From QFT to QG ...and back

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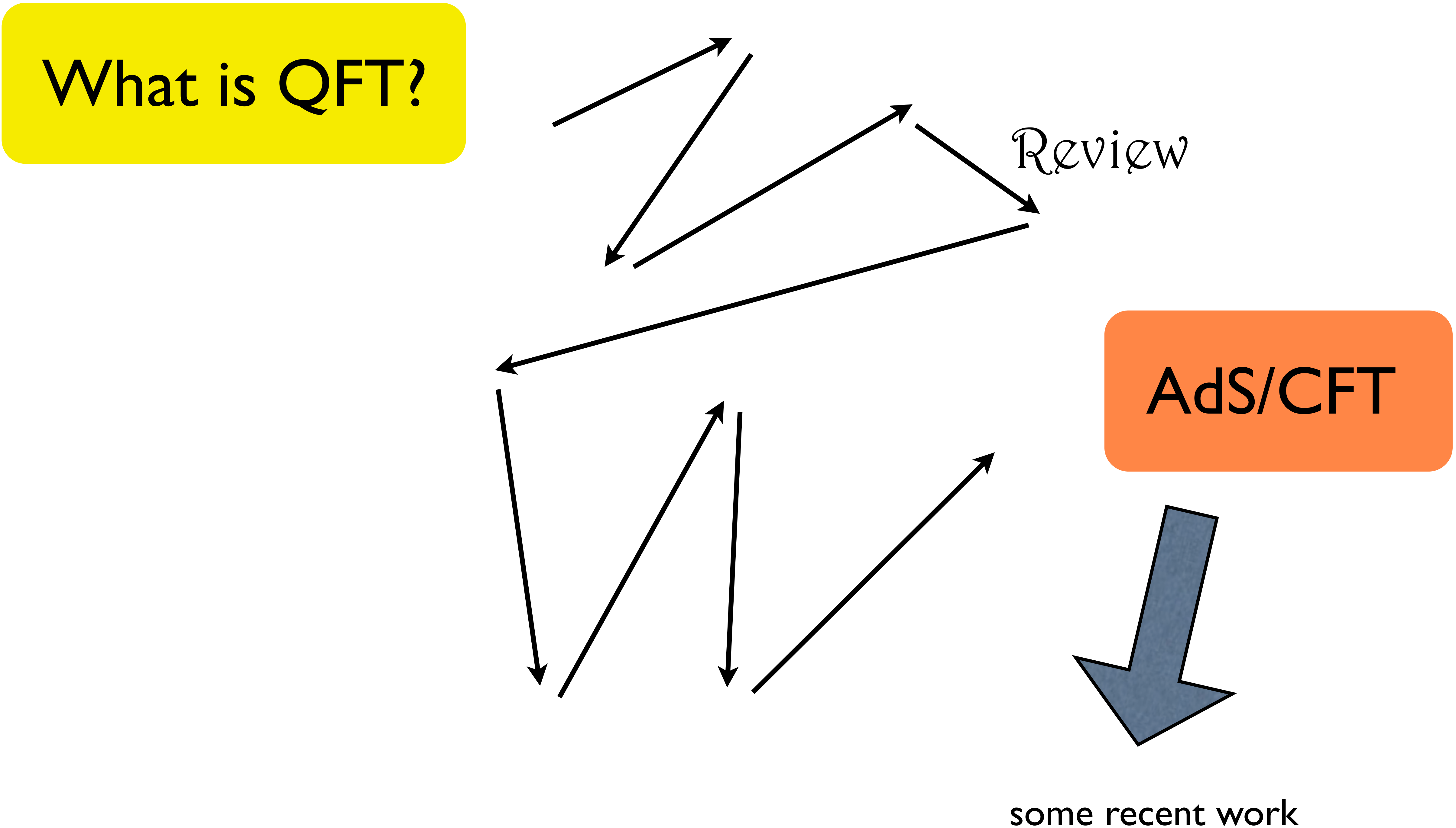
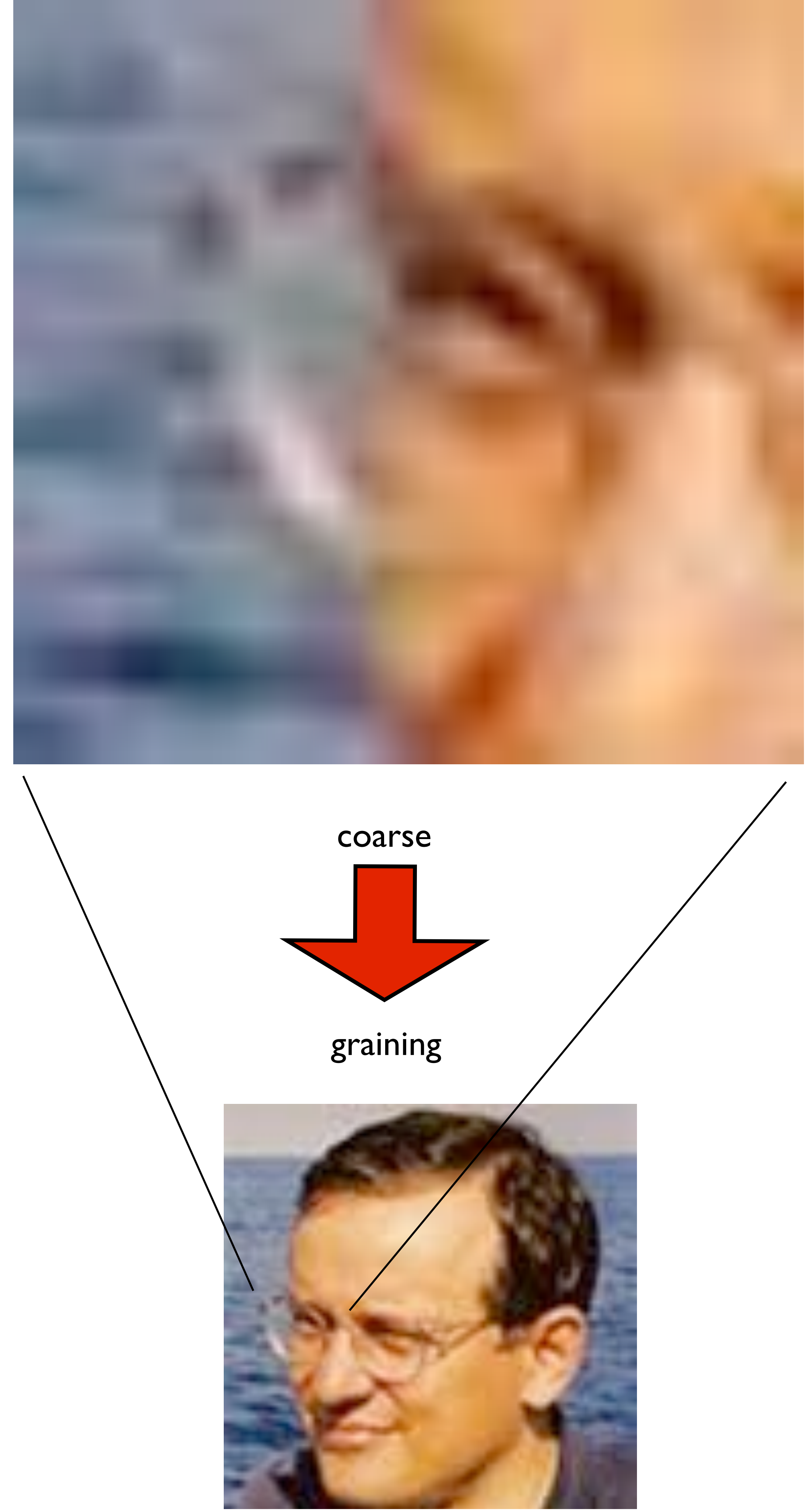
OUTLINE...



What is QFT?

$$\mathrm{QFT} \leftrightarrow \mathrm{CFT}_{\mathrm{UV}} + \text{relevant deformations}$$

What CFT_{UV}?



Deep UV,
just hypothetical information

In practice...

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{CFT}_{\text{IR}}} + \sum_{\mathcal{O}\in\text{relevant}} g_{\mathcal{O}} \cdot \Lambda^{d-\Delta_{\mathcal{O}}} \; \mathcal{O}$$

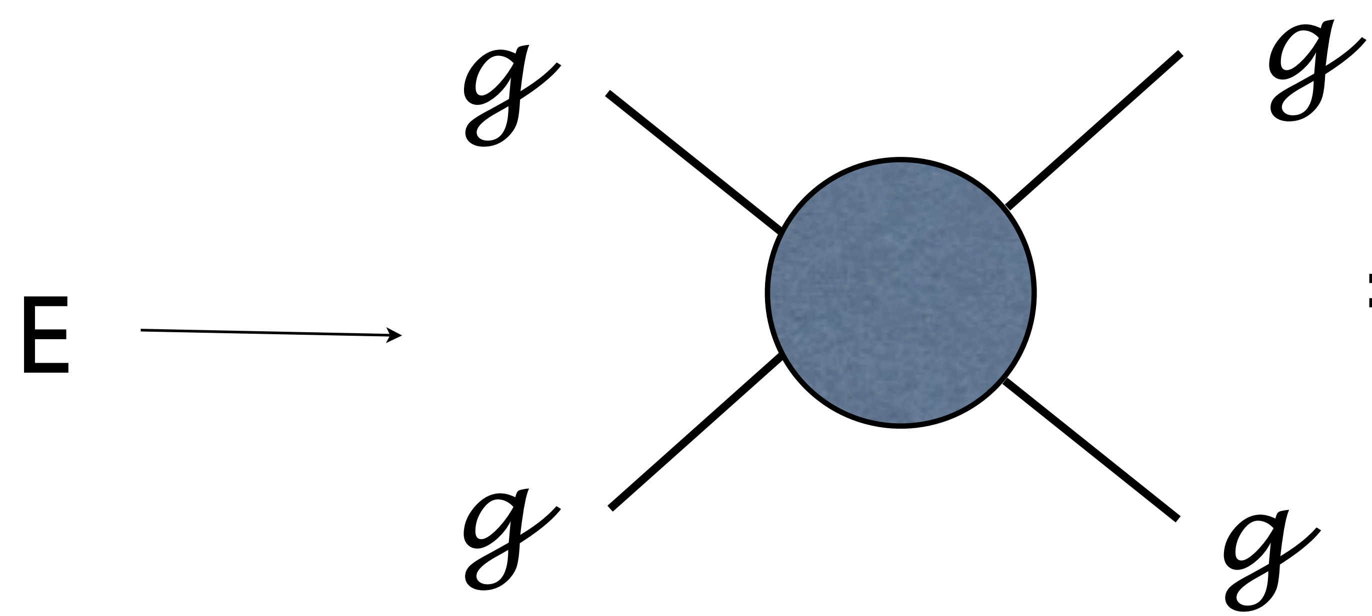
Parametrization of IR knowledge

$$+ \sum_{\mathcal{O}\in\text{irrelevant}} \frac{g_{\mathcal{O}}}{\Lambda^{\Delta_{\mathcal{O}}-d}} \, \mathcal{O}$$

Parametrization of UV ignorance

Gravity sits here!

Look at $2 \longrightarrow 2$ graviton scattering



$= \alpha_G(E)$

Very small at low energies

$$\alpha_G(E) \sim \left(\frac{E}{M_{\rm P}}\right)^2$$

there is naive strong coupling at the Planck scale

Two schools of thought

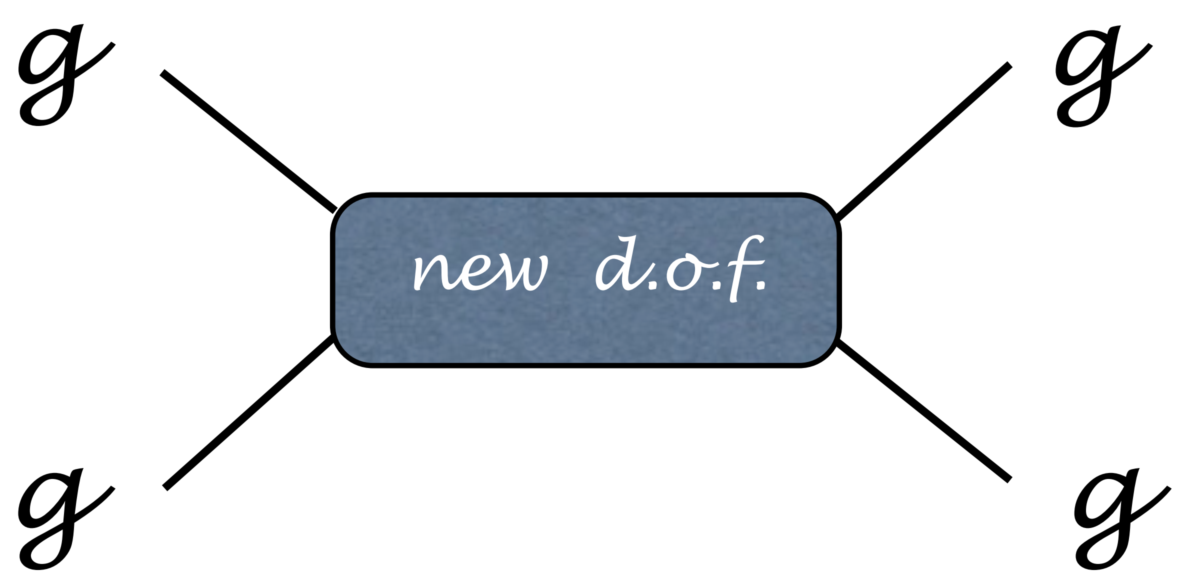
1 There is a non-perturbative UV fixed point after all.

$$\alpha_G(E \to \infty) \longrightarrow \alpha_\infty \underset{\lesssim}{\sim} \mathcal{O}(1)$$

strongly-coupled gravitons at the deep UV.
High energy scattering is **HARD**

Weinberg, Reuter, ...

2 M_P is a threshold towards new degrees of freedom (like the famous EW threshold)



such as strings, black holes, LQG states...

Everybody else...

Black holes are not quite like W-bosons...

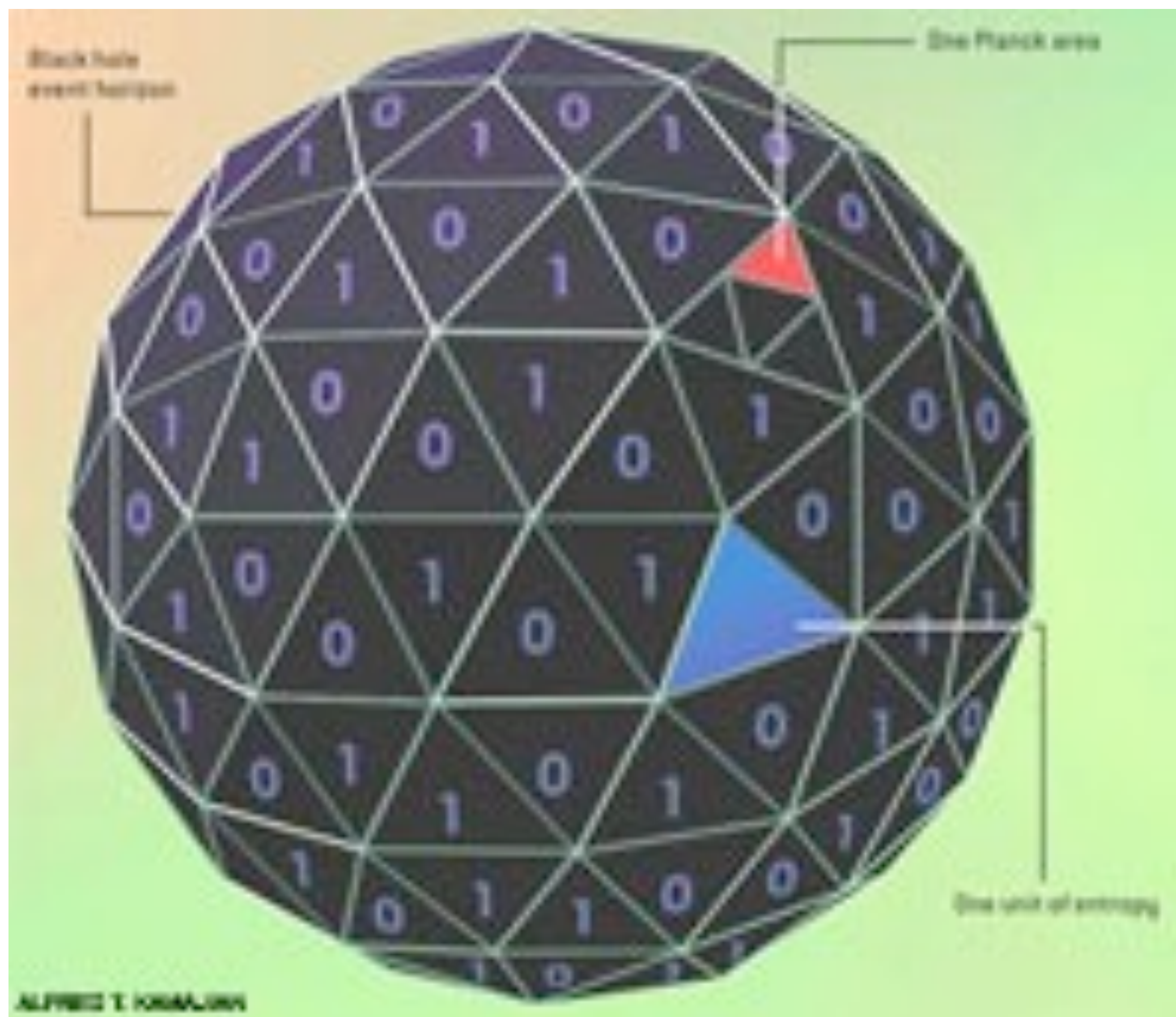
According to Bekenstein & Hawking, black holes are thermodynamical systems with e^S quantum states

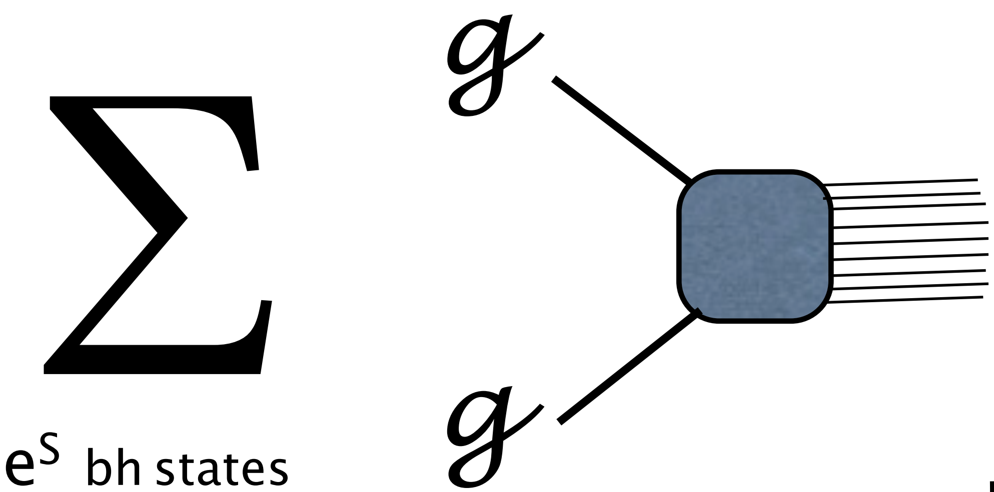
$$\frac{\partial S}{\partial M} = \frac{1}{T_{\rm H}} = \frac{1}{8\pi G M}$$

$$S_{\rm BH} = \frac{A_{\rm H}}{4G} \sim \left(\frac{M}{M_{\rm P}}\right)^2$$

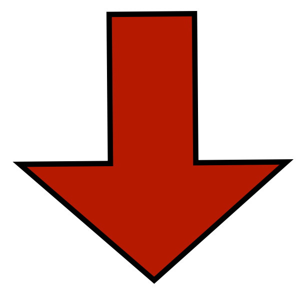
As a measure of hidden information:

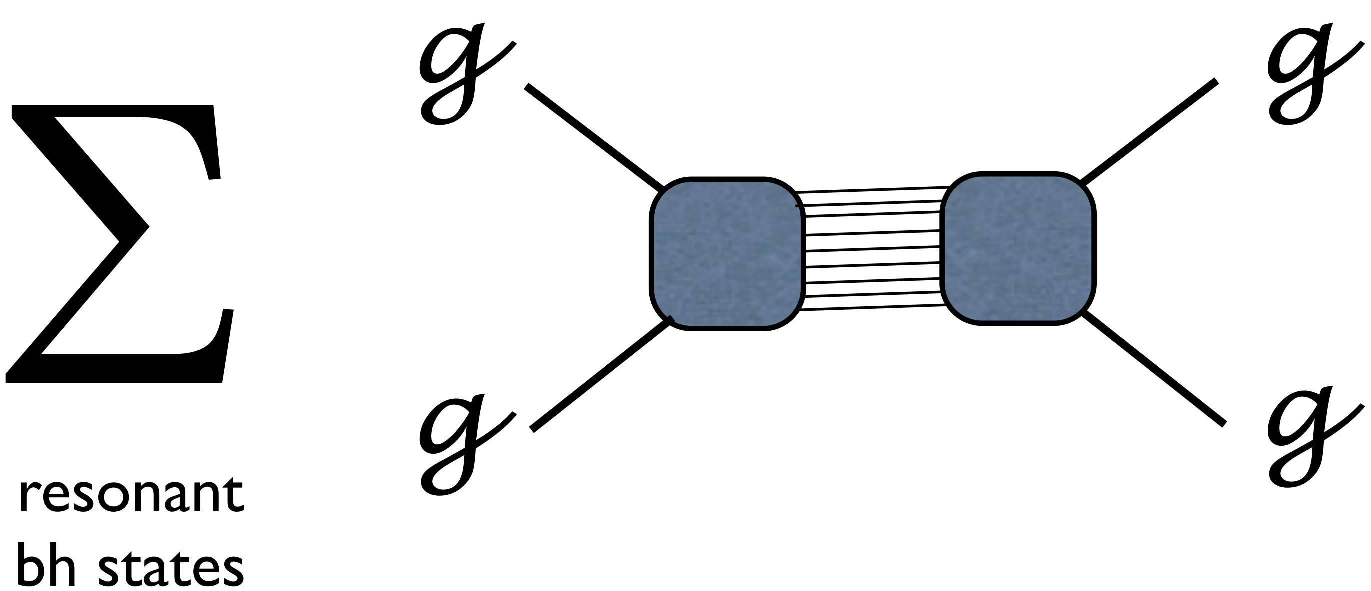
one bit per Planck area of HORIZON SURFACE





$$\approx \quad \mathcal{O}(1)$$





$$\sim \quad e^{-S} \sim e^{-cE^2/M_{\rm P}^2}$$

High energy, $E \gg M_P$ scattering is extremely **SOFT**

Size of resonances grows with E

As E grows asymptotically, information on states localizes on surfaces

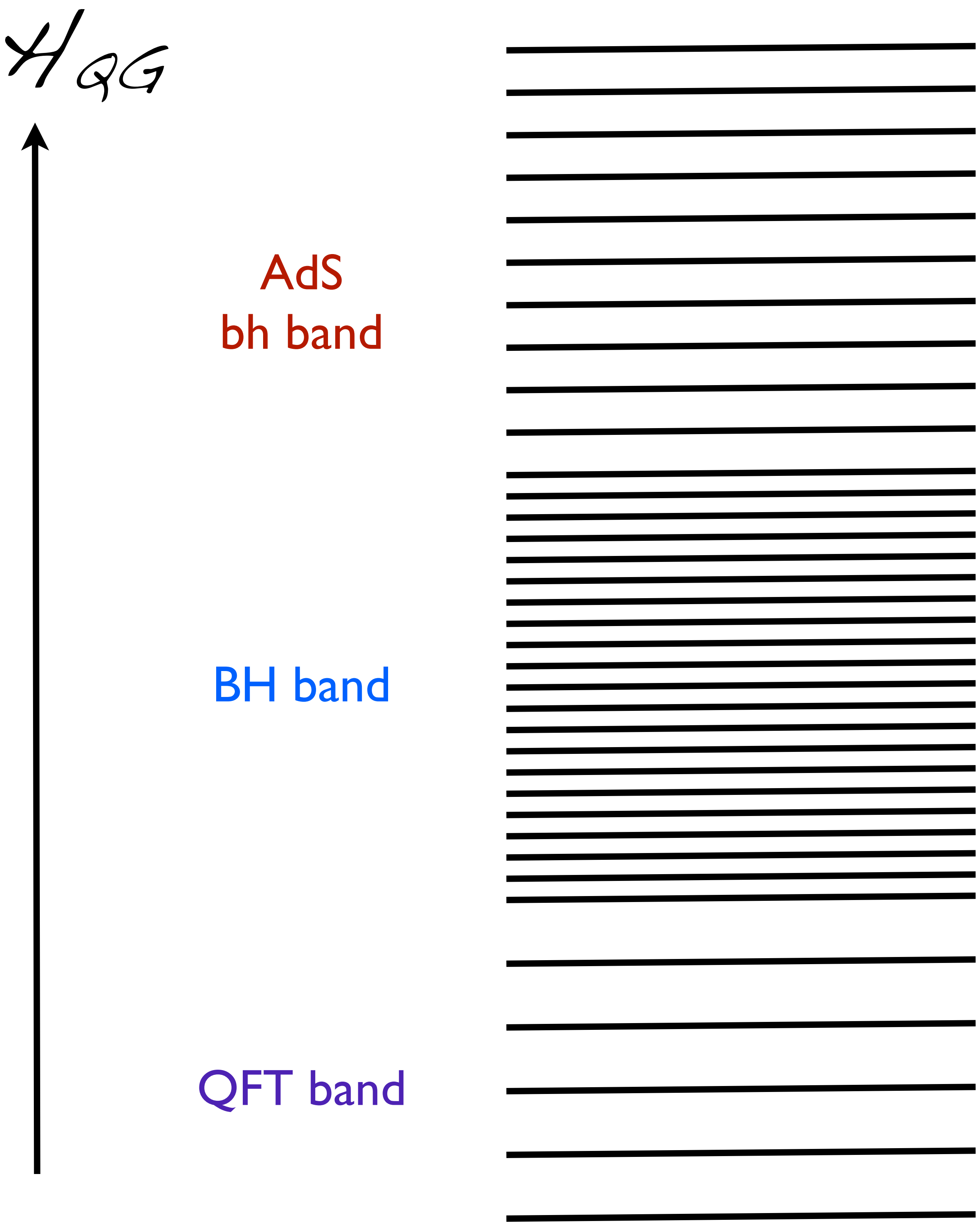
THE HOLOGRAPHIC PRINCIPLE SAYS THAT...

THIS IS ALL YOU
WILL EVER NEED...

“local” dynamics is an illusion of perturbative, “dilute” states

Non-perturbatively,
d.o.f.
localize on boundaries

density of states



$$\rho(E)_{\mathrm{AdS-BH}} \sim \exp\left[\sqrt{N_{\mathrm{eff}}}(ER_{\mathrm{AdS}})^{2/3}\right]$$

$$N_{\mathrm{eff}} \sim (M_{\mathrm{P}} R_{\mathrm{AdS}})^2$$

3-dim O(N_{eff}) local d.o.f.
with R_{box} = R_{AdS}

$$\rho(E)_{\mathrm{BH}} \sim \exp\left[(E/M_{\mathrm{P}})^2\right]$$

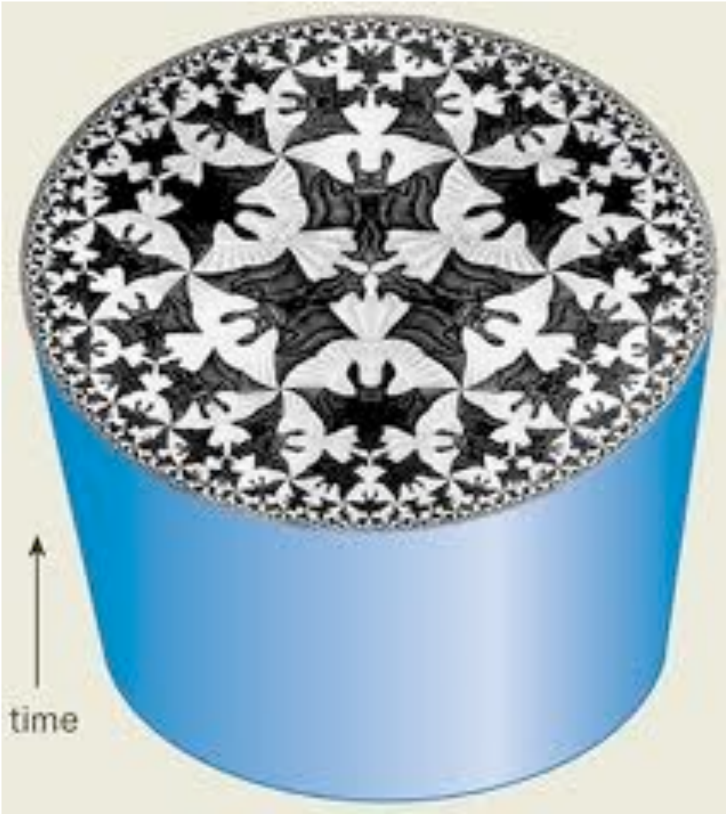
non-local!

$$\rho(E)_{\mathrm{QFT}} \sim \exp\left[(ER_{\mathrm{box}})^{3/4}\right]$$

4-dim O(1) local d.o.f.

AdS/CFT

Maldacena
Gubser, Klebanov, Polyakov
Witten



Holographic data sit on conformal boundary,
at infinity...
of AdS

Since AdS does not define a metric at infinity,
but only a conformal structure,
the holographic d.o.f. furnish a
CFT

QFT is back...
at the boundary of ADS!!!!

...with the noble purpose of DEFINING
quantum gravity!

End of part I

PART II, partially based on

Holography of AdS vacuum bubbles.
Jose L.F. Barbon, Eliezer Rabinovici, . IFT-UAM-CSIC-10-13, Mar 2010. 50pp.
Temporary entry
Published in **JHEP 1004:123,2010**.
e-Print: **arXiv:1003.4966** [hep-th]

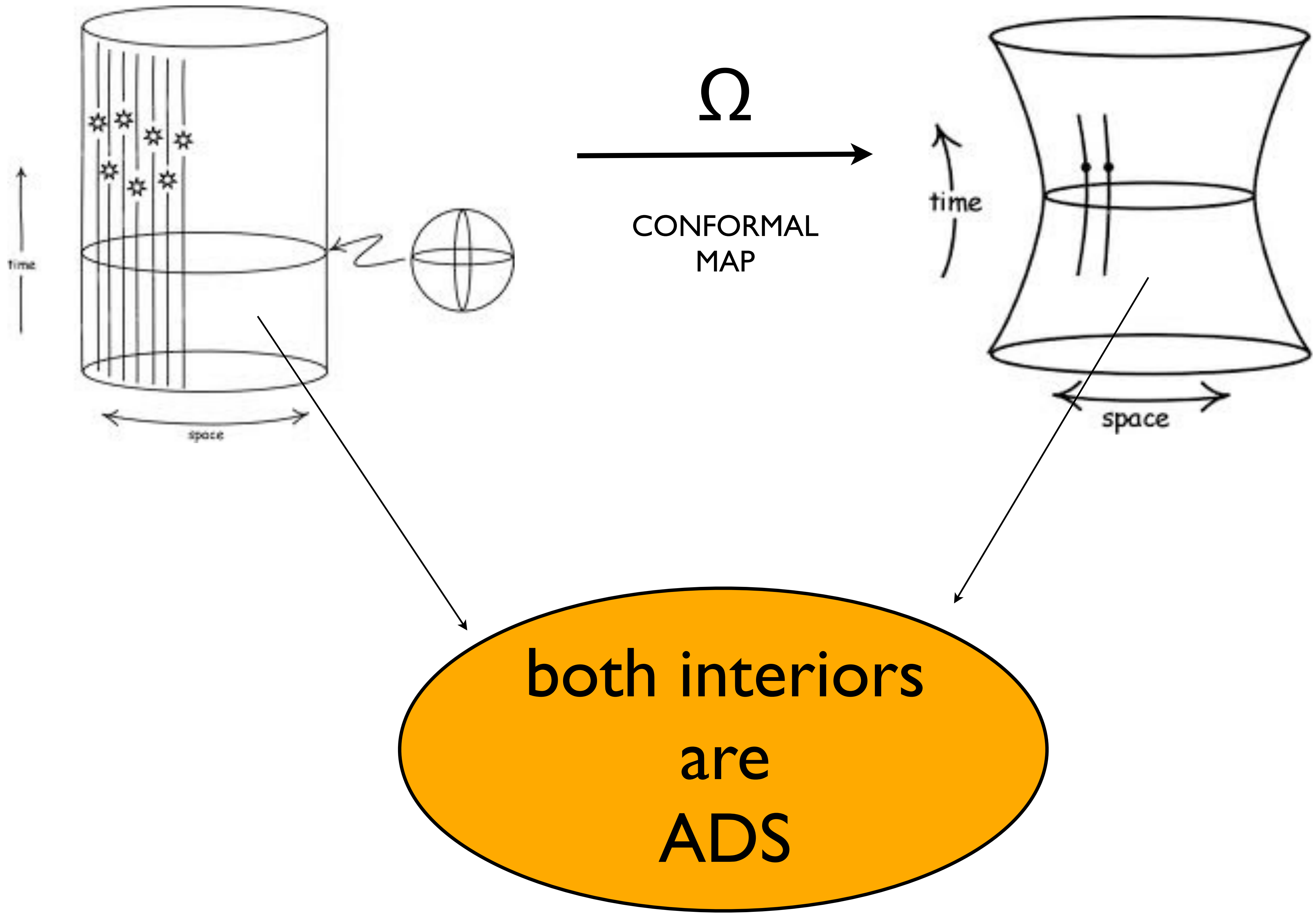
AdS Crunches, CFT Falls And Cosmological Complementarity.
J.L.F. Barbon, (Madrid, IFT & Madrid, Autonoma U.) , E. Rabinovici,
(Hebrew U.) . IFT-UAM-CSIC-11-06, Feb 2011. 32pp.
Published in **JHEP 1104:044,2011**.
e-Print: **arXiv:1102.3015** [hep-th]

A toy example
of
the conceptual power
of
AdS/CFT

Define AdS/CFT on two conformally related spaces

Einstein

de Sitter



Ω extends to a Diff in the interior AdS

The CFT metrics:

$$ds^2_{\mathrm{dS}} = -d\tau^2 + \cosh^2(\tau) d\Omega^2_{d-1}$$

$$ds^2_{\mathrm{E}} = -dt^2 + d\Omega^2_{d-1}$$

$$ds^2_{\mathrm{dS}_d} = \Omega(t)^2 \; ds^2_{\mathrm{E}_d}$$

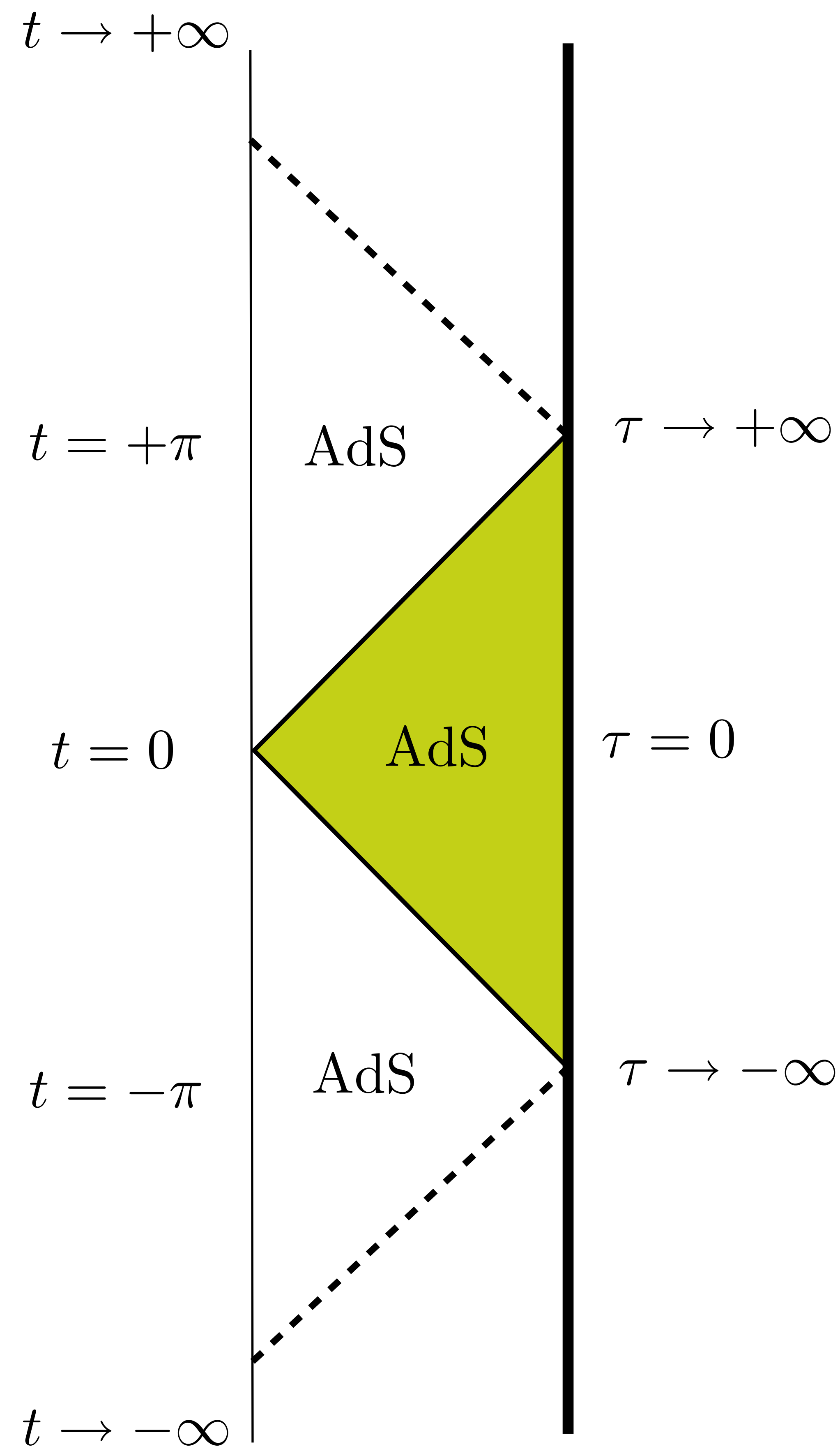
The conformal transformation is singular at

$$t_\star \in \pi \, \mathbf{Z}$$

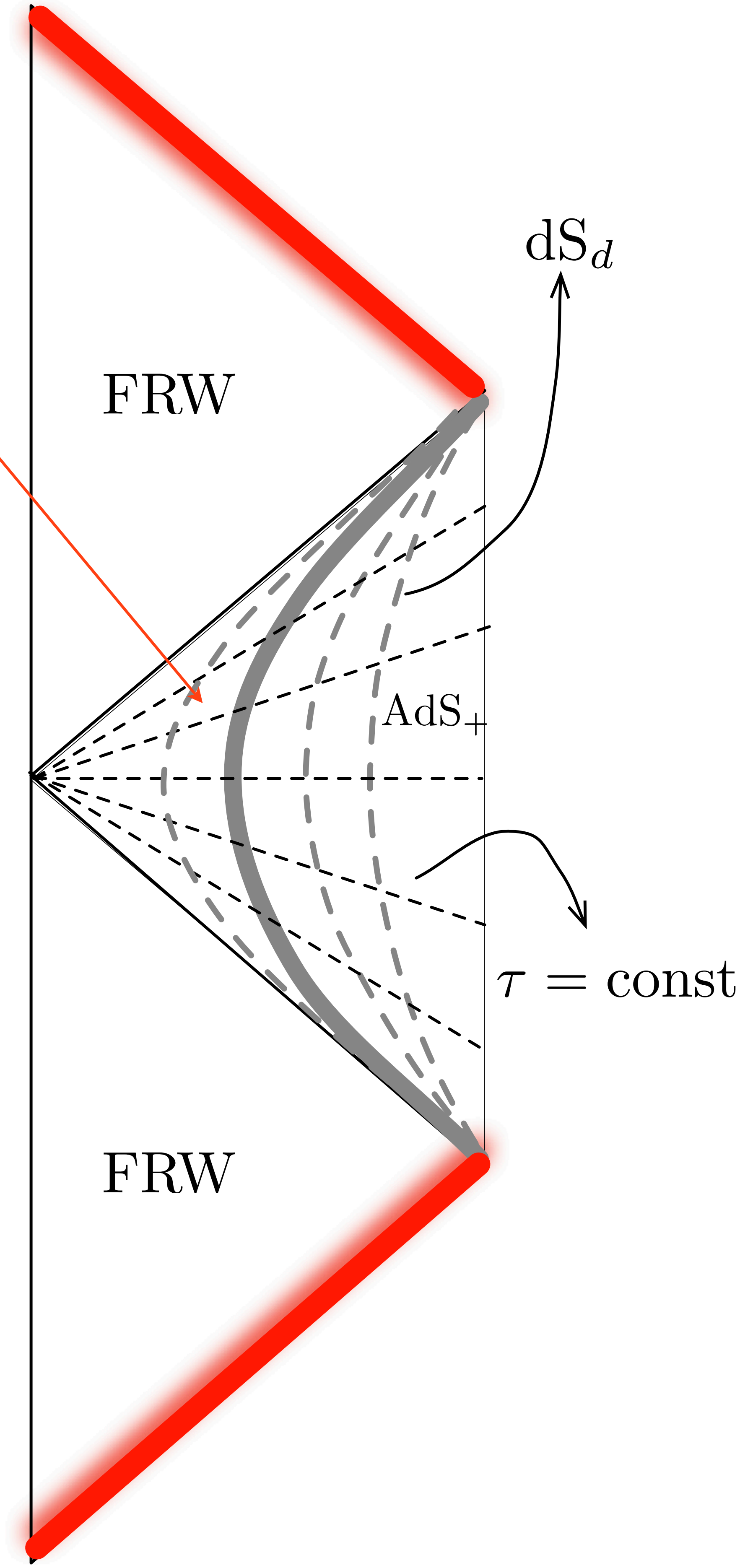
$$\Omega(\tau) = \cosh(\tau)$$

$$t = 2 \, \tan^{-1} \left[\tanh(\tau)\right]$$

Ω maps a finite extent $\Delta t_E = 2\pi$ of Einstein time into the eternity of de Sitter time $\Delta\tau_{dS} = \infty$



Something interesting happens if we add a deSitter-invariant bubble of Coleman-de Luccia type



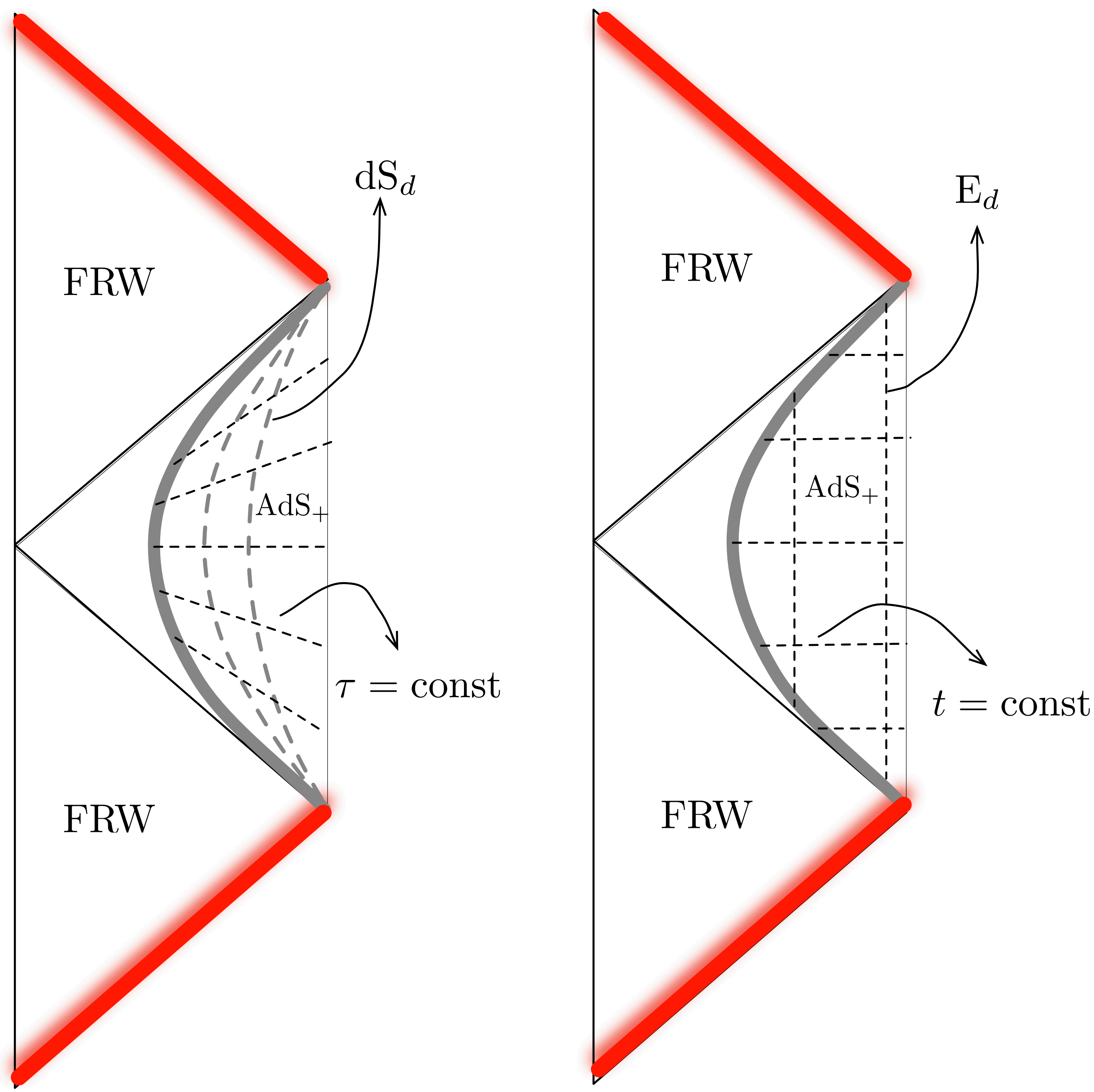
We get a cosmology with BANG and CRUNCH which we may try to interpret in the CFT!

The CRUNCH is not visible in the CFT_{dS}
since it occurs after the end of dS-time

But...

It is met head-on by the CFT_E
since it occurs in finite E-time

The interior Diff near infinity



We have an example of
HORIZON COMPLEMENTARITY

't Hooft, Susskind

The complementarity map is nothing but
the (quantum) conformal transformation between
de Sitter and Einstein manifolds

How do we generate the bubble in the CFT?

Very easy in the dS frame since the bubble is dS-invariant

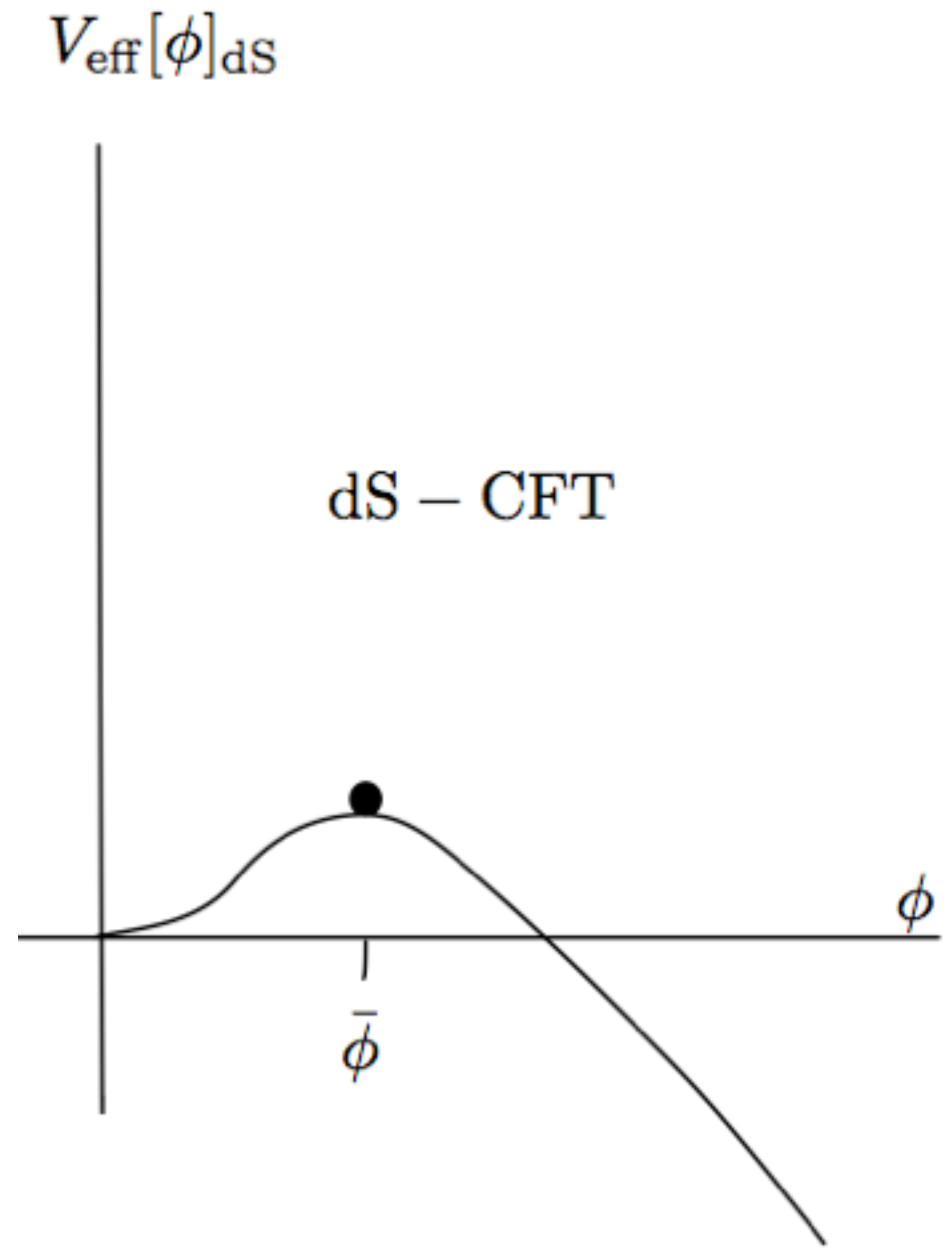
The dS-CFT$_{UV}$ must feature a scalar sector

$$\mathcal{L}[\phi]_{\rm dS} = \frac{1}{2}(\partial\phi)^2 + \frac{1}{24}\mathcal{R}_{\rm dS}\phi^2 + \lambda\phi^6$$

representing the collective coordinate of the bubble

Classical dS-inv states

CFT state dual to bulk bubble is a "thermal sphaleron"

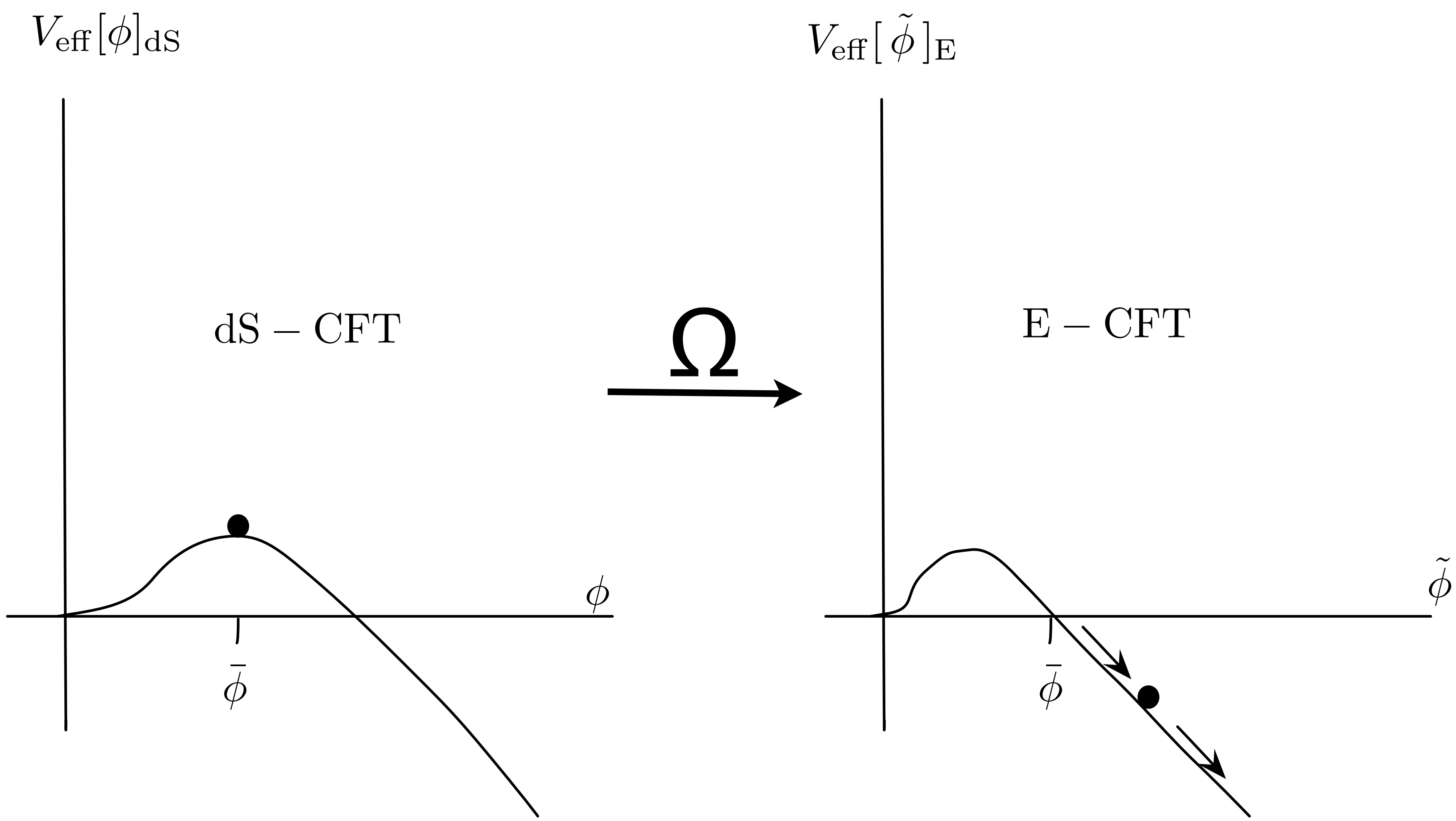


$\lambda < 0$

In E-frame the bubble is a Coleman-de Luccia tunneling!

$$\mathcal{L}[\tilde{\phi}]_{\mathrm{E}} = \frac{1}{2}(\partial\tilde{\phi})^2 + \frac{1}{24}\mathcal{R}_{\mathrm{E}}\tilde{\phi}^{\,2} + \lambda\,\tilde{\phi}^{\,6}$$

$$\tilde{\phi} = \sqrt{\Omega(t)}\,\phi$$



Singularity = Infinite fall in finite time

Thus, the CFT signature of a cosmological crunch is an infinite energy fall in the Hamiltonian that "sees" the singularity

This is still unitarily equivalent to a stationary state in a de Sitter QFT

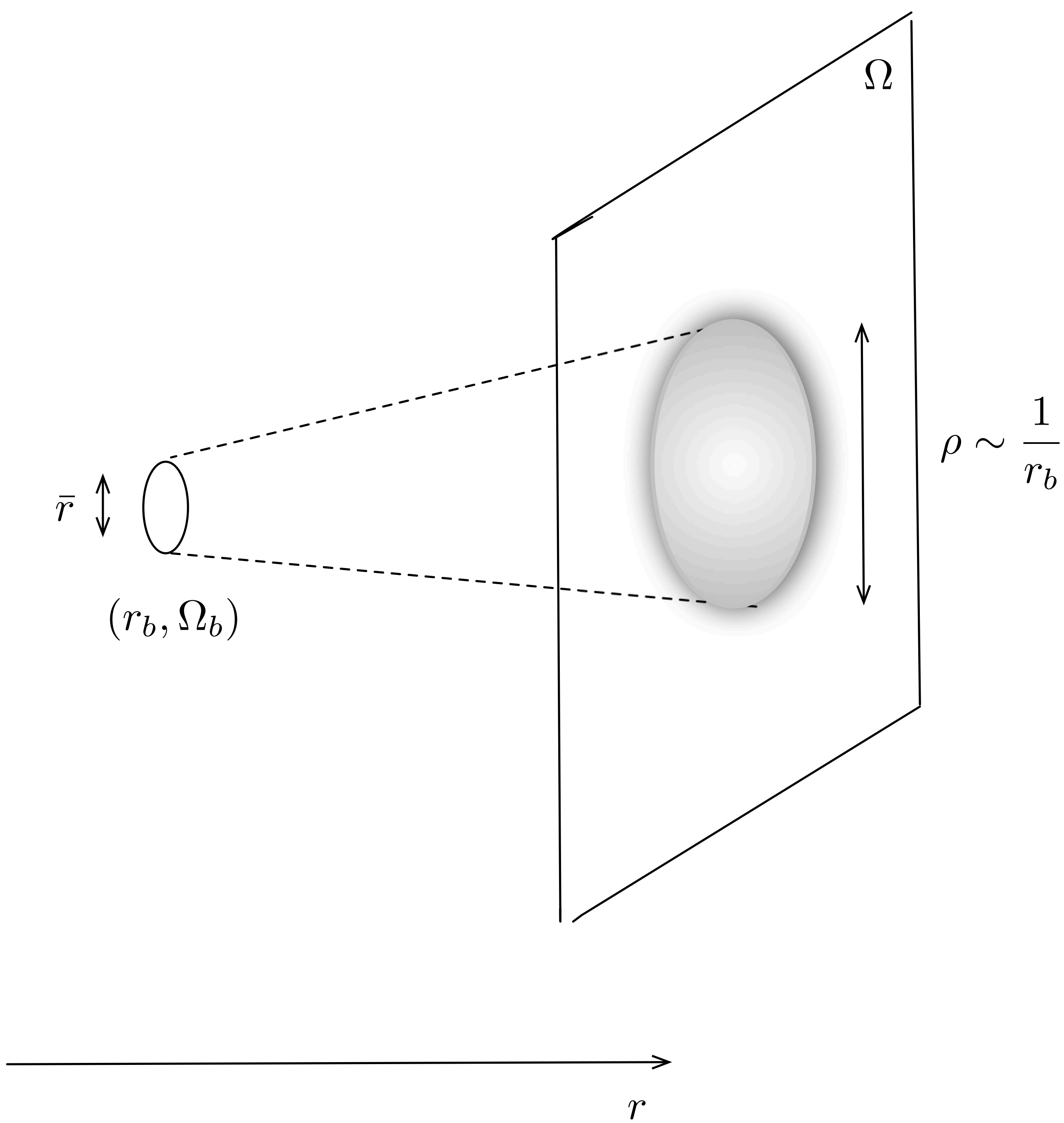
Less symmetrical bubbles of Coleman-de Luccia type are mapped to Fubini-Lipatov instantons of the CFT

$$\phi_{\rm inst}(x) = \left(\frac{d-2}{\sqrt{2}|\lambda|}\right)^{\frac{d-2}{2}} \left(\frac{\varrho}{|x-x_0|^2+\varrho^2}\right)^{\frac{d-2}{2}}$$

with single-instanton moduli measure

$$d^d x_0 \, \frac{d\varrho}{\varrho^{d+1}} e^{-S_{\rm inst}} \qquad S_{\rm inst} = \frac{1}{|\lambda|^{\frac{d-2}{2}}} \frac{{\rm Vol}(\mathbf{S}^{d-1})}{2^{\frac{d-2}{2}}} \left(\frac{d-2}{2}\right)^d B\left(\frac{3}{2}, \frac{d-2}{2}\right)$$

There is perfect matching with the CdL bulk calculation under the UV/IR map:



in the limit

$$|\lambda| \ll 1$$

Previous appearance
Fubini-Lipatov in AdS/CFT in
de Haro, Petkou & Papadimitriou

Concluding Remarks

- AdS/CFT realizes a particular case of a "triumph" of QFT over the QG problem
- Is this specific to asymptotically AdS spacetimes?
- Quantum conformal transformations can be seen as implementing the cosmological version of the black-hole complementarity
- Big crunches are infinite energy falls and should not be "regularized"
- Is there any lesson to be learned regarding the anthropic landscape?

Thank you