Kosmologietag Bielefeld 2011

Trapped Inflation in higher Dimensional Field Spaces

arxiv: 1004.3551
(and work in progress)

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Outline

1. Extra Species Locations (ESL/ESP)
    - Example
    - Trapped inflation

2. Terminal Velocity
    - Particle production at an ESP
    - Heuristic motivation and result

3. Inflation
    - Conditions for successful inflation

4. Conclusions/Outlook

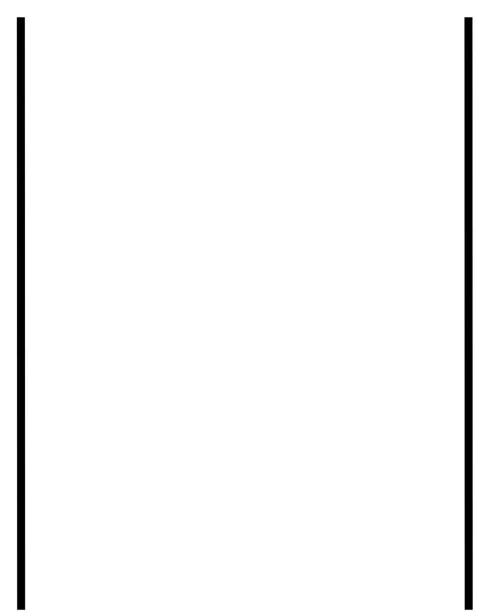
$m_p^2 \equiv 1$ throughout

1. Extra Species Loci/Points (ESL/ESP)

Locations, often associated with additional symmetries, where additional degrees of freedom (DOF) become light - need to be included in the low energy effective theory.

Example: D-branes

E.Witten 95



Inter-brane-distance

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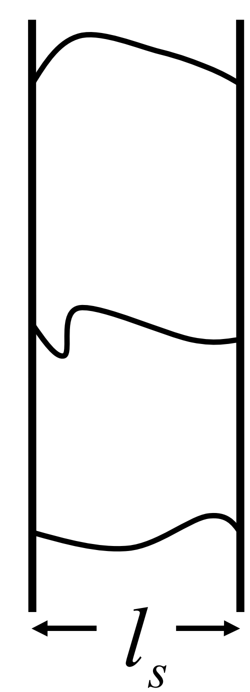
scalar modulus field φ in 4D effective theory



Strings stretching between branes become light and are produced when the branes come close to each other – additional DOF.

Extra Species Loci/Points (ESL/ESP)

Other Examples: N.Seiberg, E.Witten 94; K.A.Intriligator, N.Seiberg 95; S.H.Katz, D.R.Morrison, M.Ronen Pleser 96; M.Bershadsky, K.A.Intrilligator, S.Kachru, D.R.Morrison, V.Sadov, C.Vafa 96; Witten 96, …

ESL's are a common feature. Backreaction leads to attractive force towards the ESL.

Consequences:

- Moduli trapping/string Higgs effect
- Particle production during inflation and backreaction onto the inflaton

Almost all studies focused on one or two dimensional moduli spaces (D=1,2) containing extra species points or lines (d=0,1), with D-d=1; yet, there are hundreds of moduli-fields in string theory and D-d can be much larger than 1.

Backreaction onto Inflaton(s)

Backreaction of produced particles temporarily traps or slows down the inflation

- Trapped Inflation

  L.Kofman, A.Linde, X.Liu, A.Maloney, L.McAllister, E.Silverstein 04;
  D.Green, B.Horne, L.Senatore, E.Silverstein 09

- Monodromi Inflation

  E.Silverstein, A.Westphal 08

- …

Note: Scalar speed limits at strong coupling also exist, leading to DBI Inflation

E.Silverstein, D.Tong 04;
M.Alishahiha, E.Silverstein, D.Tong 04

Question

What are the effects of ESLs (general d)
in higher dimensional moduli spaces (large D limit)?

In 1004.3551 we work in the 4D, low energy effective theory and

- Discuss moduli trapping (unlikely if D-d>1).
- Derive a terminal velocity on moduli space if ESLs are ubiquitous.
- Generalize trapped inflation.
- Provide a worked, simple example of trapped inflation in higher dimensions.

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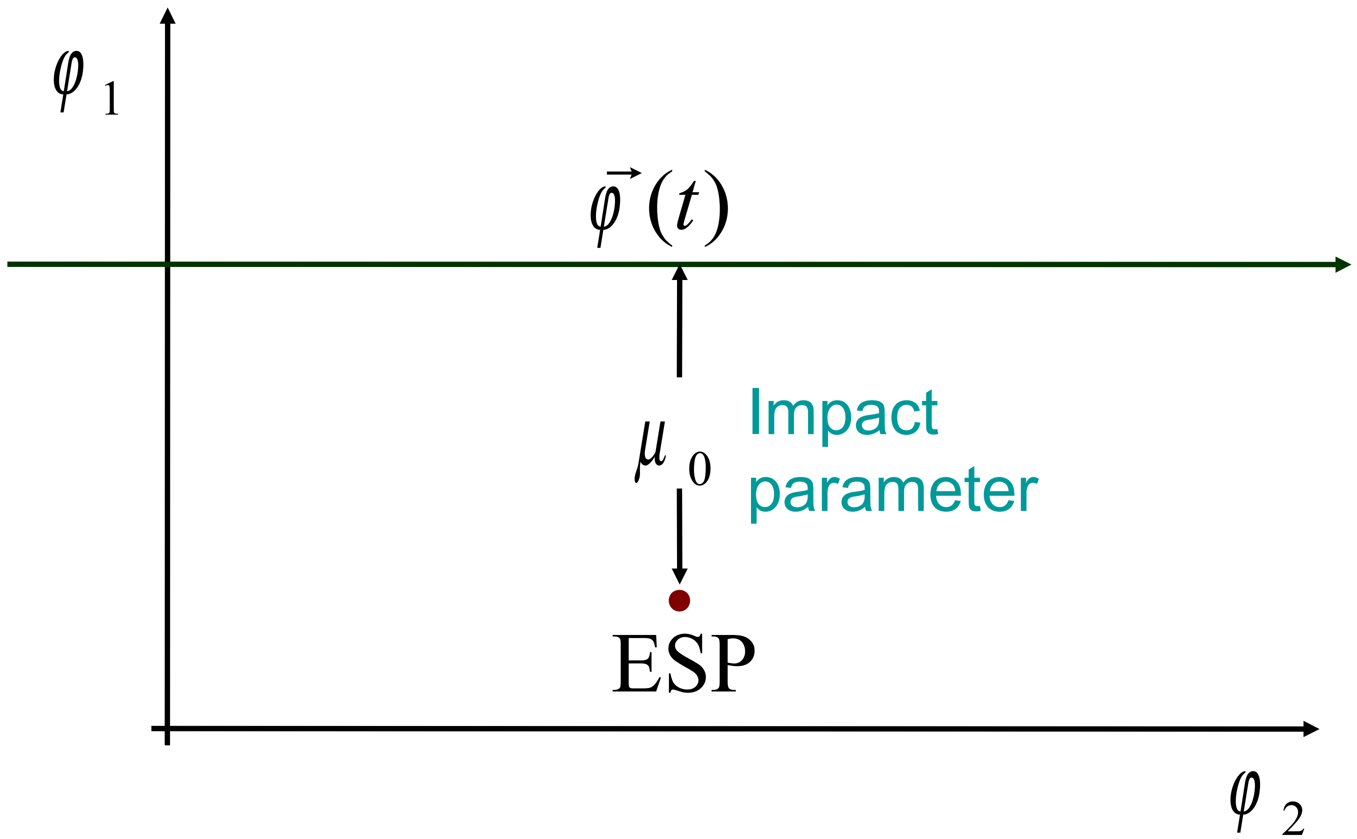
In the following I focus on the derivation of the terminal velocity and consequences of its presence.

I restrict the discussion to ESPs throughout (generalization to ESL is straightforward) and work from a phenomenological point of view.

2. Encounter with a single ESP

New, light degrees of freedom near ESP, modeled by massless, scalar field χ

Interaction with moduli-fields: $\frac{g^2}{2}\chi^2 \sum_{i=1}^{D} \left(\varphi_i - \varphi_i^{ESP}\right)^2$



D=Dimensionality of moduli space

Speed along trajectory
$v \equiv |\dot{\vec{\varphi}}(t)|$

χ -particles are produced during the encounter

Particle Production: number density in a Fourier mode (WKB-approx.)

: $$n_k = \exp\left(-\pi\frac{k^2+g^2\mu_0^2}{gv}\right)\left(\frac{a(t_{\mathrm{ESP}})}{a(t)}\right)^3$$

Particle production

Extensively discussed in the theory of pre-heating after inflation; single field:

J.H.Traschen, R.H.Brandenberger 90;
L.Kofman, A.D.Linde, A.A.Starobinsky 97; …
review: B.A.Bassett, S.Tsujikawa, D.Wands 05

Multiple fields:

D.Battefeld, S.Kawai 08;
D.Battefeld 08;
D.Battefeld, T.B., J.T.Giblin 09;
J.Braden, L.Kofman, N.Barnaby 10;

We can directly apply these known results;

Bottom line:

Explosive particle production occurs primarily during a short interval when the trajectory is closest to the ESL; particle- and energy-density can be computed reliably using the WKB approximation.

Particle production at a single ESP

Energy density

$$\rho_\chi = \int \frac{d^3k}{(2\pi)^3} n_k \sqrt{k^2 + g^2(\vec{\varphi}(t) - \vec{\varphi}_{ESP})^2} \approx g\,|\vec{\varphi}(t) - \vec{\varphi}_{ESP}|\,n_\chi$$

Number density

$$n_\chi = \int \frac{d^3k}{(2\pi)^3} n_k \approx \frac{(gv)^{3/2}}{(2\pi)^3} e^{-\pi g \mu_0^2/v} \left(\frac{a(t_{\rm ESP})}{a(t)} \right)^3$$

Once particles are produced, back-reaction yields a classical attractive force towards the ESP. Moduli trapping is possible if the encounter is close.

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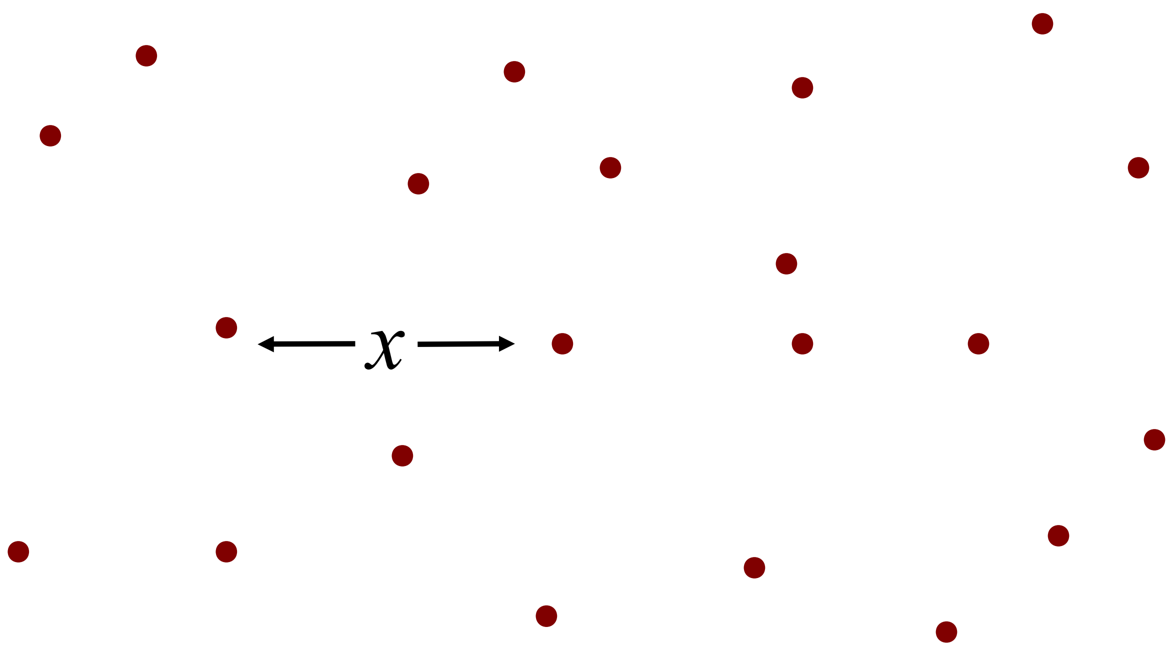
Back-reaction is important for

$$\boxed{\mu_0 \lesssim \sqrt{\frac{v}{g}} \equiv \mu}$$

For larger impact parameters, the particle number, and thus back-reaction, is exponentially suppressed.

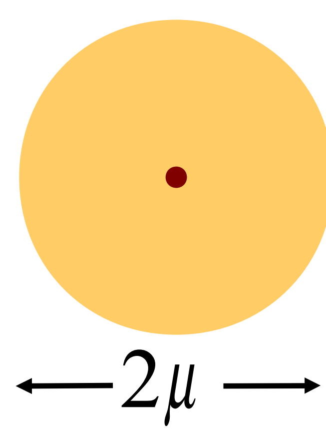
Why should there be a the Terminal Velocity?

Assume ESP's are ubiquitous.



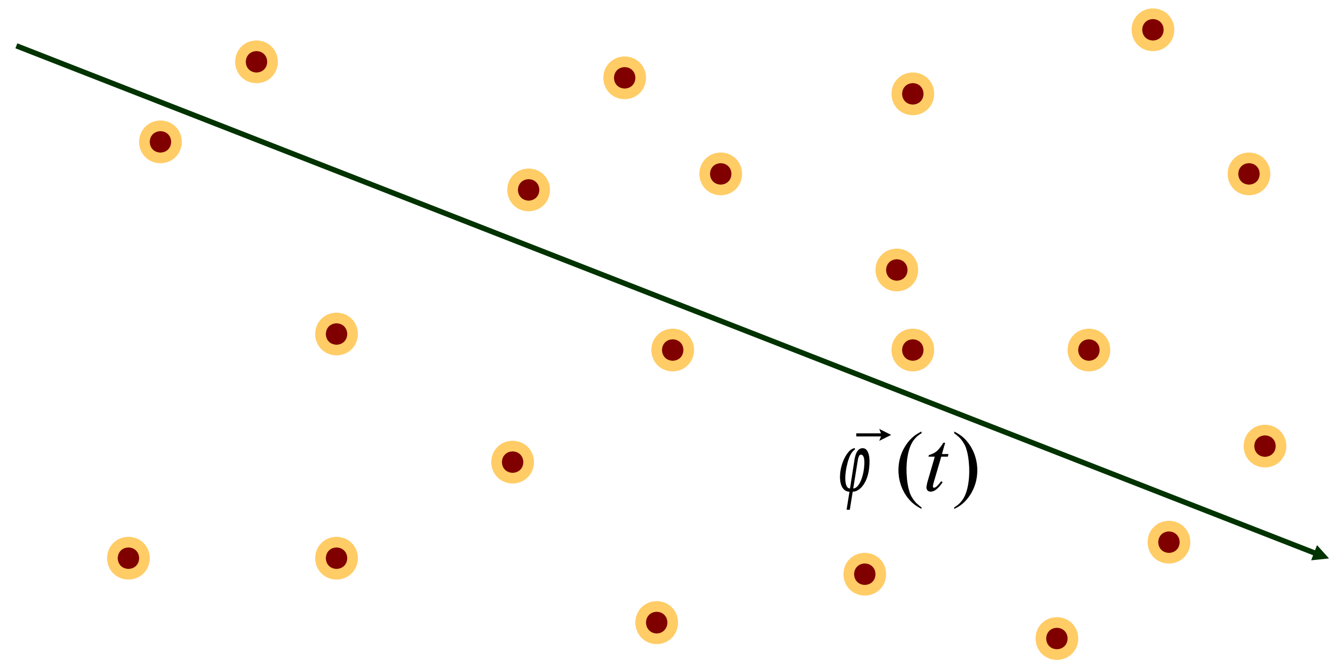
$x \equiv$ characteristic inter - ESP distance

Critical impact parameter around each ESP:



$$\sqrt{\frac{v}{g}} \equiv \mu$$

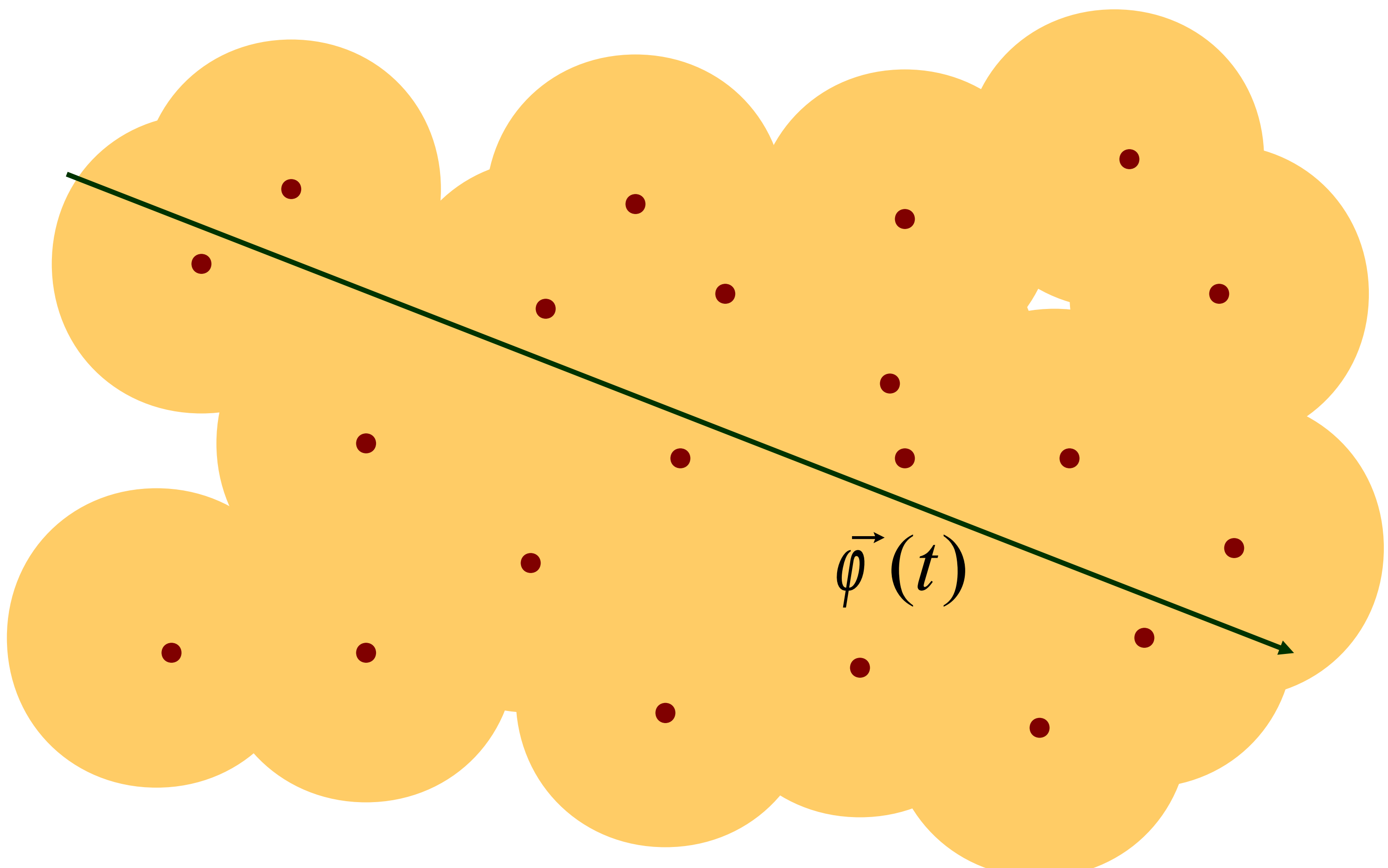
Small speed: $x >> \mu$



For large D, it is exceedingly unlikely to come close enough to an ESP to produce enough particles for back-reaction to become important.

Dynamics of moduli fields is entirely determined by their classical potential.

Larger speed: $\mu \sim x$

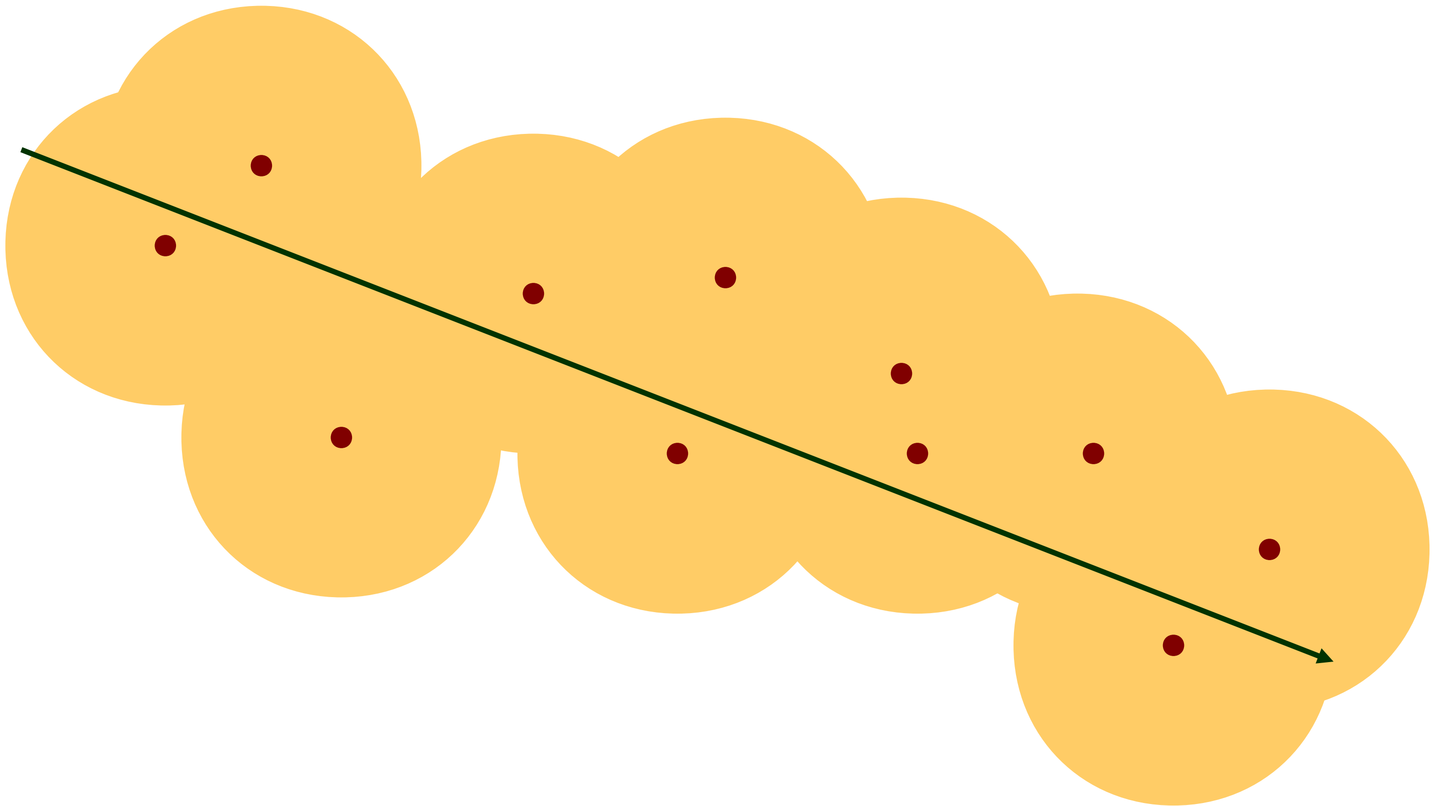


For large D, at any point on the trajectory one is close to many ESPs

(exposed to $n_{ESP} \sim e^{D/2}$ in the large D limit)

The number of ESPs increases sharply once $\mu \sim x$

Focus on ESP where particle production occurred



These ESP attract the trajectory. The combined back-reaction of particles near ESPs in the wake of the trajectory leads to a classical force opposite to the velocity. This force is stronger, the larger the velocity is. Setting $x = \mu$ and solving for v, the terminal velocity is

$$v_t \sim g x^2$$

We can derive the terminal velocity thoroughly (see 1004.3551) by equating the driving force due to the potential with the one caused by backreaction, leading eventually to

$$v_t = |\dot{\varphi}_1| \approx g x^2 \Delta$$

$$\Delta \equiv \left(\frac{(2\pi)^3 3H}{g^5 x^4} \frac{\partial V}{\partial \varphi_1} \right)^{2/(D+4)}$$

In the large D limit $\Delta \rightarrow 1$ so that

$$\boxed{v_t \approx g x^2}$$

independent of the potential.

This speed limit is generic in the presence of ESPs (or more generally ESLs if D>>d).

Question

Can we drive inflation at the terminal velocity?

Possible advantages

- potential can be steeper, yet velocity remains small
- eta-problem can be alleviated
- no fine tuning of the initial velocity is needed

Conditions for Inflation at terminal velocity:

- Large D, so that the relevant timescale for backreaction is smaller than the one for the classical potential to change the speed.

- Ubiquitous ESPs so that the terminal velocity is sufficiently small and inflation lasts long enough.

- Straight trajectory over a few Hubble times, so that backreaction is opposite to speed.

- Steep enough classical potential so that Hubble friction can be ignored.

- Potential energy > kinetic energy > energy of new particles, so that inflation occurs.

- Large enough terminal velocity, so that reheating temperature is high enough.

- Perturbations from IR cascading should be subdominant.

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⇒

$$\text{(big enough } T_{rh}) \; 10^{-35} \leq v_t \leq 10^{-8} \text{ (enough inflation)}$$
$$g \leq 0.1 \text{ (IR cascading)}$$
$$D \geq 10 \text{ to} \sim 100 \text{ depending on potential.}$$

A worked example and comments on additional observational signatures can be found in 1004.3551

Conclusions

In the presence of ubiquitous ESPs/ESLs in a higher dimensional field space a terminal velocity arises at weak coupling.

If D is large, this velocity is independent of the potential.

This can aid inflation – the potential can be steeper and have features, the eta problem is relaxed, and initial velocities need not be fine tuned.

Additional observational signatures result (i.e. pert. from IR-cascading, and circular structures in the CMBR due to individual massive particles)

Possible Future Work

- What is a ``common'' distribution of ESLs on the Landscape?
- Consequences for sampling the Landscape? Moduli trapping?
- Consequences for intertwined classical trajectories?
- Concrete implementations of trapped inflation in higher dimensions?
- Investigation of additional observable signatures?

  NG from IR cascading.

  Circles in the CMBR from individual, massive particles.

- Only a few ESP encounters in higher dimensional field spaces:

  New contributions to the Power-spectrum

  Non-Gaussianities