Keijo's effect on a cosmologist career in holography

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Also a certain **Aleksi Vuorinen** attended the same school...

That is how I became
a cosmology student...

Jyväskylä summer school 2008:

New gauge/gravity duality ideas and their applications

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New gauge/gravity duality ideas and their applications

$$\frac{1}{Z}\int \mathcal{D}\Phi\, e^{-\int d^4x\left[\frac{1}{2}g^{\mu\nu}\partial_\mu\Phi\,\partial_\nu\Phi + V(\Phi) + \varphi_0(x)\,\Phi(x) + \varphi_0(x)\,\underbrace{\Phi^{\Delta}}_{\equiv\mathcal{O}(x)} + \cdots\right]}$$

quantum field

$$= e^{-\frac{1}{16\pi G_5}\int d^5x\sqrt{-g}\left(\frac{1}{2}g^{\mu\nu}\partial_\mu\varphi\,\partial_\nu\varphi + \frac{1}{2}m^2\varphi^2\right)}$$

$$(\Box - m^2)\varphi = 0$$

'Master formula'

AdS/CFT duality: 'Master formula'

An operator $\mathcal{O}$ in the boundary field theory has a dual bulk field φ

$$\left\langle \exp\left[\int d^4x\, \mathcal{O}\, \varphi\right]\right\rangle = z^{4-\Delta}\varphi\Big|_{\text{boundary}}$$

An expectation value in the full 3+1 dimensional QFT

N=4 Super-Yang-Mills theory

3+1-dimensional Minkowski

a conformal theory

gluons, 6 scalars, 4 fermions

very strongly coupled

A classical solution in 4+1 dimensional GR in AdS

classical gravity (GR)

5-dim Anti-de Sitter space

weakly coupled

AdS/CFT duality: the bulk geometry

The metric of Anti-de Sitter space using global coordinates

$$ds^2 = -f(r)\,dt^2 + \frac{dr^2}{f(r)} + r^2 d\Omega_{n-1}^2 \qquad f(r) = 1 + r^2$$

The geometry encodes the state of the field theory!

The AdS-Schwarzschild metric has a horizon where *f(r)* = 0:

$$f(r) = 1 + r^2 - \frac{m}{r^{n-1}}$$

The temperature of the BH is now the temperature of the state of the field theory

Thin-shell collapse

Replace the AdS-Schwarzschild metric with pure AdS inside some radius r_s

$$f(r) = \begin{cases} 1 + r^2 - \frac{m}{r^{n-1}}, & r > r_s \\ 1 + r^2, & r < r_s \end{cases}$$

Now there is a shell at the radius r_s

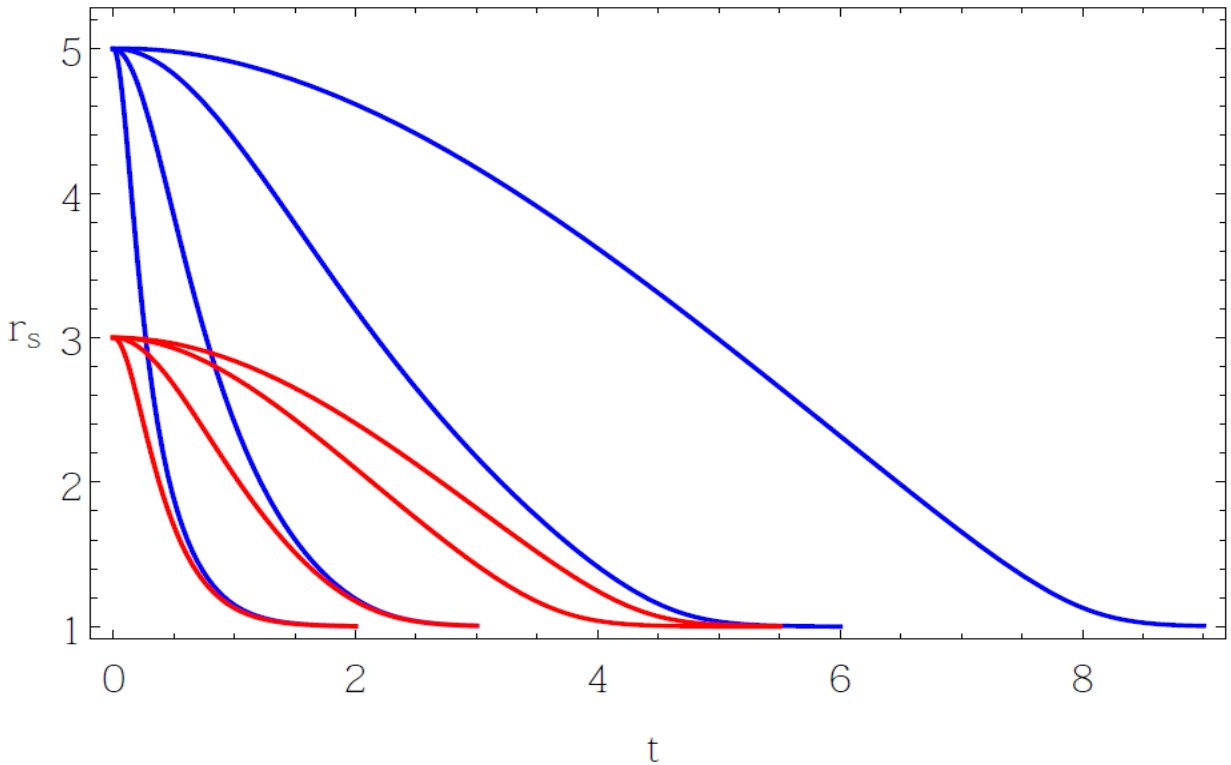
The Israeli junction conditions relate the jump in extrinsic curvature across the shell to its E-M content

$$K_{ij}\Big|_{\text{inside}} - K_{ij}\Big|_{\text{outside}} \propto T_{ij}$$

Equation of state is the only free parameter

Collapse of the shell

For (almost) all equations of state, the shell collapses

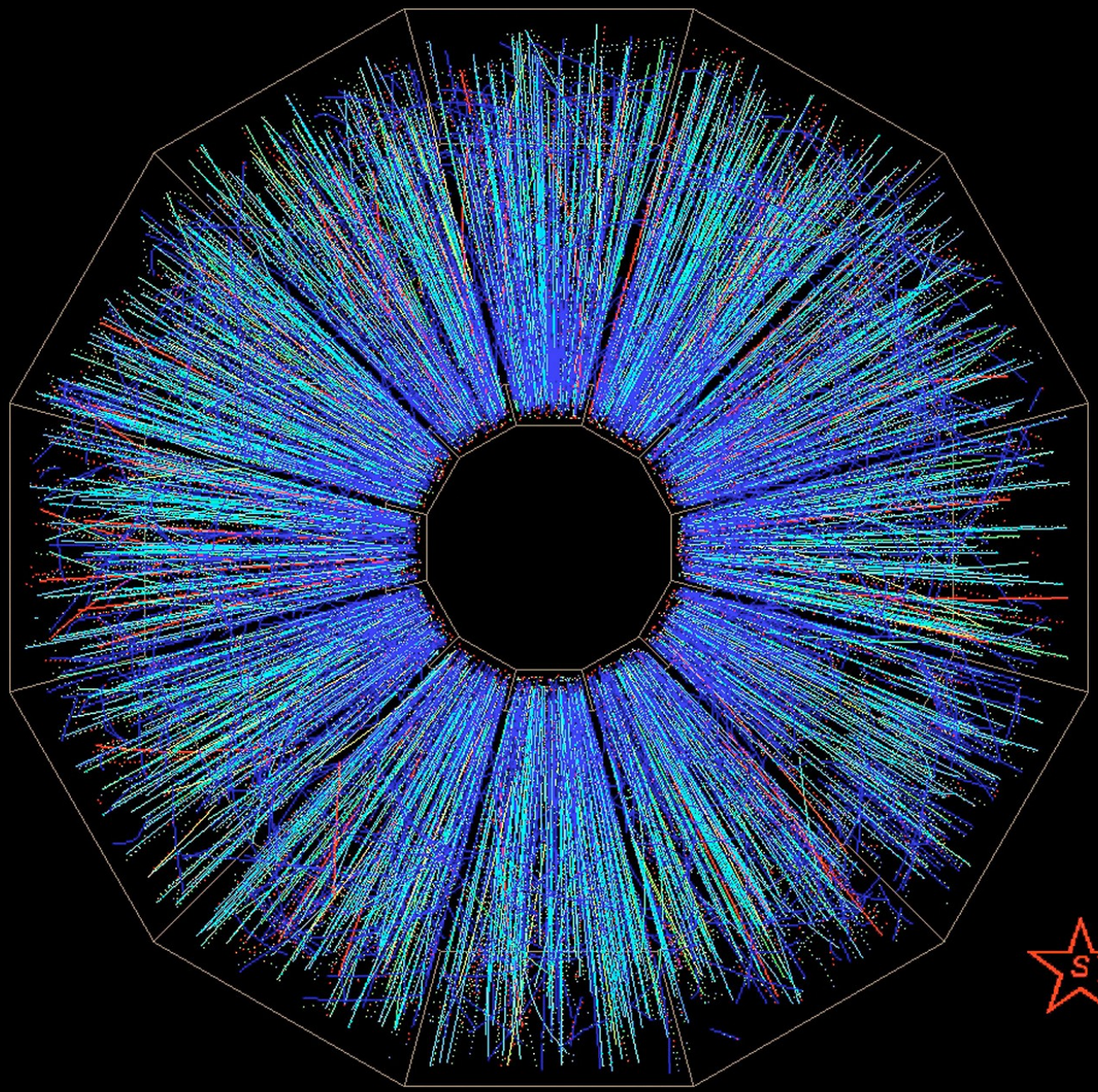


Bulk Start with a spherical shell, end up with a BH

CFT End up with finite-T equilibrium, start with...?

Can be used to study the thermalization of strong coupling

Thermalization of strongly coupled systems



How to probe thermalization?

Geometric probes

Two-point correlators

von Neumann or entanglement entropy

One-point functions

Components of the energy-momentum tensor

Other stuff

Emission rates of dileptons and photons

Dynamics of gravitational collapse and holographic entropy production,
Ville Keränen, Hiromichi Nishimura, Stefan Stricker, OT, Aleksi Vuorinen
Phys. Rev. D90 (2014) 6

Critical scalar field collapse in AdS3: an analytical approach
Rudolf Baier, Stefan Stricker, OT
Class. Quant. Grav. 31 (2014) 025007

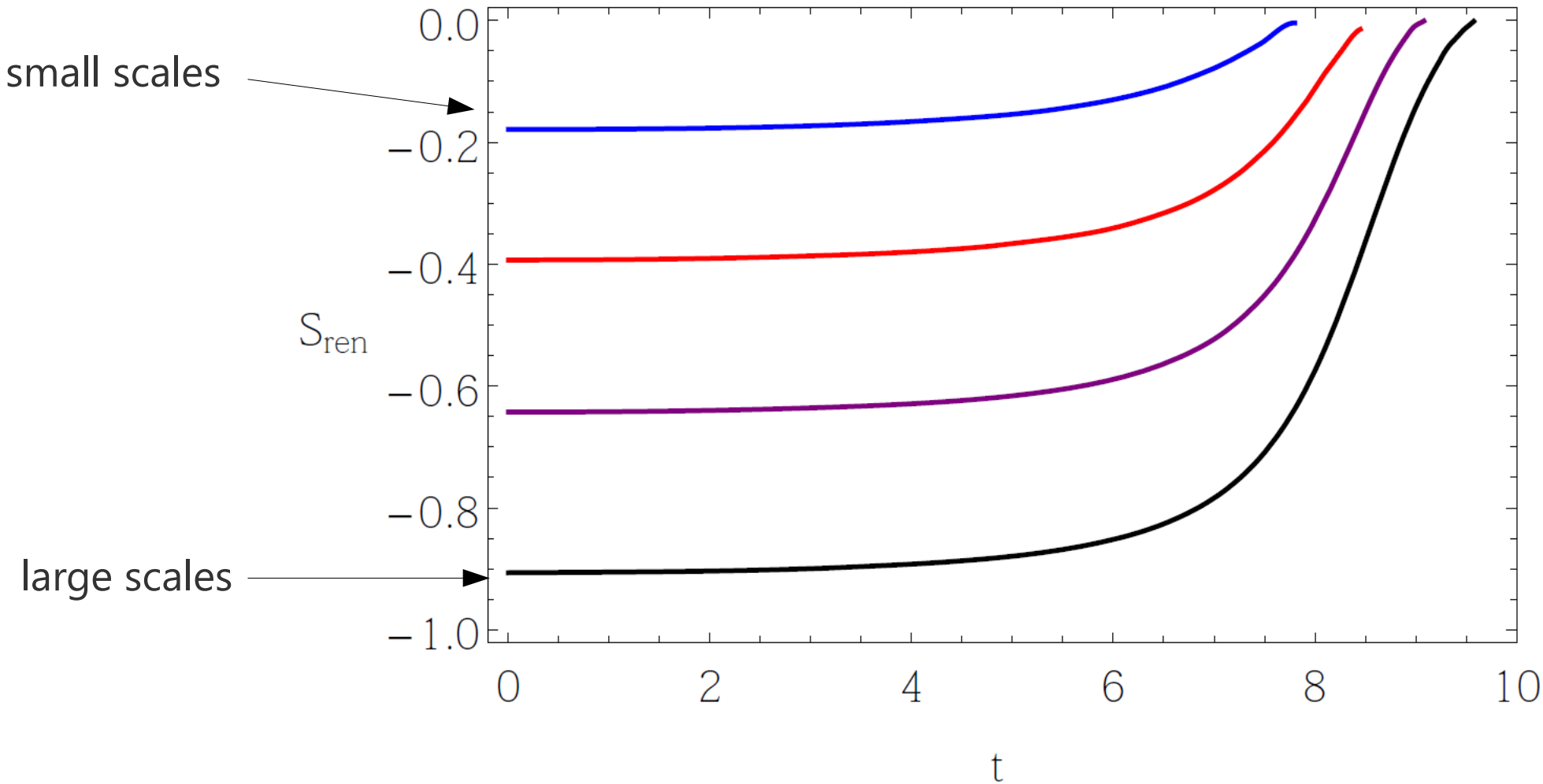
Production of Prompt Photons: Holographic Duality and Thermalization
Rudolf Baier, Stefan Stricker, OT, Aleksi Vuorinen
Phys. Rev. D86 (2012) 081901

Holographic Dilepton Production in a Thermalizing Plasma
Rudolf Baier, Stefan Stricker, OT, Aleksi Vuorinen
JHEP 1207 (2012) 094

Few more papers in preparation

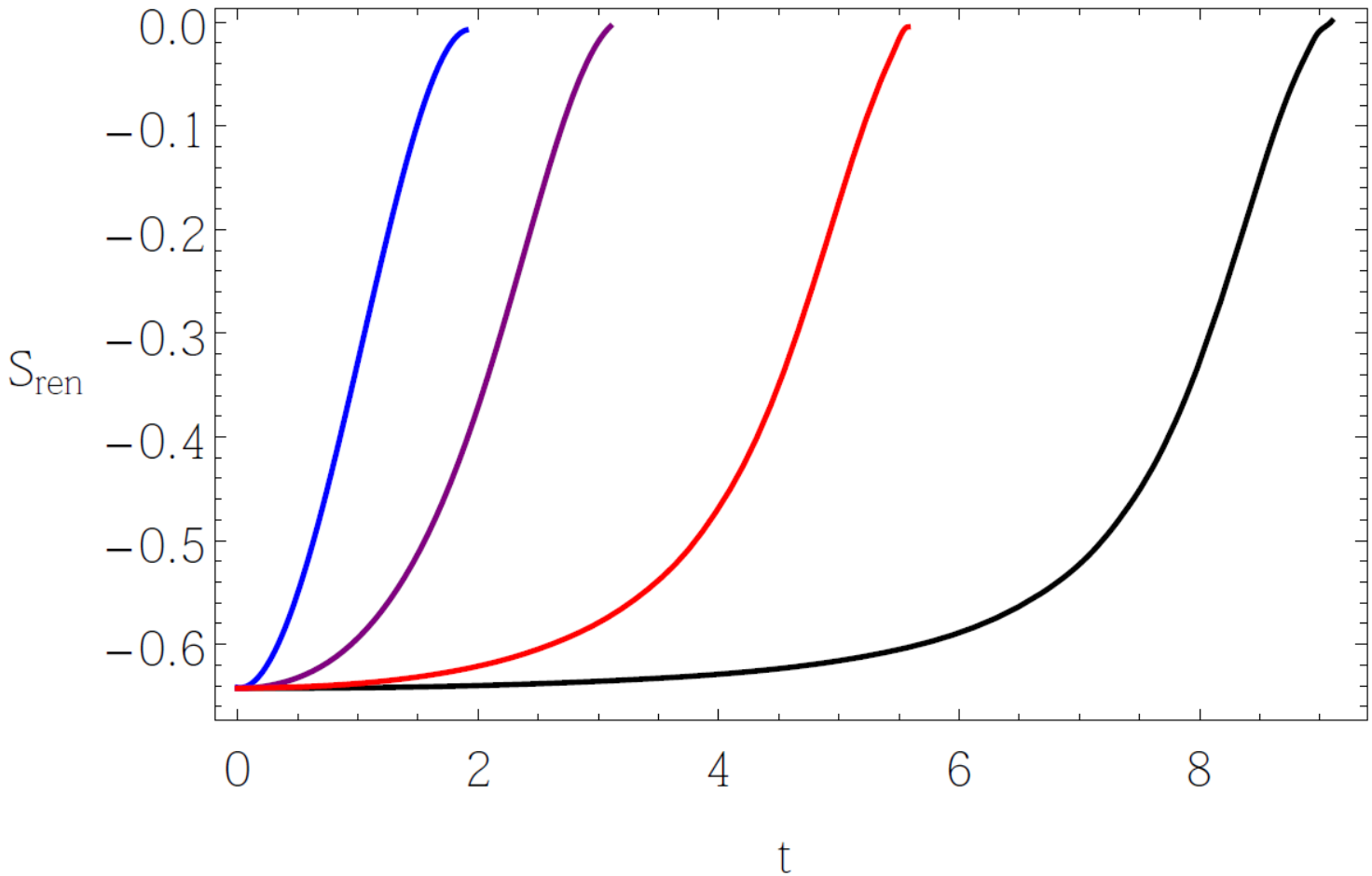
Time evolution of entropies

Calculate the time evolution of the different entropies in the thin-shell model



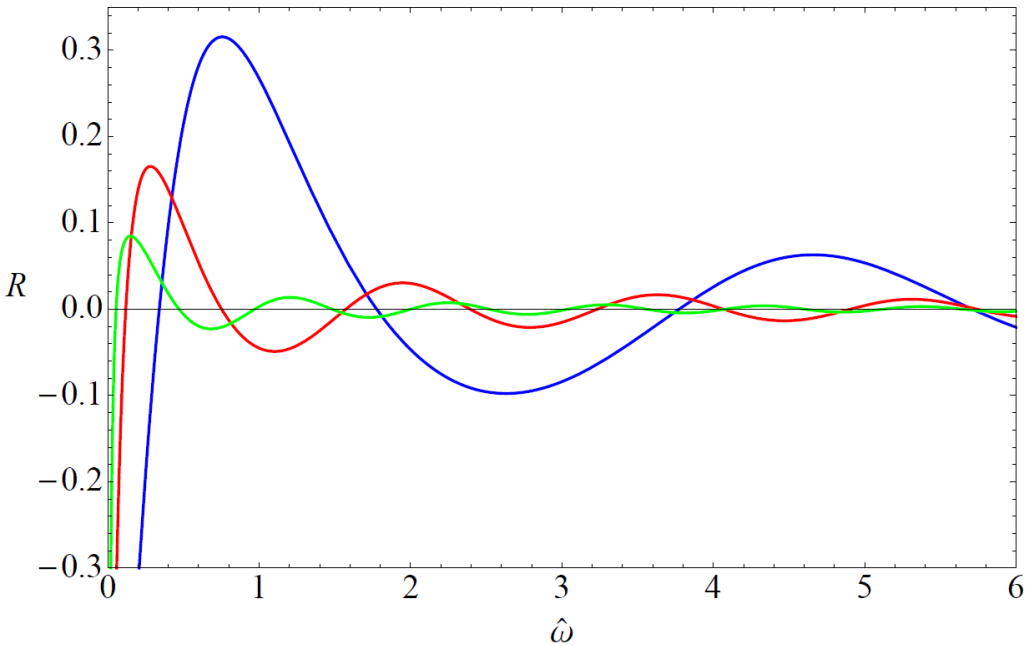
Universal scaling law for entropies

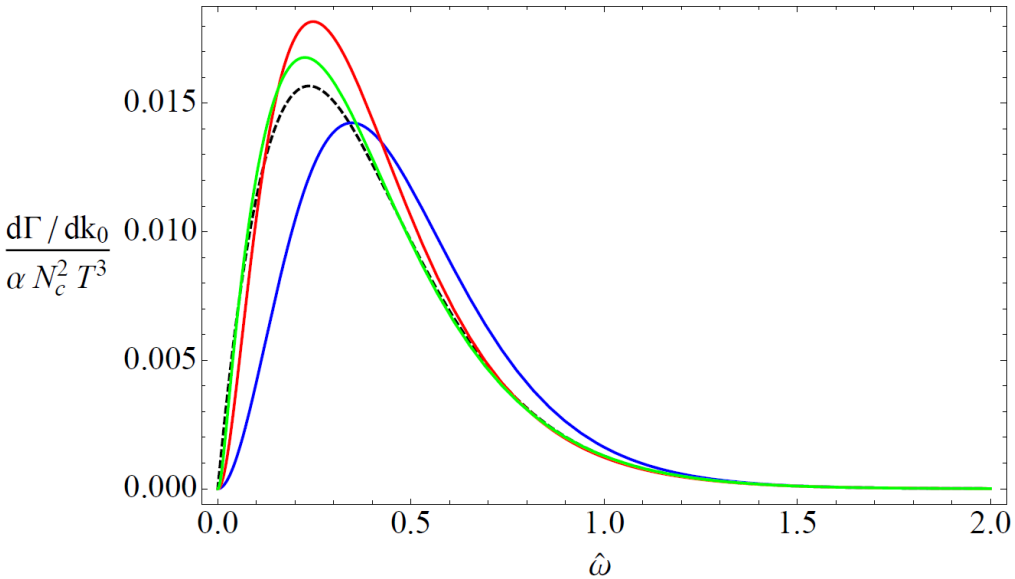
$S_A(t)$ = const. + number × A × t



Different curves have different equations of state of the shell

Photon production rates





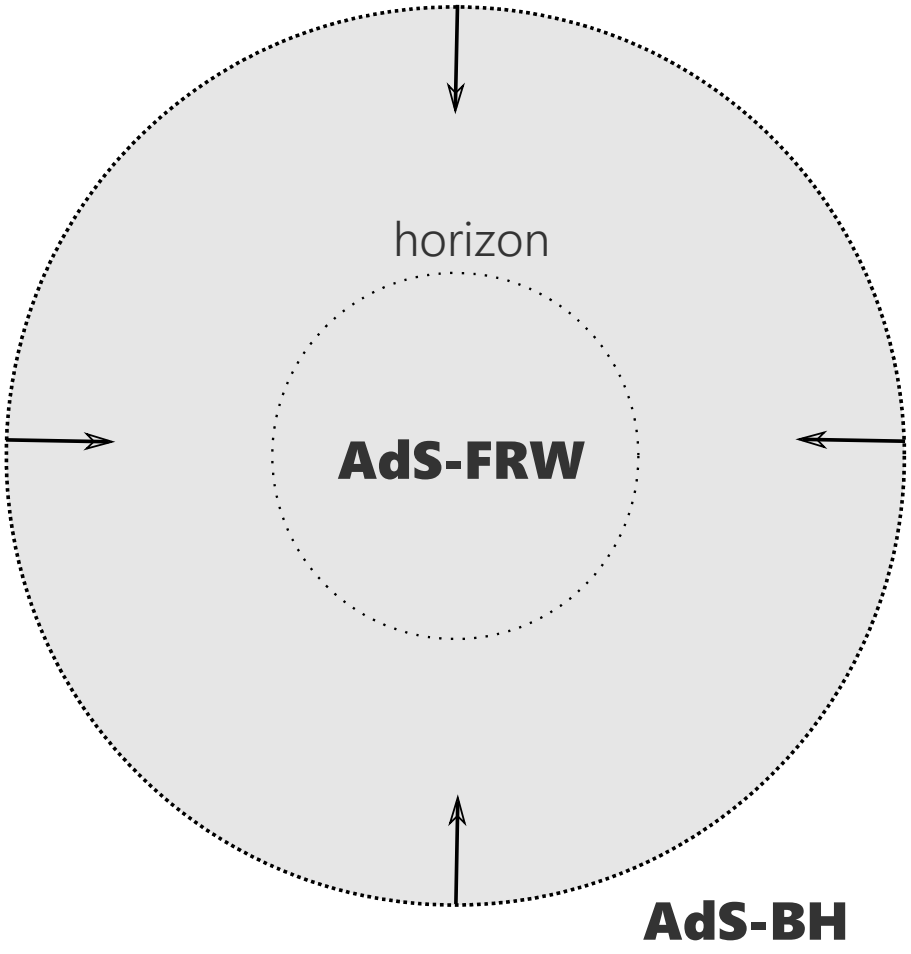
Calculate the photon and dilepton production rate in SYM plasma in the thin-shell model as a function of time, and compare with equilibrium

Oppenheimer-Snyder collapse

Simplest possible model of gravitational collapse: A ball of dust collapses to a BH

No pressure!

Oppenheimer & Snyder work published in 1939



Now do it in 5 dimensions with a negative cosmological constant

AdS-Oppeheimer-Snyder collapse

To make the homogenous and isotropic nature of the ball of dust explicit, one needs to use cosmological coordinates inside:

$$ds^2 = -d\eta^2 + a^2(\eta)\left[\frac{d\rho^2}{1+\rho^2} + \rho^2 d\Omega_{n-1}^2\right]$$

The radial and temporal coordinates inside and outside cannot be identified with each other

Lessons learned for QGP?

$\mathcal{N}$=4 SYM is not QCD

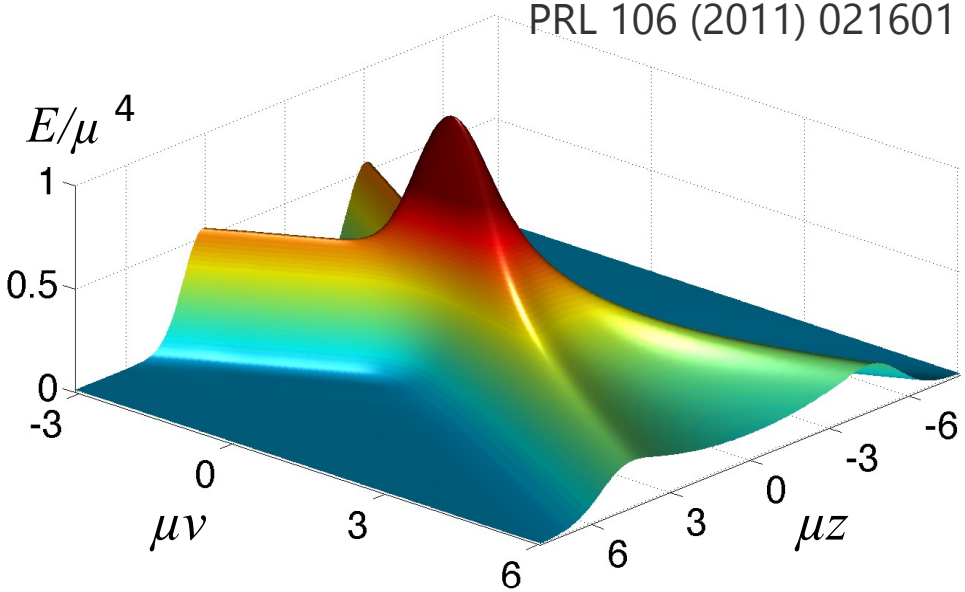
Finite temperature breaks SUSY
Hard-wall, soft-wall, IHQCD (Kiritsis-model)...

Spherical collapse is not a collision

The dual of the spherical collapse model is homogenous and isotropic

More realistic models requires numerical GR

Figure from Chesler & Yaffe, PRL 106 (2011) 021601



My dissertation

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Me

Primordial Perturbations from a Self-interacting Curvaton

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Primordial Perturbations from a Self-interacting Curvaton

Olli Taanila

Thank you Keijo!

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