What Are the Limits of Effective Field Theory?

Madrid IFT Swampland Conference Sept 19 -21, 2018

Traditional Answer

$$\mathcal{L} = \mathcal{L}_0 + \sum M^{-p} \mathcal{L}_p .$$

- Implies Gravitational Effective Field Theory OK, when energy density and curvature are small.

- Implies QUEFT should be a good approximation during inflation and near a large black hole.

- Implies c.c. mystery and motivates QUEFT calculation of low energy corrections to c.c.

Classical Indications Traditional Answer is Wrong

- Finite entropy of dS space and Black holes. Large increase in local entropy of black holes when light particle dropped on them ($R_S << R$).

- Localized Excitations DECREASE entropy of dS space

- JACOBSON 1995!!!! : Derives Einstein equations

$$K^\mu K^\nu (R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R - 8\pi G T_{\mu\nu}) = 0,$$

$$K^\mu(x) K_\mu(x) = 0$$

- From $dE = T\,dS$ plus $S = A/4A_P$ For Maximal Area Surface in foliation of the boundary of generic causal diamond.

- Field Theory = Hydrodynamics

- c.c. NOT a local energy density

- TB and Fischler: Causal diamonds have two invariant geometric sizes: proper time and holoscreen area. c.c. controls relation of two asymptotic limits.

Resolves two Problems in Field Theory Treatment of Classical Horizons

- dS vacuum is max entropy state. Typical energy scale 1/R. Localized excitations are constrained states with E_{loc} R the number of constraints. This gives a classical derivation of the dS temperature.

- Transitions Larger black hole <— —-> smaller black hole plus particle. Huge entropy increase in backward transition implies small black hole plus particle is constrained state of large black hole with E/T = ER constraints. Resolves firewall problem because it takes a time of order R_S to unfreeze constraints.

AdS Space Gives identical picture of Minkowski diamond for R>> string scale

- Most States of AdS are vacuum of any given Minkowksi diamond (Susskind Polchinski “arena”)

- Assume a finite dimensional operator algebra of dimension given by the CEP for the arena. Page’s theorem implies density matrix of diamond is maximally uncertain, with probability exponentially close to one as a function of the diamond radius to the cutoff on the AdS radial coordinate.

- dS and AdS agree: Minkowski space does not have a unique vacuum. Localized states are constrained.

Understanding the Constraints via Scattering Theory

- TB: Scattering Theory is a map between current algebras in the past and future.

- View Conformal Boundary via its Fourier Transform: Momentum Null Cone.

- Minimal set of currents: $Q^i_\alpha(P)$

$$P_\mu \gamma^\mu_{\beta\alpha} Q^i_\alpha(P) = 0$$

Scattering Representations of Awada Gibbons Shaw Algebra: Exclusive Sterman-Weinberg Jets

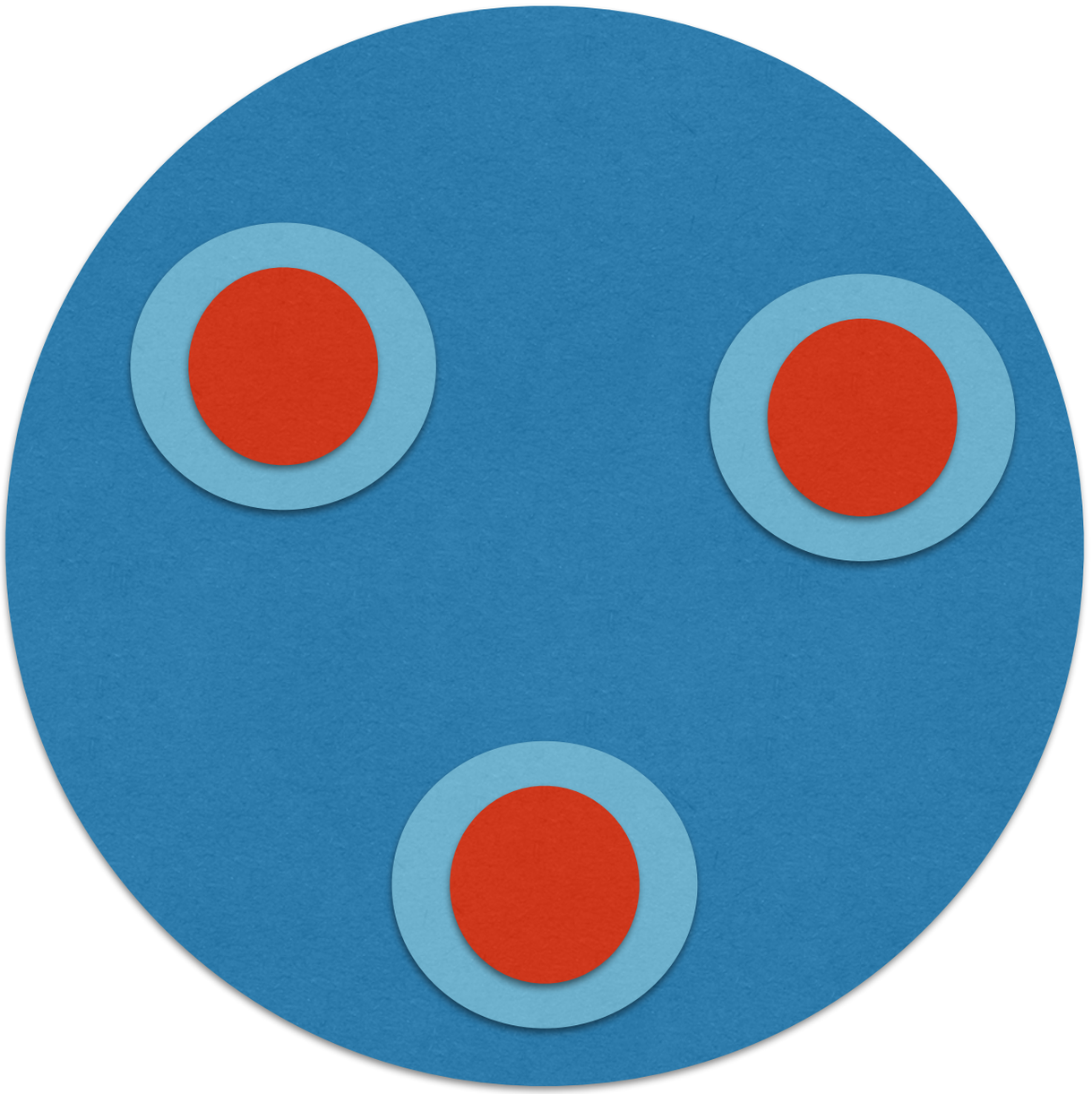
$$\int f_i^{\alpha}(P) Q_{\alpha}^{i}(P) |Jets\rangle = 0$$

- Unless a) f (p > 0 , **N**) vanishes outside a finite number of caps of finite opening angle.

- b) f(p = 0 , **N**) vanishes in annuli surrounding those caps

- P = p(+/- 1, +/- **N**) , **N** outward pointing unit vector on the sphere.

- Sign of time component distinguishes past from future



Regularize Scattering Theory by Finite Causal Diamond

$$Q^i_\alpha(P) \to Q^i_a[M_1 \dots M_{d-2}] \quad M_i \leq L$$

- Cut off angular momentum L < RM_P

- Bilinears in Q are matrices. Hamiltonian is single trace. Constrained states are those on which matrices block diagonal.

$$Diag(B_1 \dots B_k, L - \Sigma B_k),$$

- $\sum B_i^{d-3} L$ Constraints

- Need $\sum B_i^{d-3} L \ll L^{d-2}$ for jet interpretation to

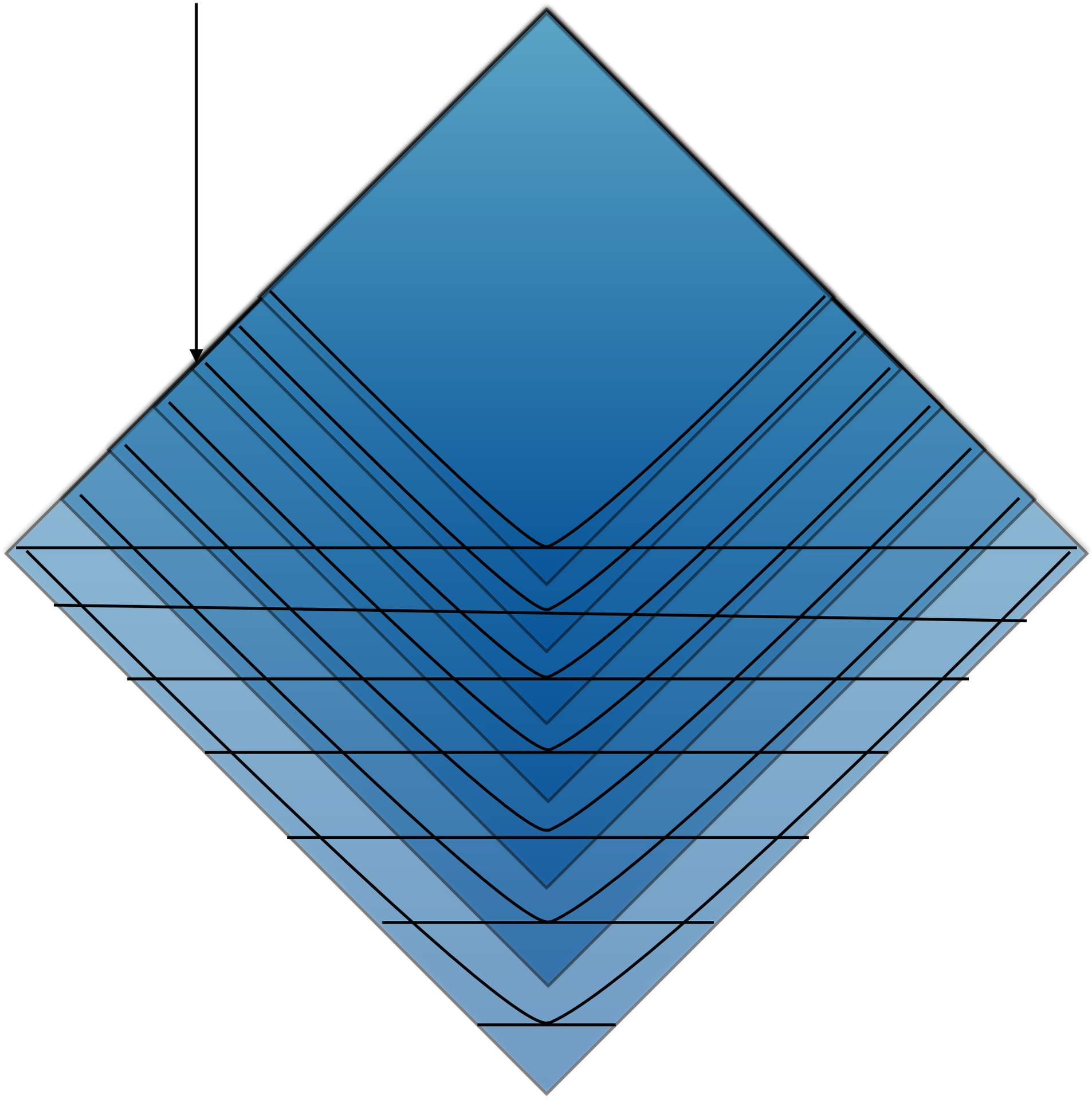
- Make sense in causal diamond of size L

- Explains temperatures of horizons, time scales of scrambling

Inflation

- Inflationary fluctuations imply entropy bound saturated inside horizon. Implies field theory is not a good approximation.

- HST model insight: localized states imply initial constraint.Most probable constraint with a fixed amount of energy, single black hole. Conjecture: most probable initial condition leading to a radiation dominated era: dilute gas of black holes with maximum homogeneity allowed by QM fluct ~ $S^{-1/2}$ Relation between HST and FRW slices shows this is a model of inflation that lasts for half the conformal time of the universe.



- $\zeta = \frac{\delta H}{\epsilon H}, \quad \epsilon H^2 = -\dot{H}$

- Different formulae as function of ϵ , but can choose slow roll metric to fit scalar two point function. Tensor two point function and higher point functions definitely different but might be small : $r \propto \epsilon^2$

- Black hole decay source of Hot Big Bang, maybe baryogenesis, maybe primordial BH dark matter. Model has very few parameters especially if it gives rise to acceptable PBH spectrum.

A Brief History of "Swampland" Conjectures

T. Banks hep-th/0011255 - Real processes in M^4/dS cannot access higher dS minima of EFT

T.Banks, M.Dine JHEP 0110, (2001) hep-th/0106276: No Inflation in Perturbative regimes of string theory.

T. Banks hep-th/0211160 and Aguirre Banks Johnson hep-th 0603107: NoCDL instability for "half" of EFTs with positive and negative c.c. minima

Banks,Dine,Gorbatov,Fox: hep-th/0303252 Empirical evidence for the scalar version of the WGC

Banks, hep-th/0306074,Banks,Dine,Gorbatov, hep-th/0309170,Banks,hep-th/0412129,12085715 Multiple arguments against the string landscape

Vafa, hep-th/0509212, Arkani-Hamed,Motl,Nicolis,Vafa hep-th/0601001,Ooguri-Vafa, hep-th/0605264 - Invention of Swampland and WGC