The World as a Hologram

FRW/CFT duality arXiv:hep-th/0606204, arXiv:0908.3844

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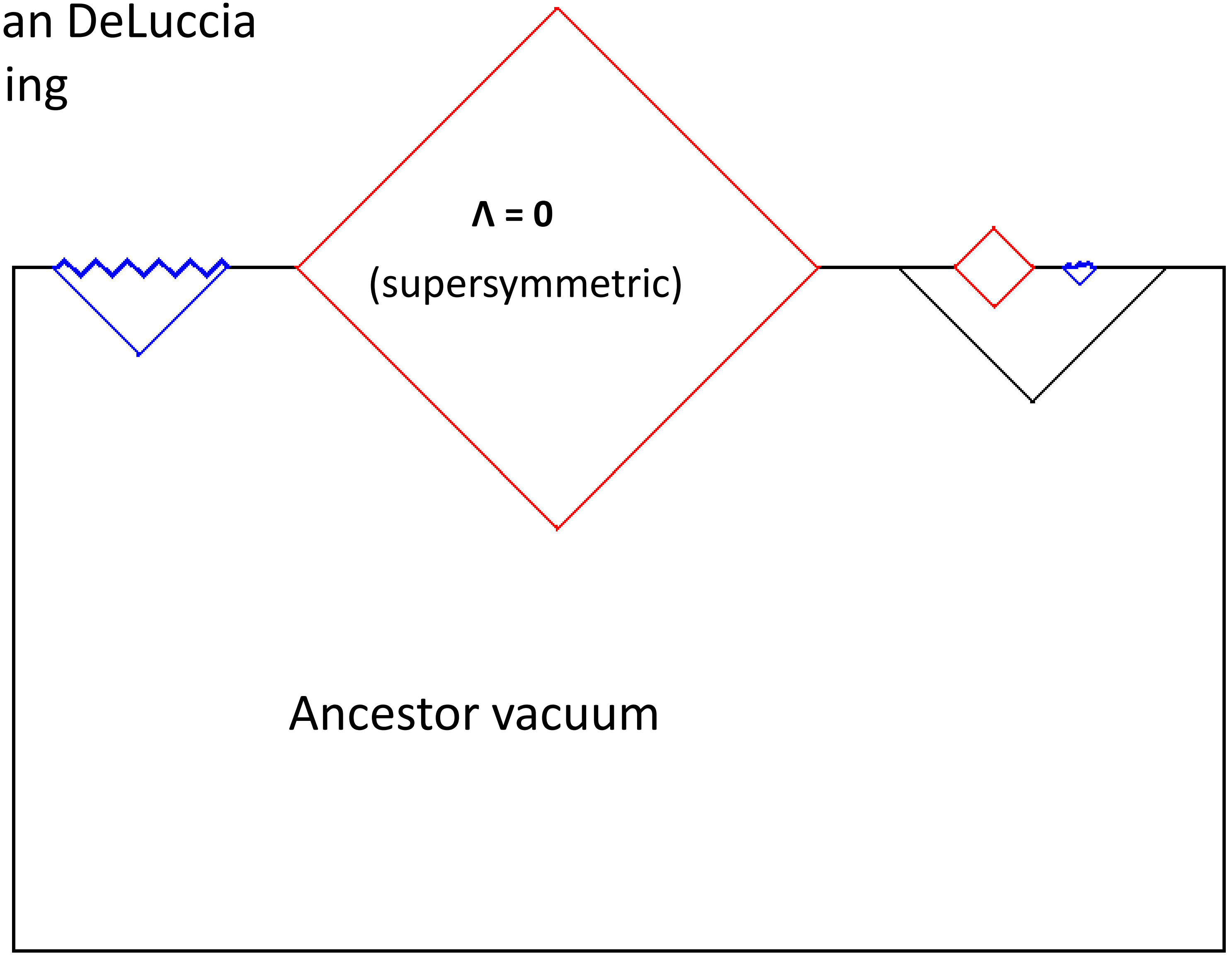
~~Philosophy~~

Eternal Inflation and Coleman DeLuccia tunneling



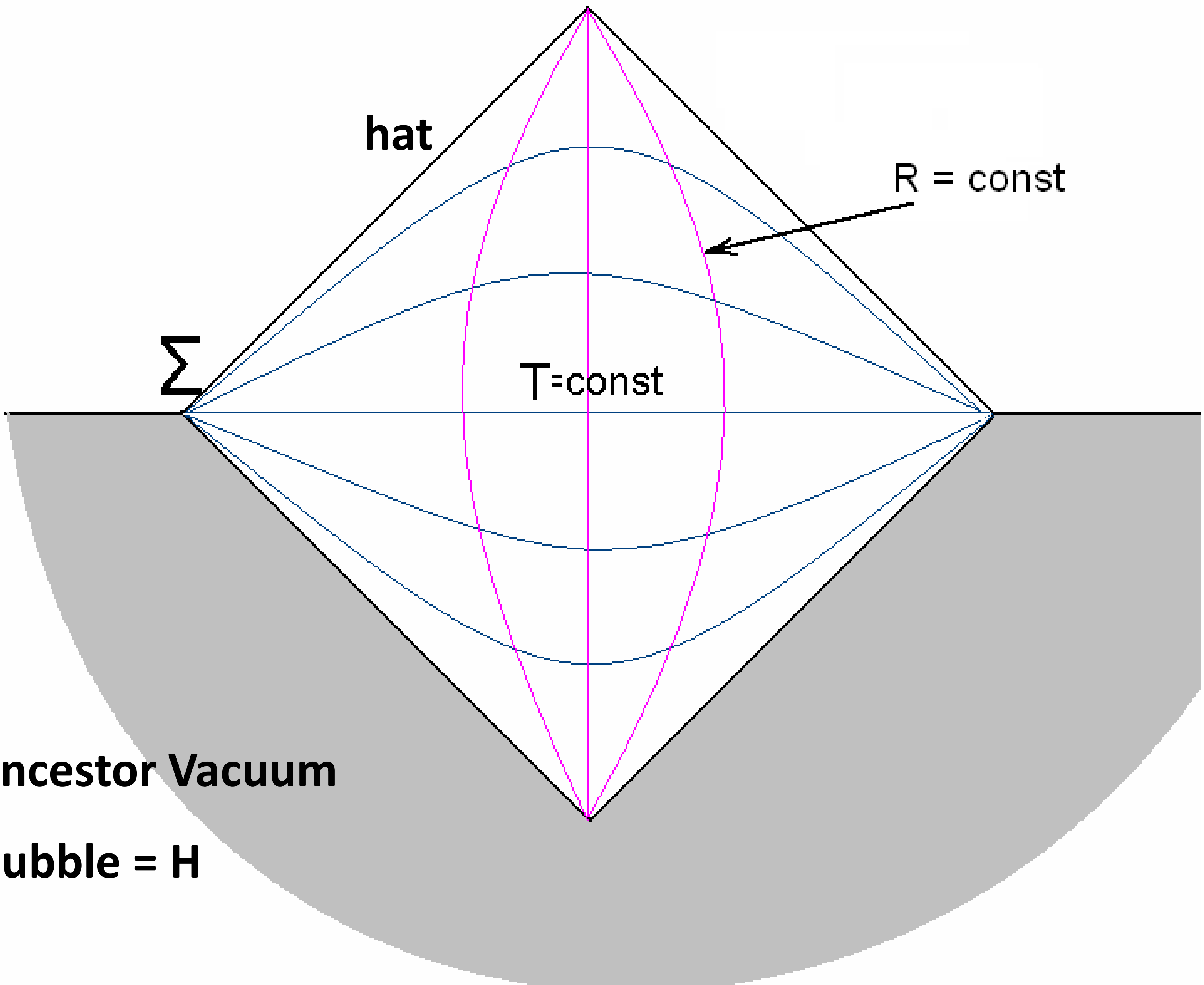
For obvious reasons we prefer to avoid singularities.

This leaves us with (supersymmetric) $\Lambda=0$ regions as platforms for observation.

Coleman DeLuccia bubble nucleation leads to an open, negatively-curved FRW universe.

We want to describe this universe holographically.

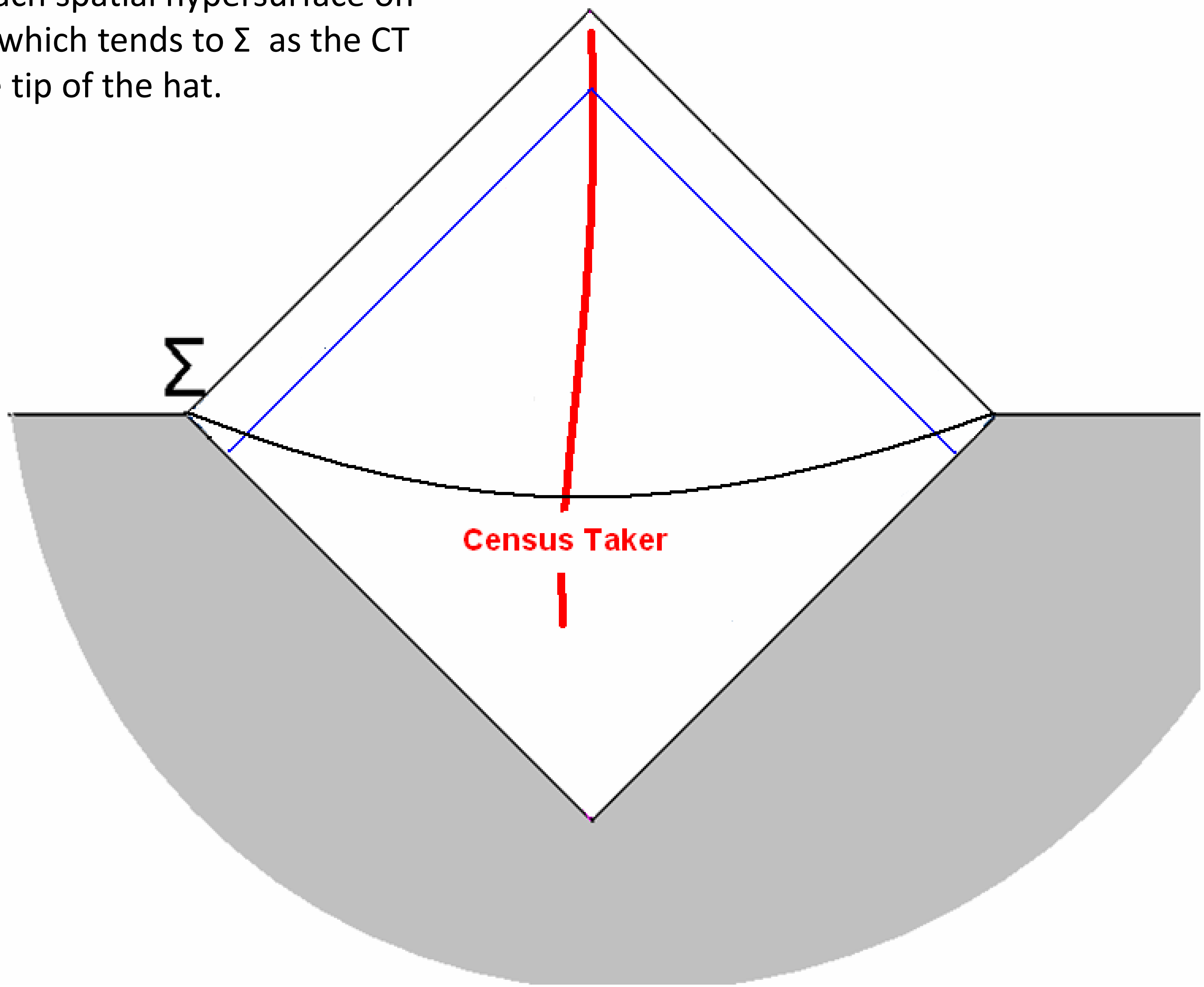
$$ds^2 = a(T)^2 \{ - dT^2 + dR^2 + \sinh^2 R \, d\Omega^2 \}$$



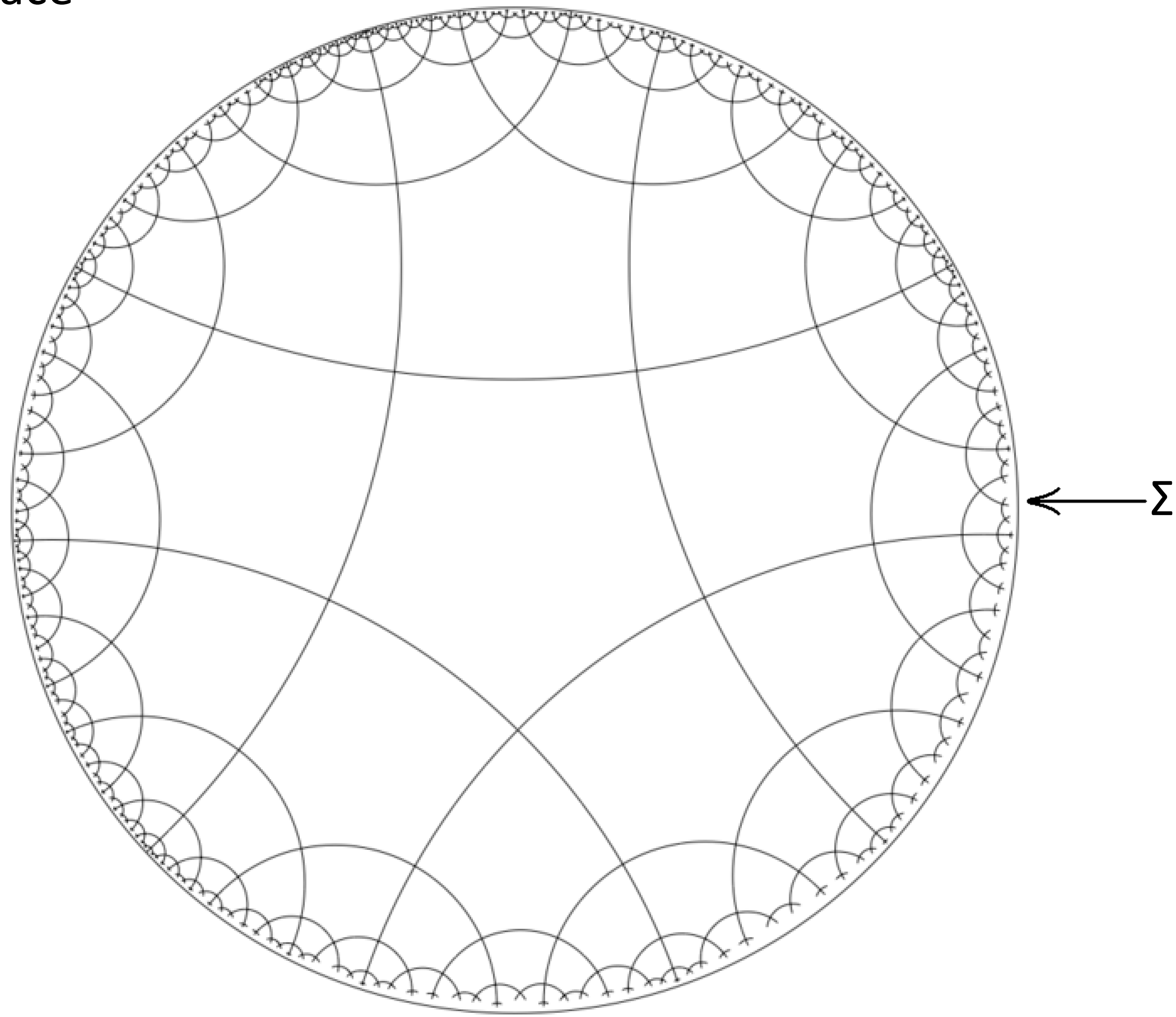
Ancestor Vacuum

Hubble = H

The Census Taker's past light-cone intersects each spatial hypersurface on a 2-sphere, which tends to Σ as the CT tends to the tip of the hat.



T=const surface



- T=const-surface is Euclidian ADS(3)

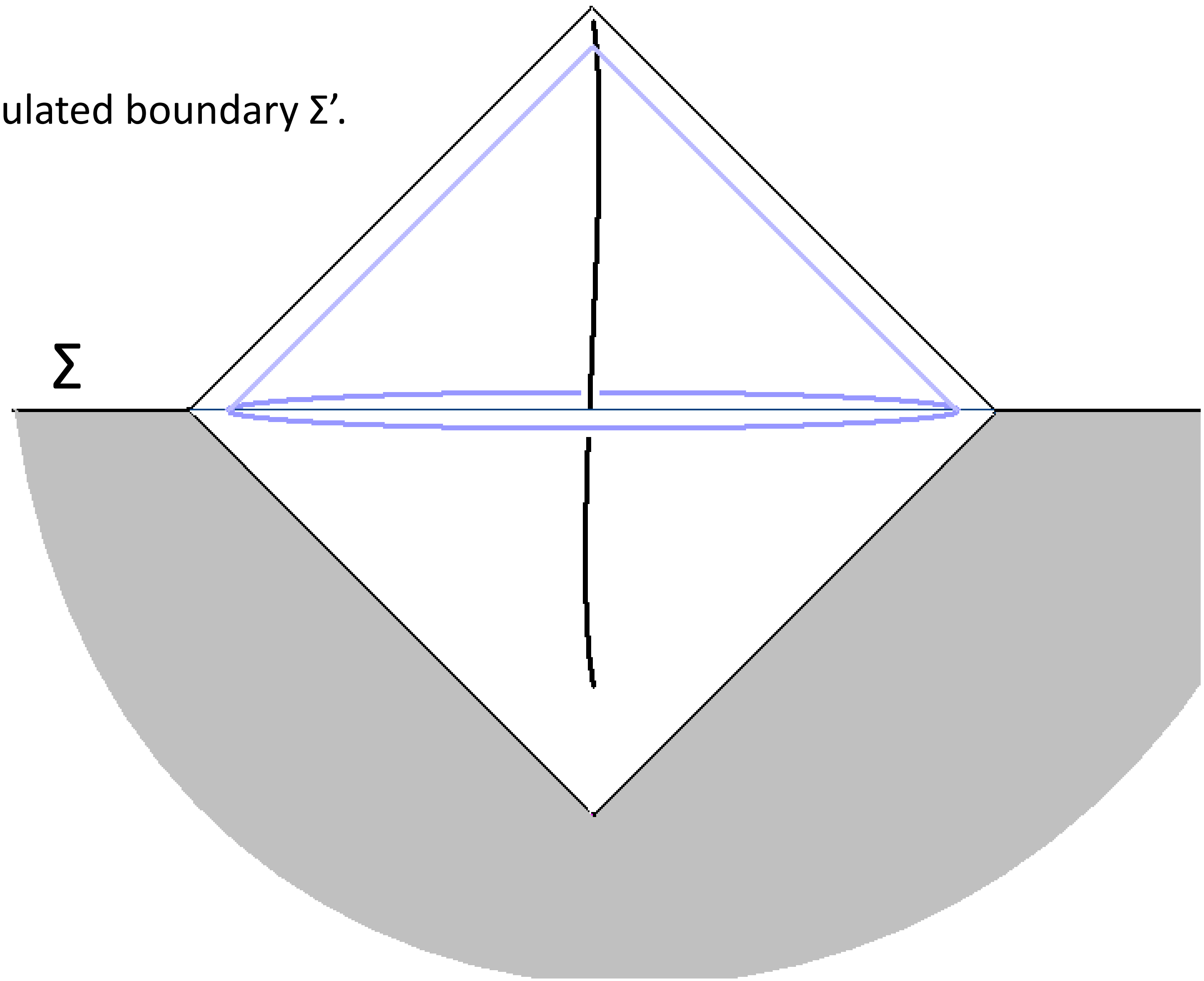
- Spatial translations-rotations → O(3,1).

- O(3,1) = conformal group on Σ.

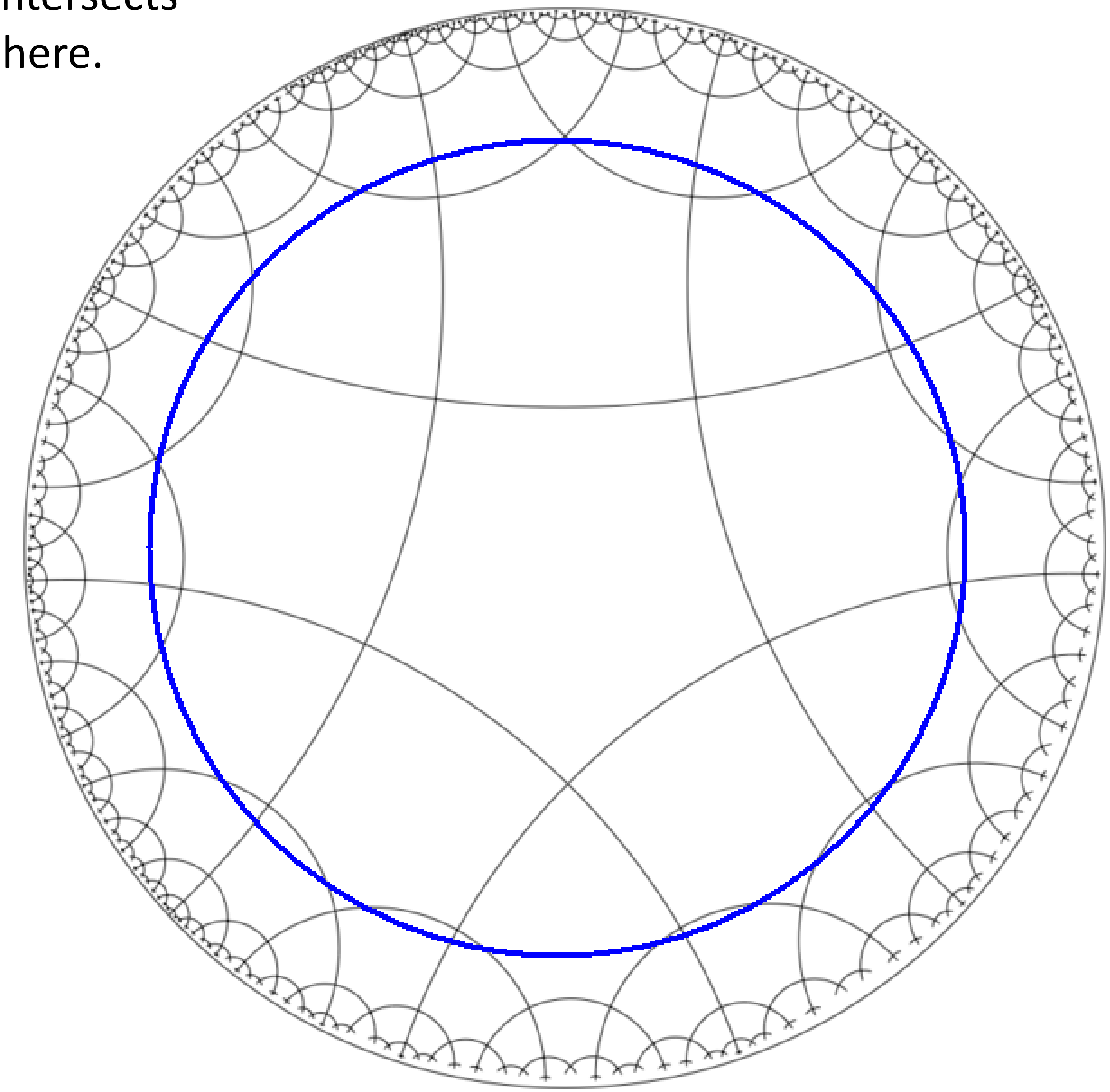
  Holographic CFT on Σ.

CT's past light-cone intersects T=const on a 2-sphere.

This defines regulated boundary Σ'.

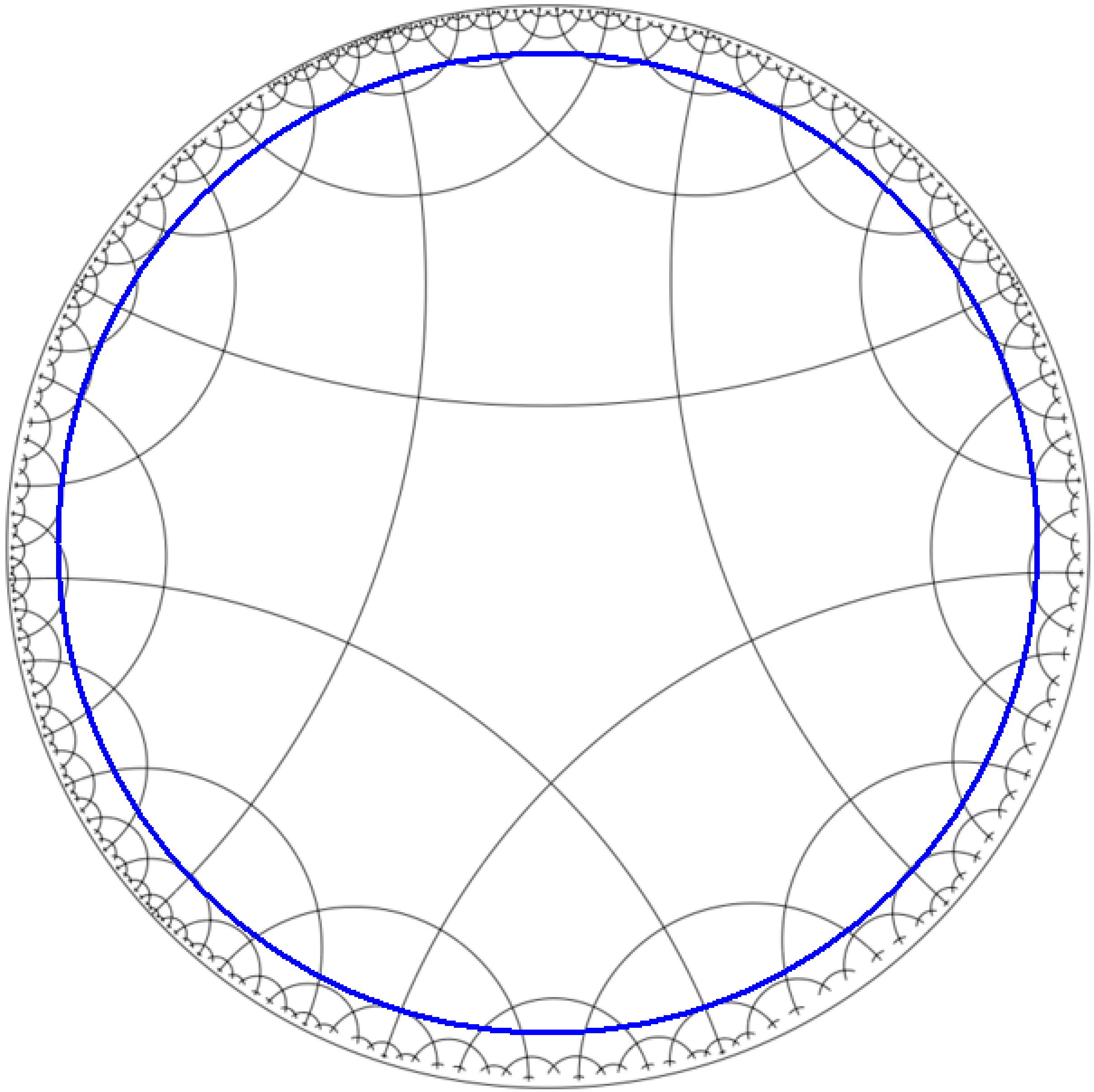


CT's light-cone intersects
T=const on 2-sphere.



As the CT time →∞, regulated boundary → Σ.

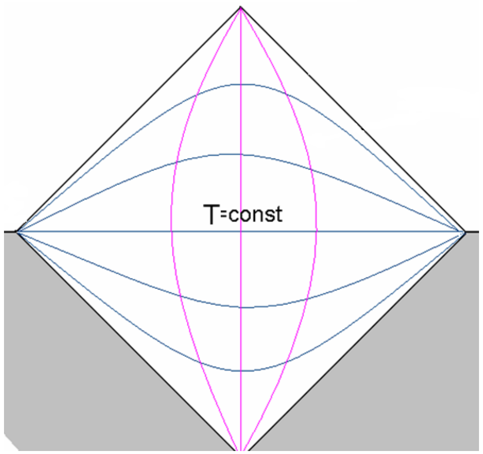
RG flow for CFT on Σ.

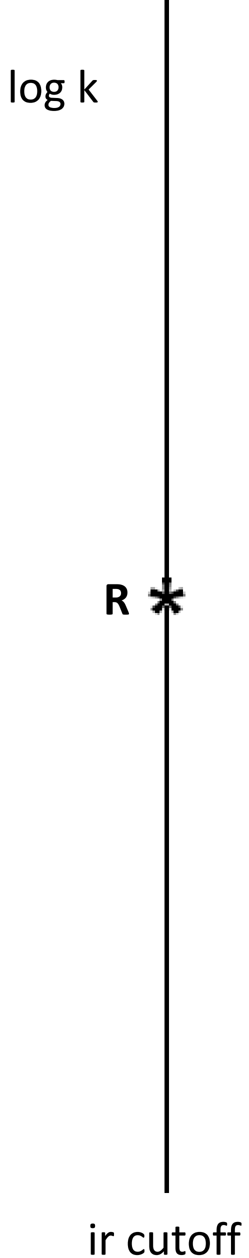


In ADS the coordinate R =RG flow parameter.

This will still be true in FRW.

But where does T come from?





Reminder about Wilsonian RG and ADS/CFT

- R (the RG scale) is a sliding reference scale.
- Integrate out all degrees of freedom with $k > e^{R}$ to define an effective action at R.
- Physical quantities <u>do not</u> depend on the reference scale R.
- The effective action S_{eff} <u>does</u> depend on R and RG tells us how it varies.

- Motion in the radial direction (R) of ADS is all about how the effective theory varies with log k.

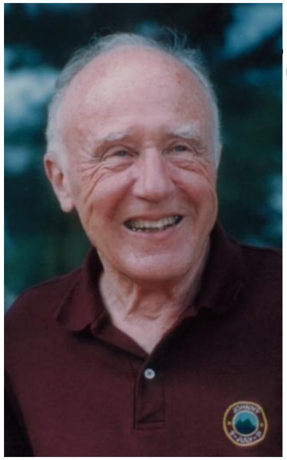
But what about T?

(Scale factor) time is geometry.

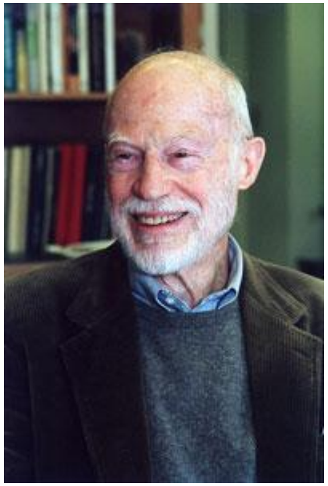
$$ds^2 = a(T)^2 \{ - dT^2 + dR^2 + \sinh^2 R \, d\Omega^2\}$$

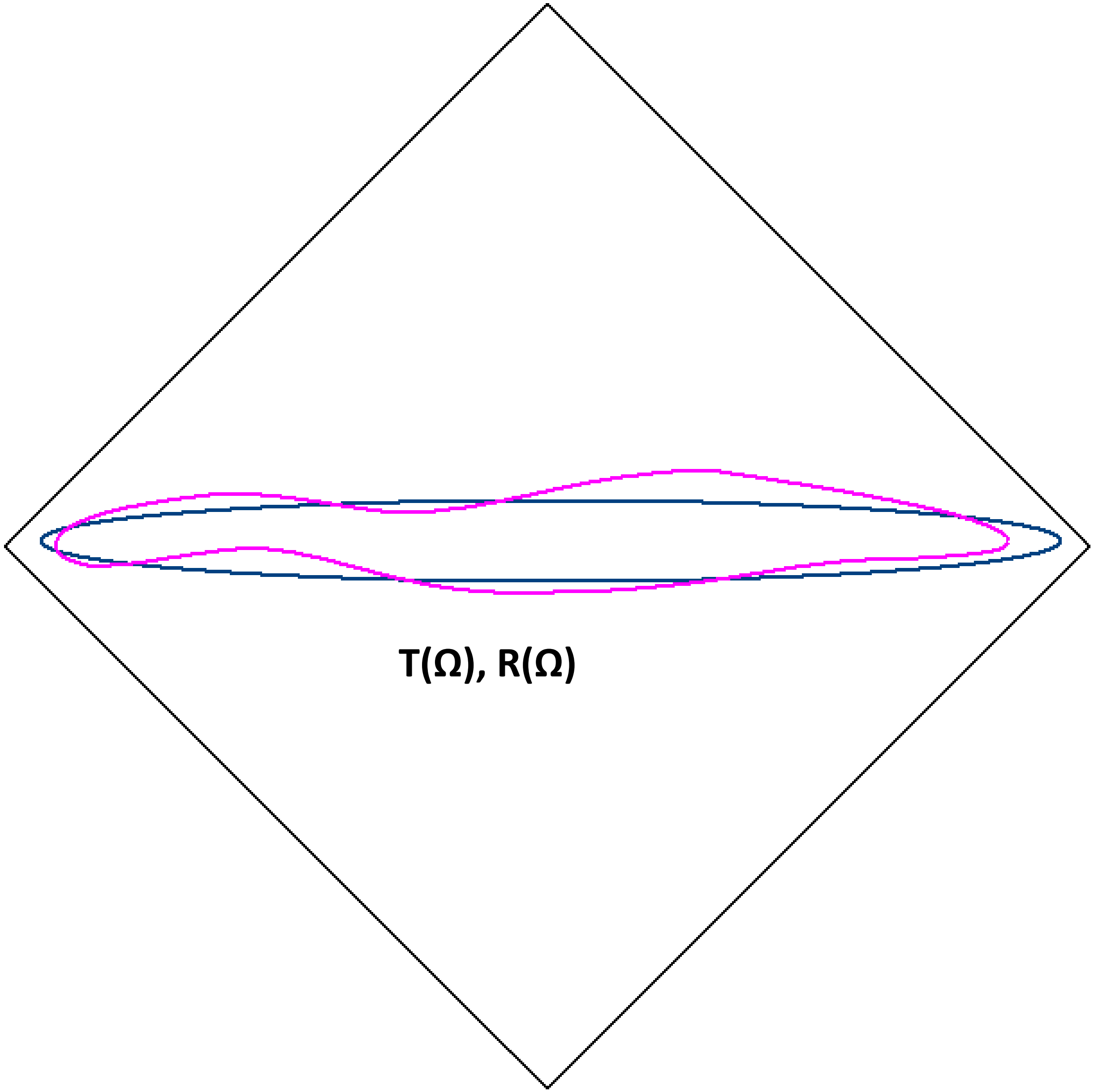
$$\rightarrow a(T)^2 \, e^{2R} \, d\Omega^2$$

Define regulated boundary Σ' in local way:



(Ω), $R(\Omega)$





T(Ω), R(Ω)

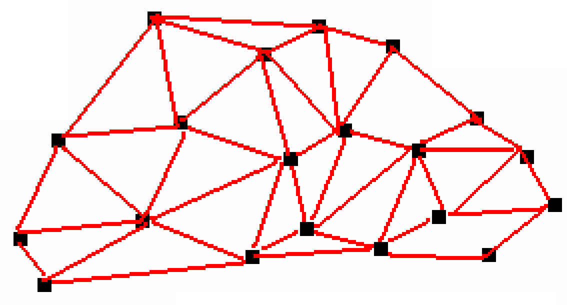
$$\mathbf{a(\Omega) = e^{L(\Omega)}} \qquad \text{(L for Liouville)}$$

Metric on Σ’: $\mathbf{ds^2 = e^{2L(\Omega)}\, e^{2\,R(\Omega)}\, d\Omega^2}$

Define reference metric: $\mathbf{ds_R^{\,2} = e^{2R(\Omega)}\, d\Omega^{\,2}}$

$$\mathbf{ds^2 = e^{2L(\Omega)}\, ds_R^{\,2}}$$

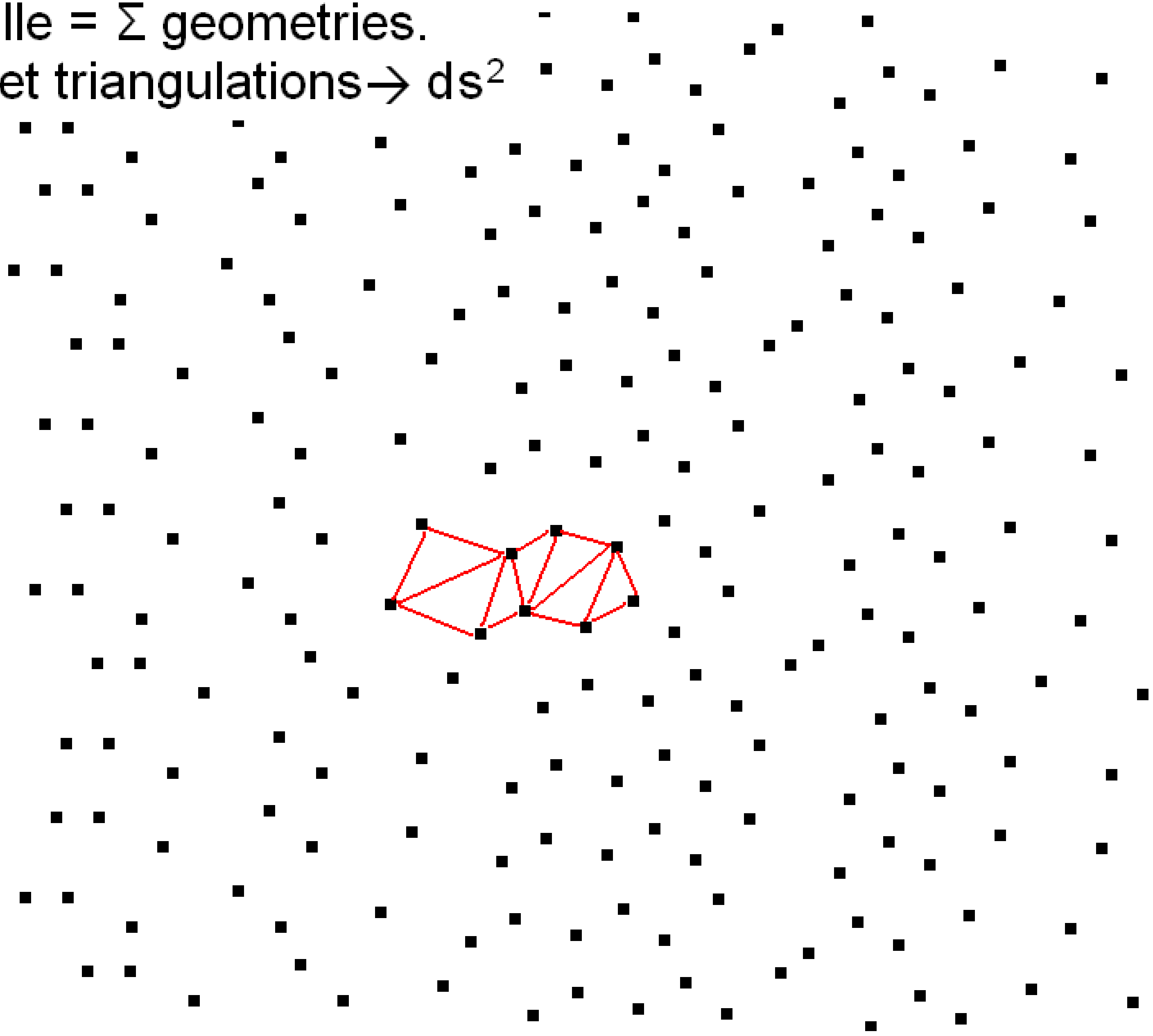
L is a trick for Σing over 2-D geometries, "Fishnet" triangulations, or planar Feynman diagrams



Fishnet diagram → metric ds

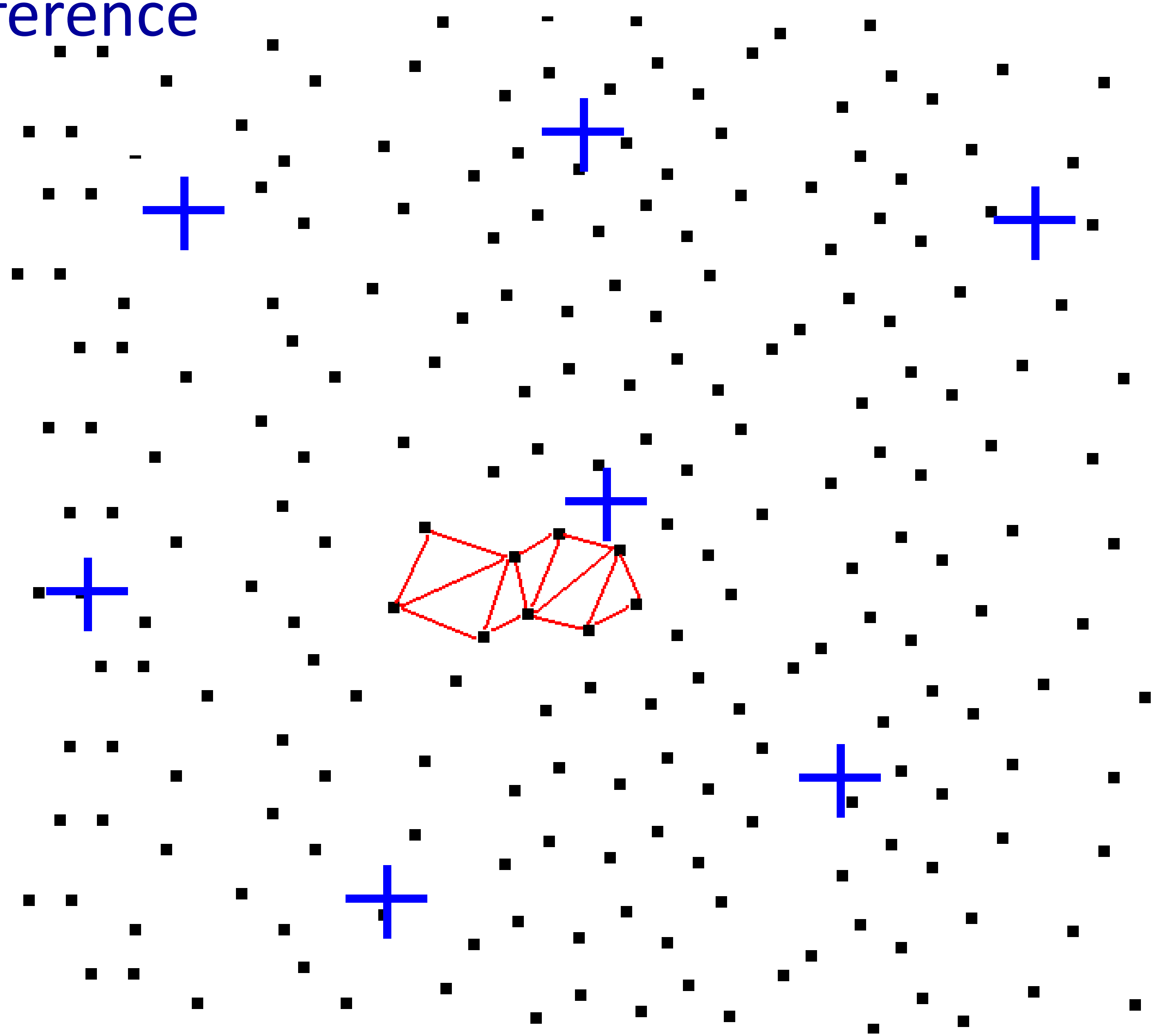
Liouville = Σ geometries.

Fishnet triangulations → ds^2



To sum over geometries we want to use the methods of QFT. To do that we introduce a reference metric ds_R

The Reference metric



$$ds^2 = e^{2L(\Omega)}\, ds_R{}^2$$

$$= e^{2L(\Omega)}\, e^{2R(\Omega)}\, d\Omega^2$$

Summing over structures that vary on scales smaller than the reference lattice defines a Wilsonian effective theory on the reference lattice.

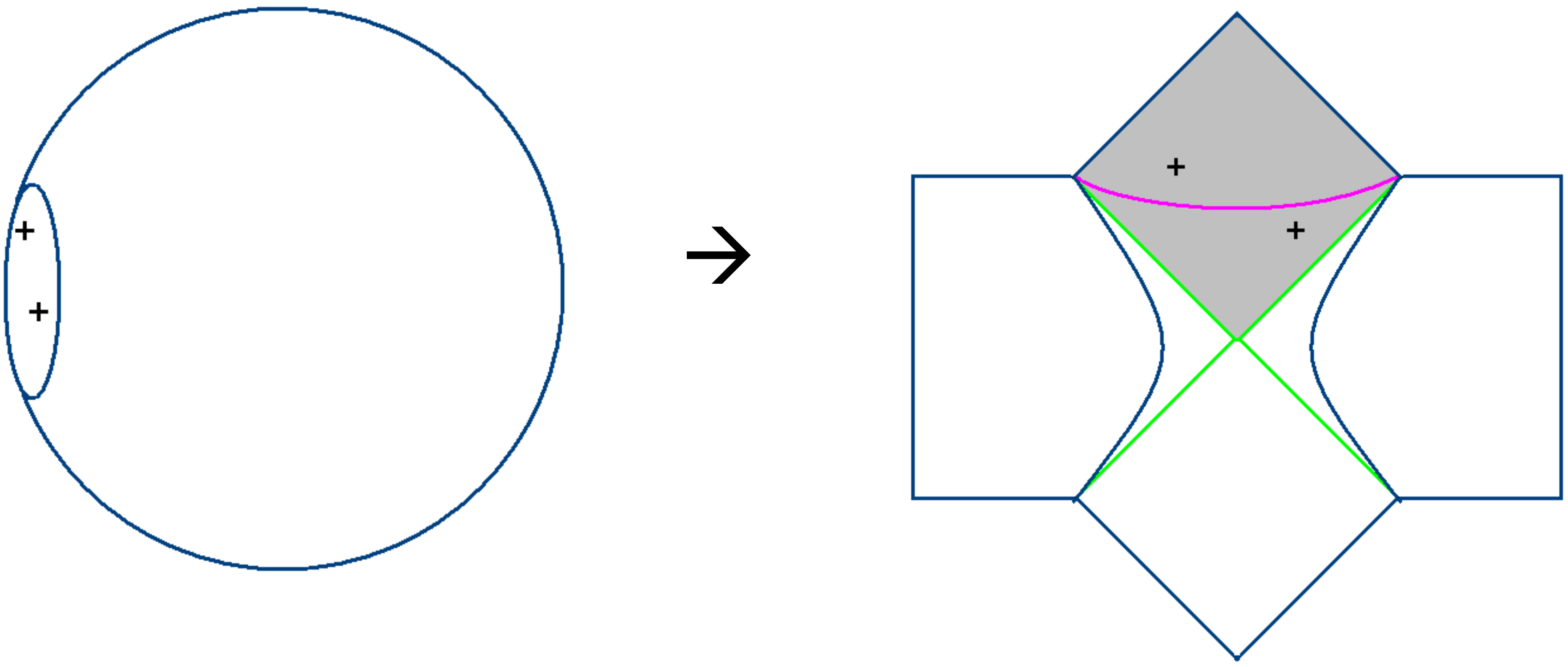
The effective theory has a Liouville field $L(\Omega)$

You can see where this is going. Summing boundary geometry → Liouville → scale factor time.

But before going on I want to explain what the evidence is for a duality between two dimensional Liouville theory and FRW is.

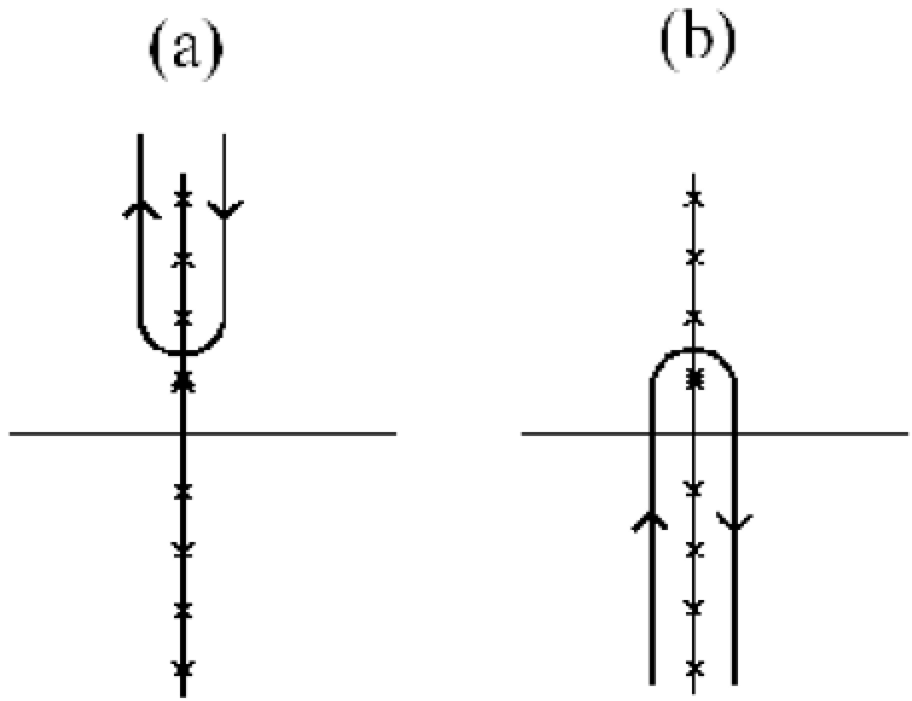
Freivogel and Sekino

Calculation scalar and tensor correlations by analytic continuation from greens functions in the Euclidean Coleman DeLuccia geometry.



$\langle \varphi \, \varphi \rangle =$

$$\left\{ \oint_a \frac{dk}{2\pi} \mathcal{R}(k) \frac{e^{-ik(T_1+T_2-l)}}{2 \ \sinh l \ \ \sinh k\pi} + \oint_b \frac{dk}{2\pi} \mathcal{R}(k) \frac{e^{-ik(T_1+T_2+l)}}{2 \ \sinh l \ \ \sinh k\pi} \right\}$$



$T^{\pm} = T \pm R$

α = angular separation

$$e^{-(T_1^+ + T_2^+)} \sum_{\Delta=2} G_\Delta e^{(\Delta-1)(T_1^- + T_2^-)} (1-\cos\alpha)^{-\Delta}$$

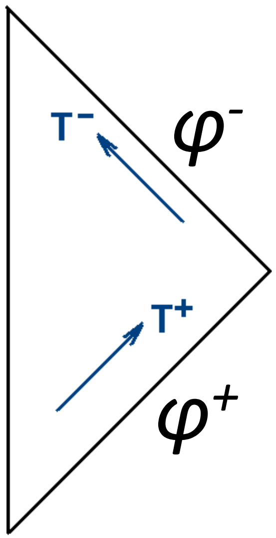
$$+ \ \tilde{G}_\Delta \ e^{(\Delta-1)(T_1^+ + T_2^+)} (1-\cos\alpha)^{-\Delta}$$

$$+ \ e^{-(\Delta-1)(T_1^+ + T_2^-)} (1 - \cos\alpha)^{-\Delta}$$

$$+ \ e^{-(\Delta-1)(T_2^+ + T_1^-)} (1 - \cos\alpha)^{-\Delta}$$

φ has the form

$$\phi = e^{-T^+} \sum_{\Delta} \left[C_{\Delta}^{-} e^{-(\Delta-1)T^-} + C_{\Delta}^{+} e^{-(\Delta-1)T^+} \right] \mathcal{O}_{\Delta}$$



Tensor

$$\langle h_{ij} \; h^{kl} \rangle =$$

$$e^{-(T_1^+ + T_2^+)} \sum_{\Delta=2} G_{ij\,\Delta}^{kl} \, e^{(\Delta-1)(T_1^- + T_2^-)} (1 - \cos\alpha)^{-\Delta}$$

$$+ \sum_{\Delta'=0} \tilde{G}_{ij\,\Delta'}^{kl} \, e^{-\Delta'(T_1^+ + T_2^+)} (1 - \cos\alpha)^{-\Delta'}$$

$+ \ldots\ldots$

Critical Test: the existence of a boundary energy-momentum tensor.

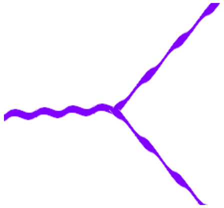
The tensor correlation function G_1 contains a dimension-2 contribution.

It is transverse and traceless. In other words it has the properties of T^{ij}.

The Central Charge by dimensional analysis

$\langle h\ h \rangle \sim H^2$

$\langle h\ h\ h \rangle \sim l_p H^4$



Freivogel et al (arXiv:hep-th/0606204)

assume $T \rightarrow q\ h$

$\langle T\ T \rangle \sim q^2 H^2$

$\langle T\ T\ T \rangle \sim q^3\ l_p\ H^4$

Schwinger $\langle T\ T\ T \rangle \sim \langle T\ T \rangle$

Thus $\langle T\ T \rangle \sim (l_p H)^{-2}$ = de Sitter Entropy of Ancestor.

Why is L time-like?

Total central charge must be 0.

$$C_L + C_M = 0$$

C_{matter} = de Sitter entropy $\gg 0$

$C_{Liouville} \ll 0$

Liouville Action and the Saddle point

$$\mathcal{L} = \frac{c_L}{24\pi}\sqrt{g_R}(\nabla_R L \nabla_R L + K_R L) + \lambda\sqrt{g_R}\, e^{2L}$$

With negative c_L there is a spherical saddle point with an area that grows like λ^{-1}.

$$e^{2L} = \frac{c_m}{\lambda}$$

λ is not a constant of the theory. It is a Lagrange multiplier that tunes the size of the boundary.

<u>λ scans time.</u>

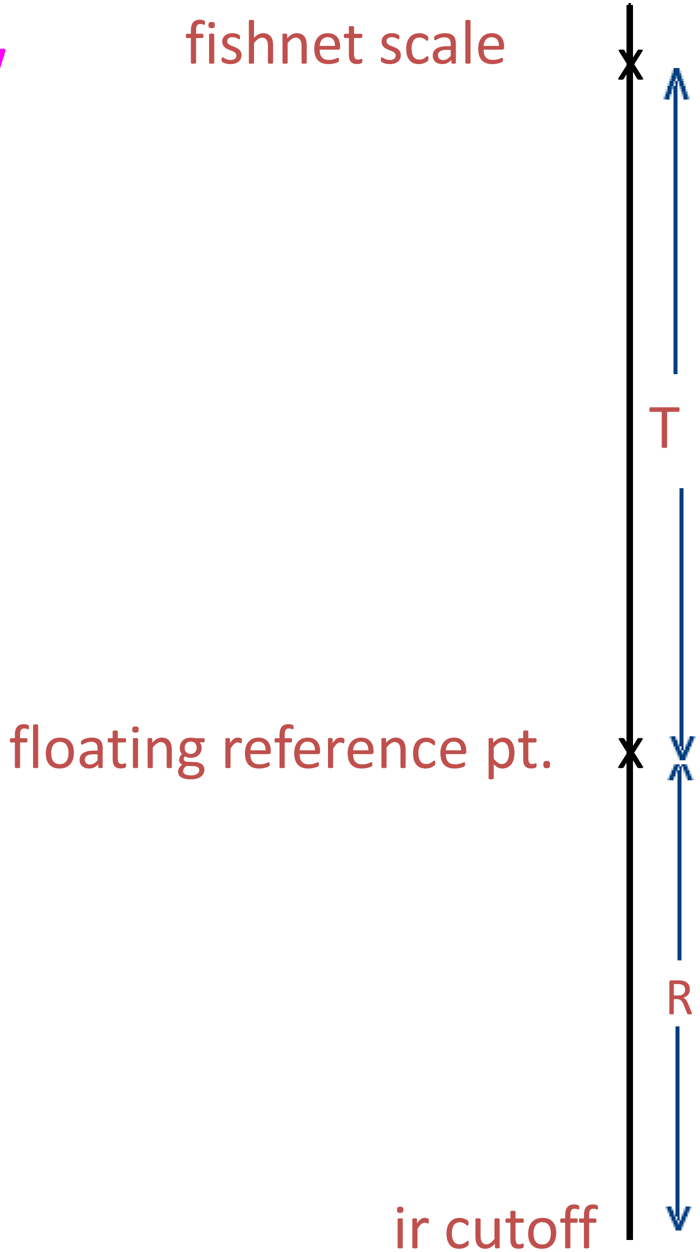
RG flow is 2 dimensional.

Wilsonian effective action is a function of the RG reference scale κ, and the 2D cosmological constant λ.

Alternately one can study the theory as a function of the physical metric of the boundary ds, and of the reference metric ds_R.

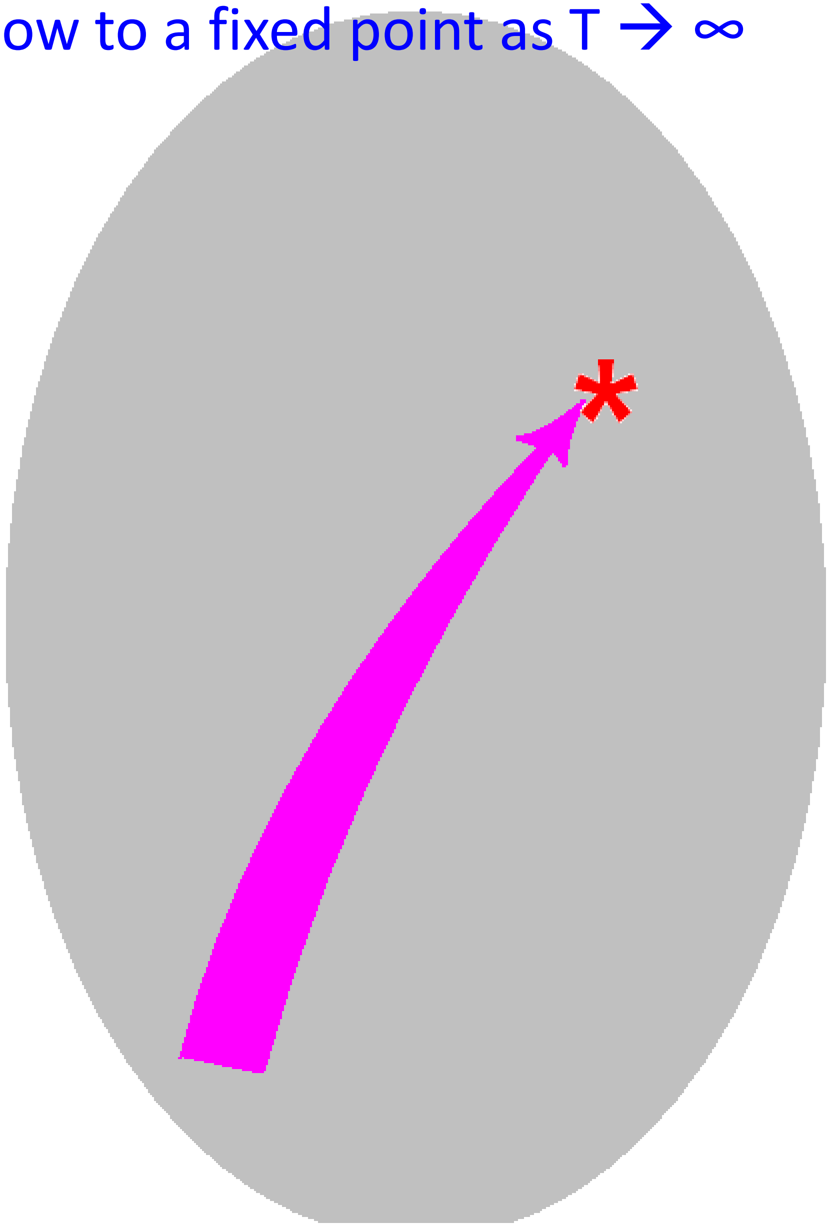
Or, R and T.

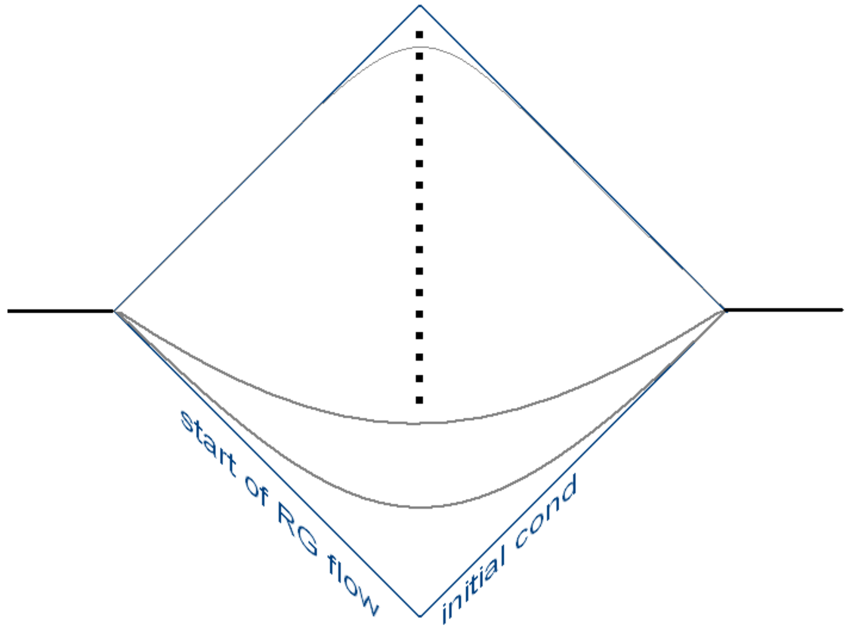
GR Flow



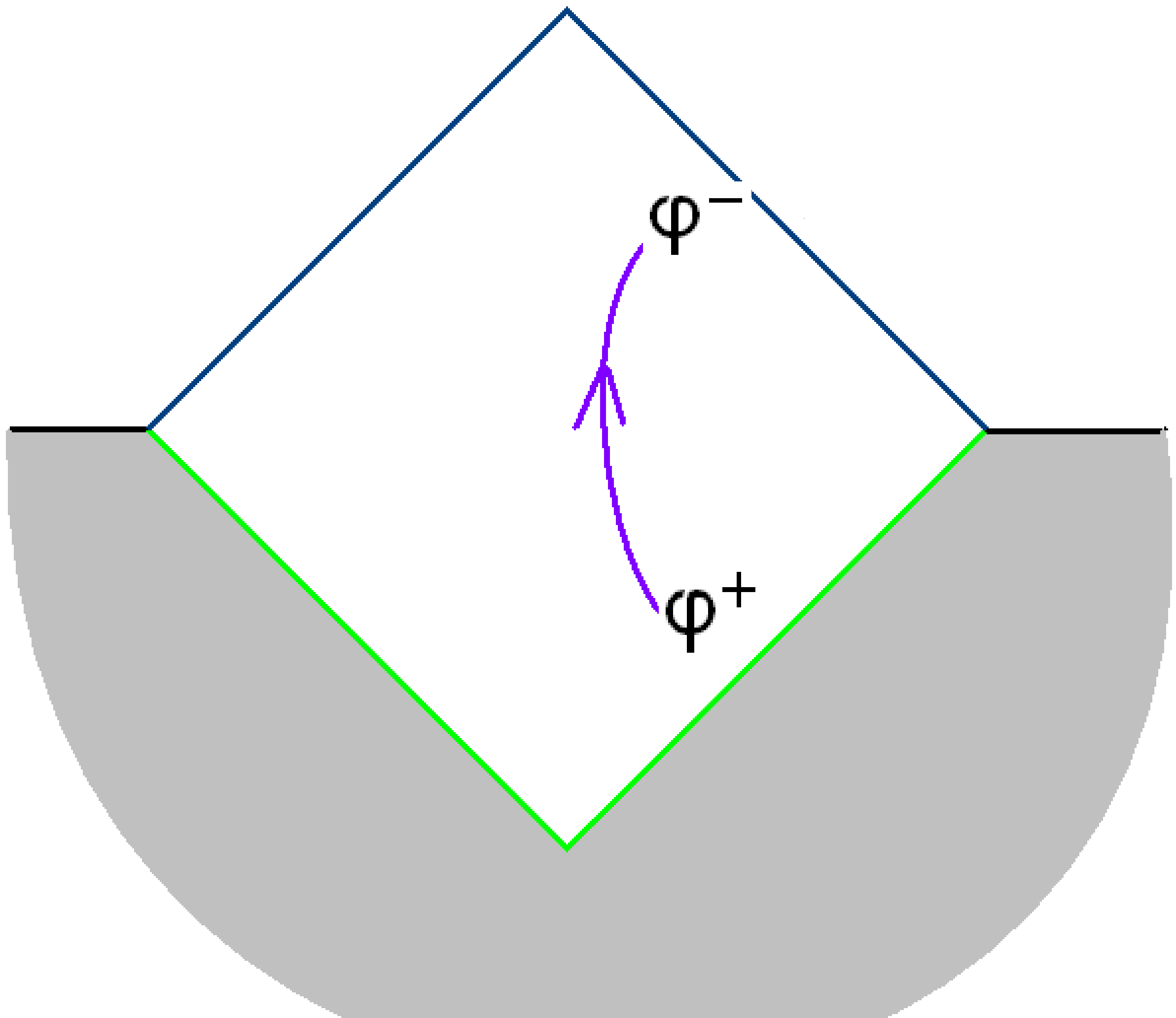
As T increases the theory tends to a continuum fixed pt theory.

Flow to a fixed point as T → ∞





Solving the wave equation from the initial data to the hat is the same as running the RG flow from the initial microscopic action to the continuum fixed point.



The correlation functions (Freivogel, Sekino) scale in exactly the right way to be the correlations of the Wilsonian effective action as a function of R and T (or κ and Λ).

Same for tensor correlators which define the energy-momentum tensor T_{ij}

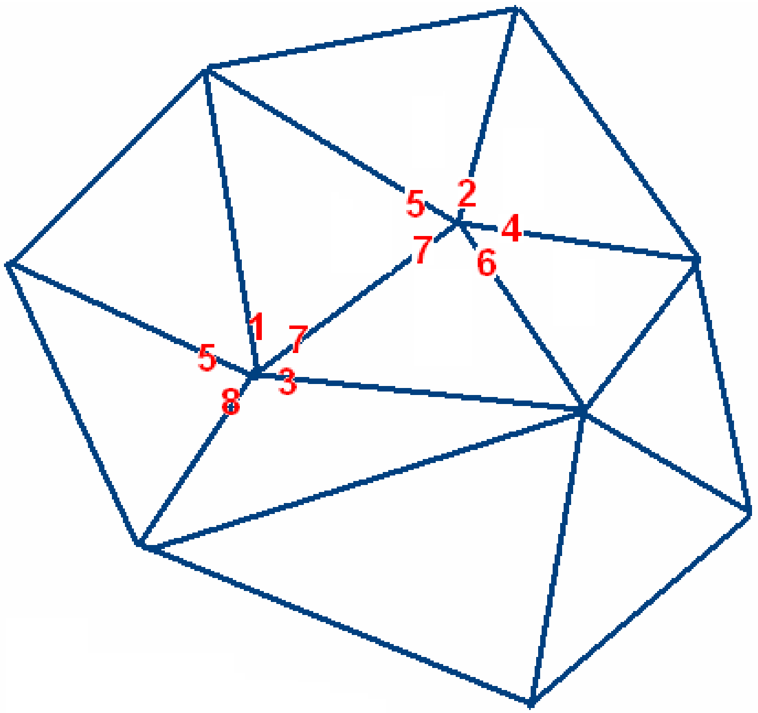
What is the underlying microscopic theory?

2D Euclidean gauge theory coupled to Liouville?

Too rich.

A 0+0 dimensional matrix integral with a large number of matrices M^i_{ab}.

$$\int e^{-S(M)} \ \Pi_i \, dM^i$$



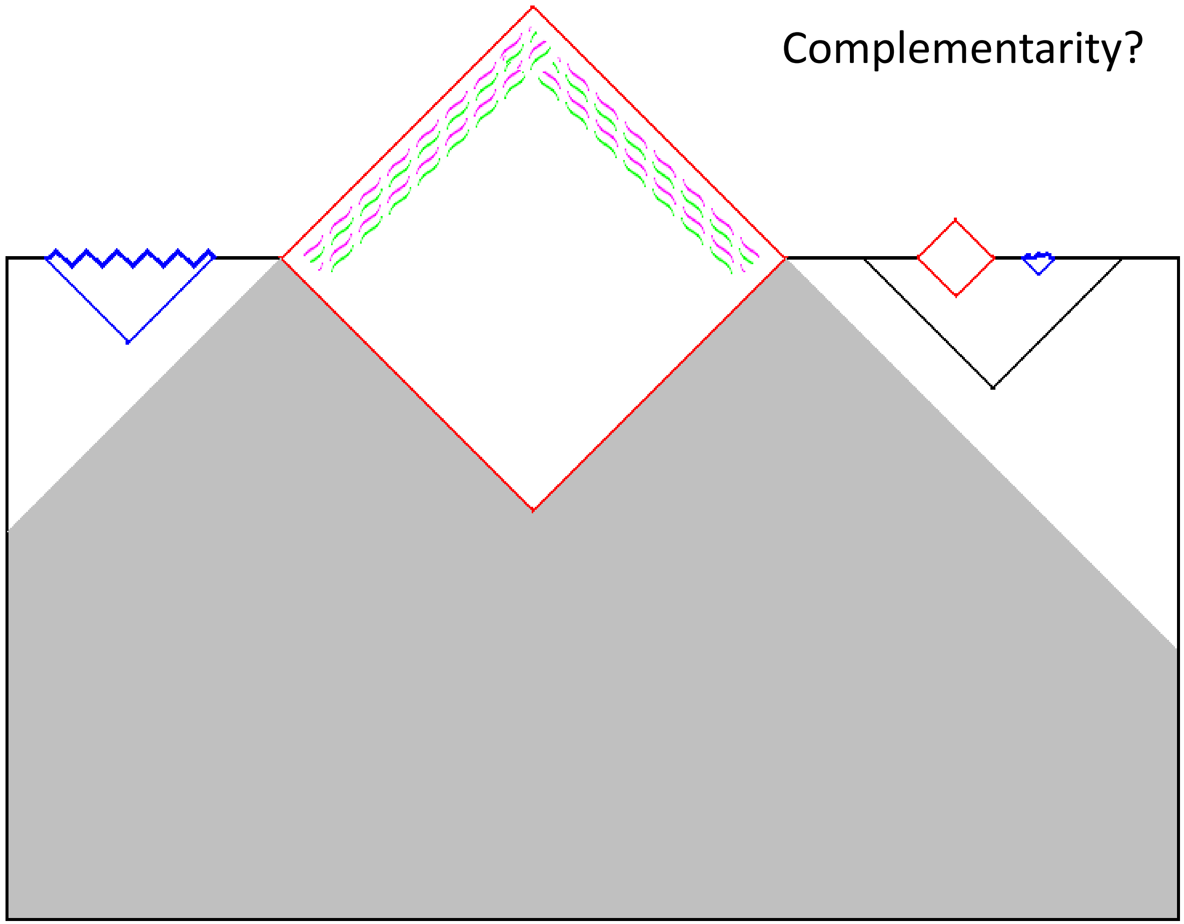
Fishnet is the planar diagrams of a large N matrix integral.

Some questions

Information questions

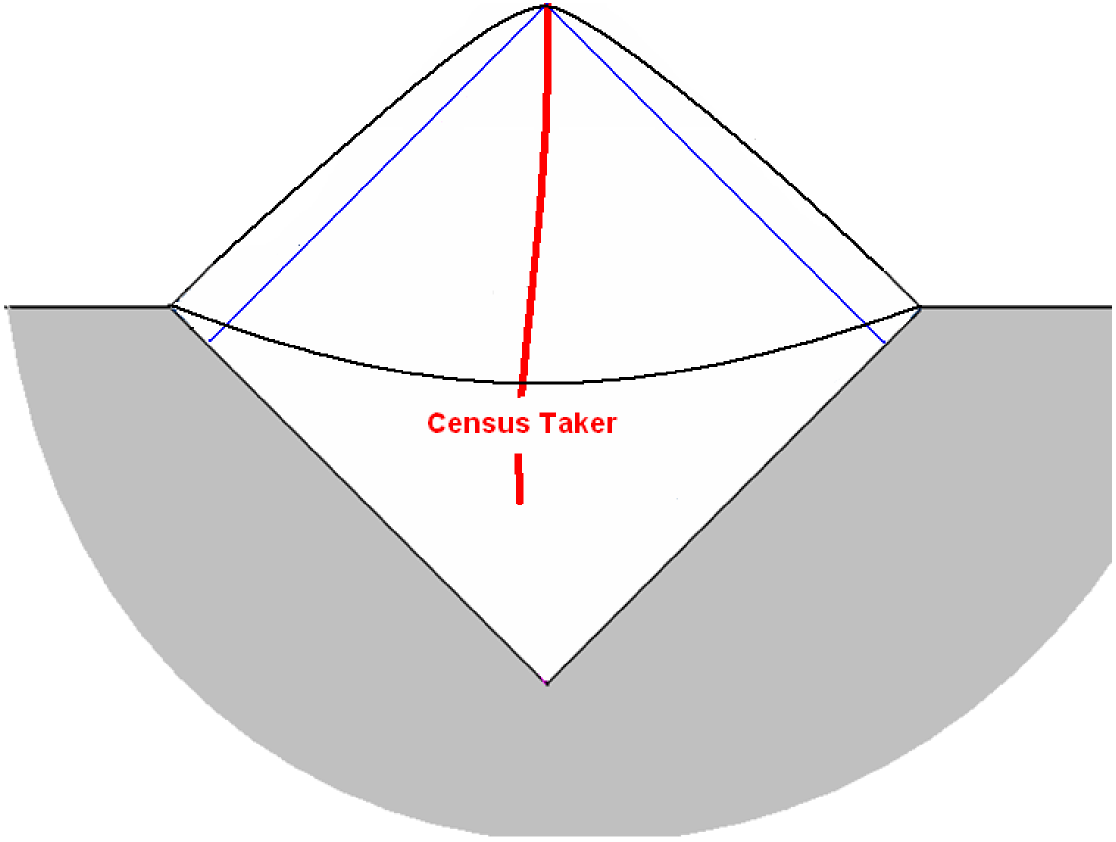
What is the connection between events outside the CT's horizon and the Hawking-like radiation that comes into the hat from the Ancestor?

Complementarity?



Description of de Sitter vacua

The CT cannot see arbitrarily close to Σ.



Obstruction to UV completion?

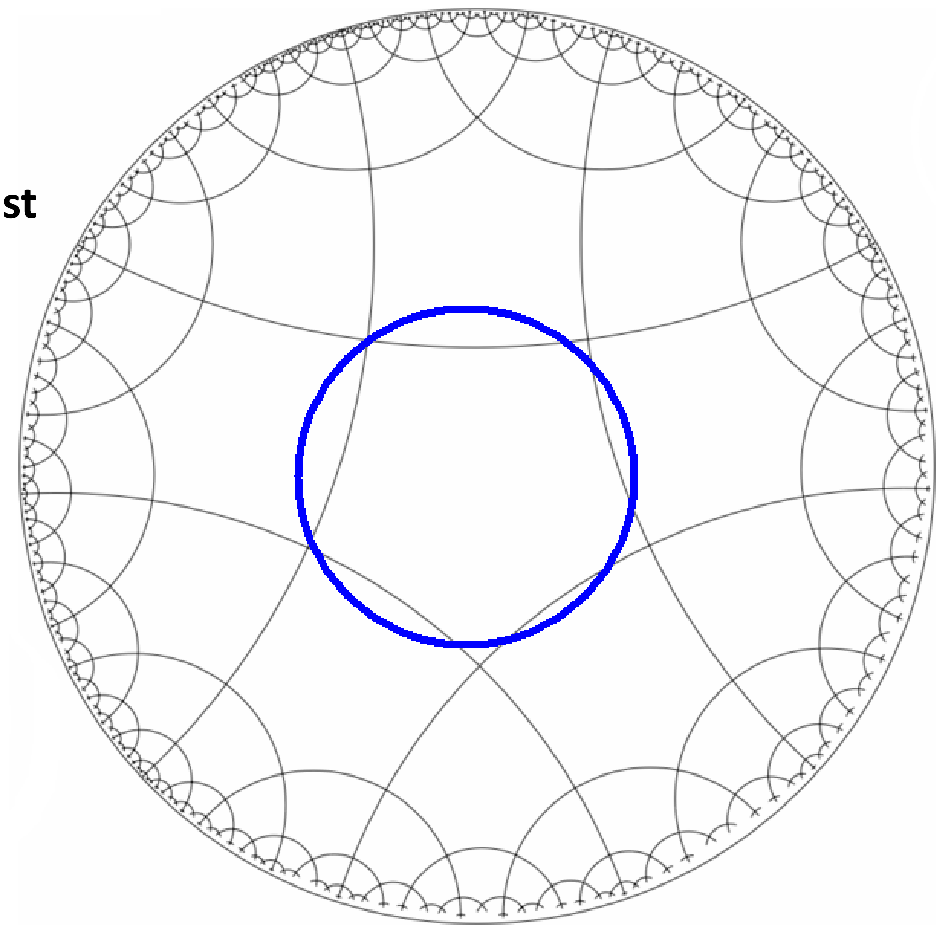
Role of supersymmetry?

Needed to remove obstruction to UV completeness?

Phenomenology: Super-curvature modes

Freivogel, Sekino

Surface of last scattering



CFT gives boundary conditions on Σ.