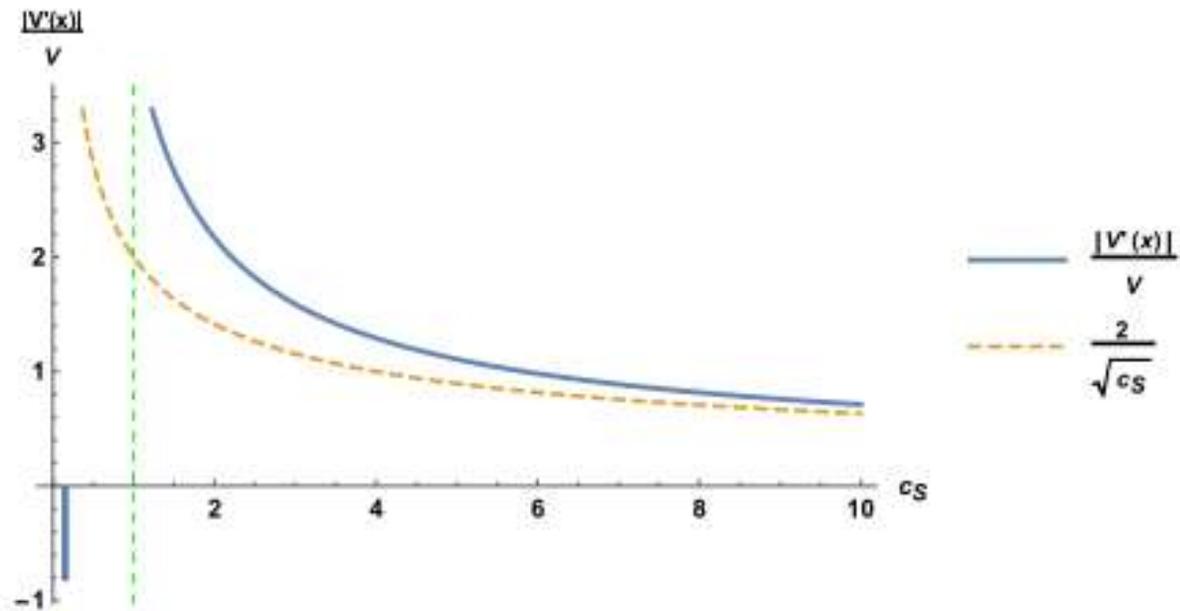


FIG. 2. In the DBI-like model, the scalar field traverses a long distance in the region $c_S \gg 1$, where the second swampland criterion is strongly violated, $\frac{|V'(x)|}{V} \ll \mathcal{O}(1)$. The solid (blue) line, $\frac{|V'(x)|}{V}$, approaches the dashed (orange) line, which is the limiting case $\frac{2}{\sqrt{c_S}}$, when $c_S \gg 1$.

Conclusions

For any potential having the leading order behavior of a power law in c_S , the condition to satisfy **both** swampland conjectures is

$$\beta = 2s/\tilde{s} < 0.$$

The Cuscuton-like model, having $\beta = -1$, passes both of the swampland criteria but the DBI-like model, having $\beta = 2$, does not.

Thank you!

Superluminal speed of sound and causality

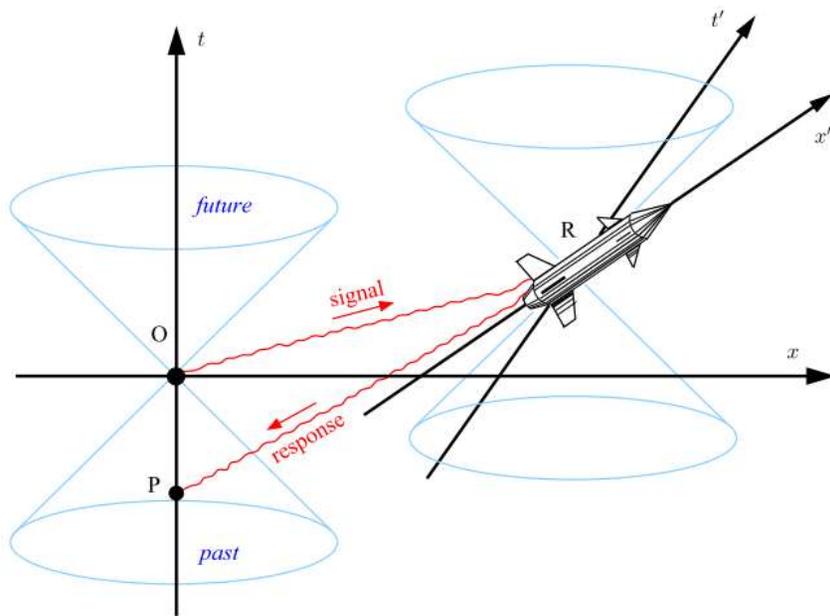


FIG. 1. The causal paradox can be constructed by using tachyons.

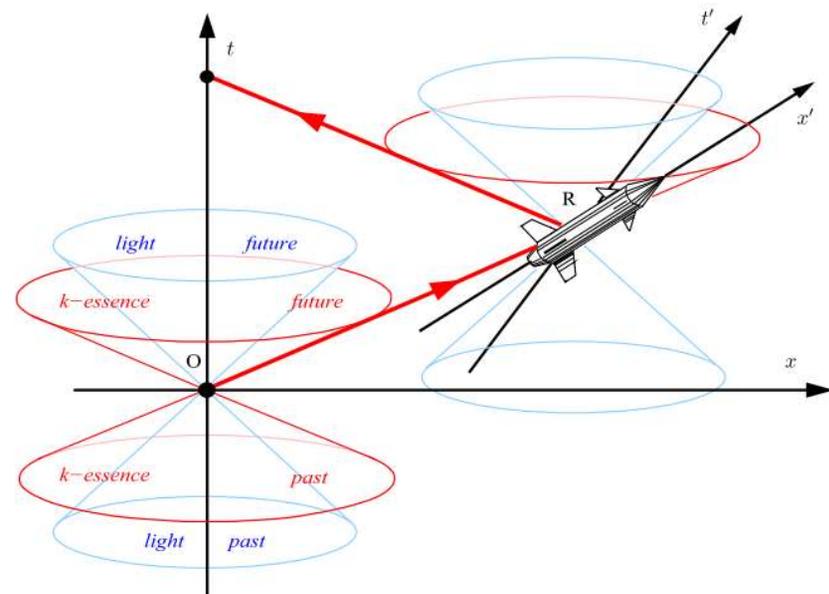


FIG. 2. The causality paradox is avoided when superluminal signals propagate in the background which breaks the Lorentz symmetry.

No closed causal curve can be created via superluminal sound speed

Within the framework of constant flow parameters, the cosmological perturbation can be solved exactly at the linear level. The scalar spectral index of perturbations for a tachyacoustic solution is given by

$$n_s = 1 - \frac{2\epsilon + s}{1 - \epsilon - s}$$

If we consider the scale invariant limit $n_s = 1$ in the case of a radiation-dominated background, $\epsilon = 2$

$$\Rightarrow s = -4$$

the sound speed drops rapidly as $c_s = e^{-sN} = e^{4N}$

