Title: On charged black holes in AdS space

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Abstract:

On Charged Black Holes in AdS space.

Moshe Rozali (UBC)

PI, Feb. 2005

with: Jiangang He
Dominic Brecher.
(+ Paul Saffin).

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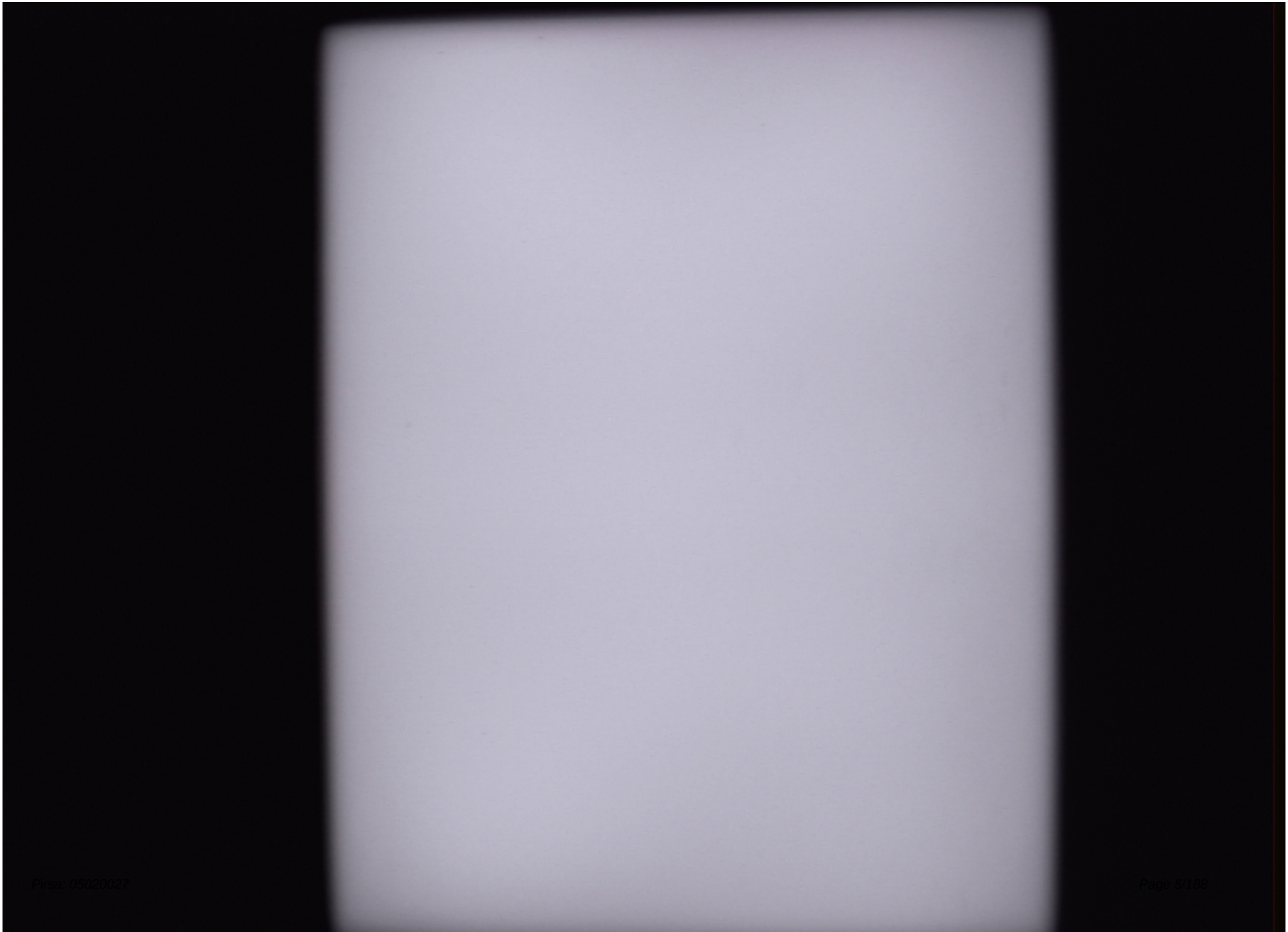
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Outline:

* Motivation, basics of charged BH in AdS_5, perturbations, inner horizon instability, Vaidya solutions, mass inflation....

* Probing thermal spacetimes in AdS/CFT : two-sided correlators.

* The calculation in unperturbed RN case: features, comparison to uncharged case.

* Scanning behind the horizon: dependence of the observables on perturbations.

* Conclusions: cross-flow, mass-inflation, need for better observables.

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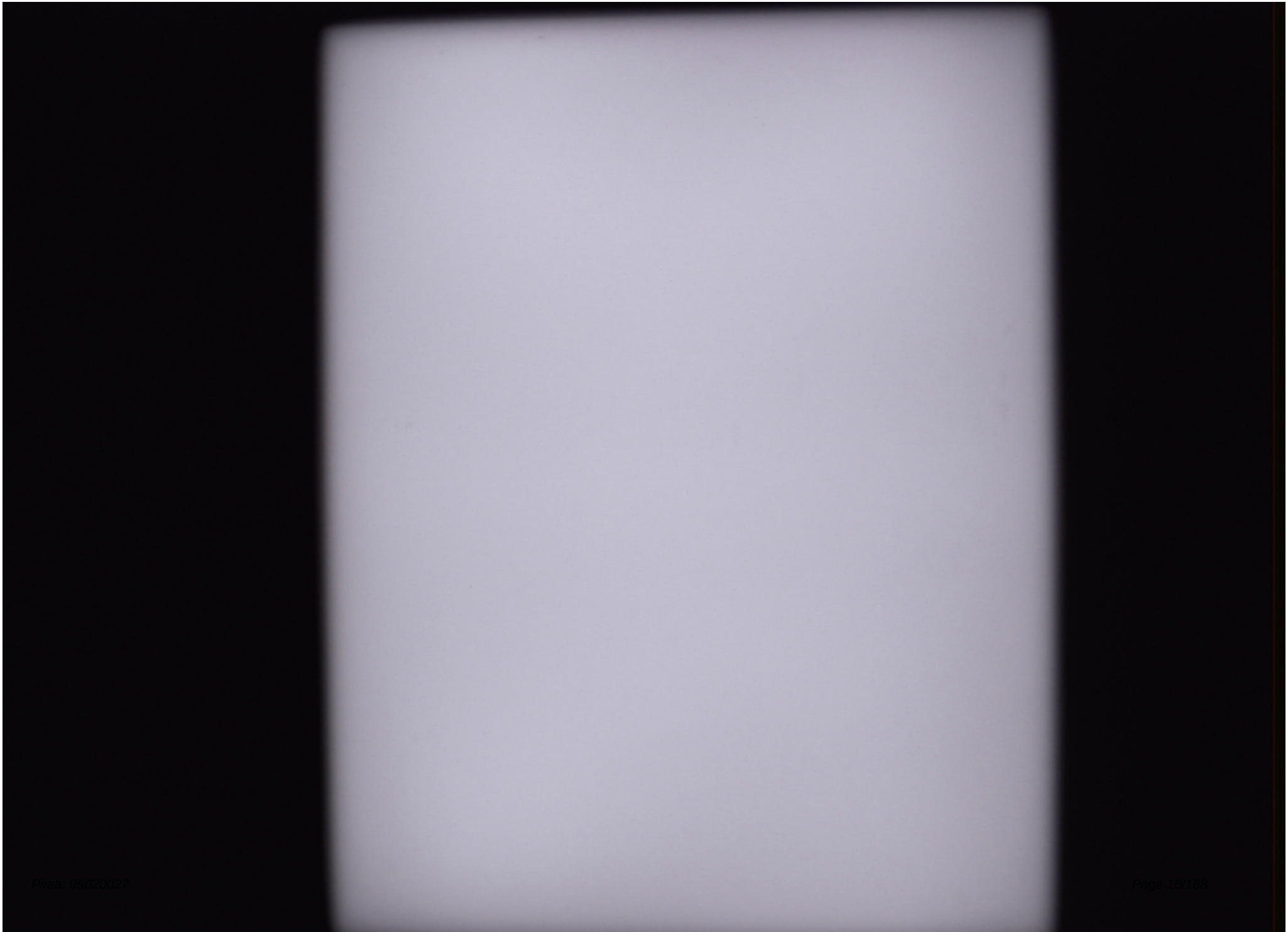
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In classical problems of classical + semi-classical GR, one would like to go a step further using string theory. e.g: singularity "resolution". Can one unambiguously calculate scattering in cases where classical GR is invalid?

Timelike sing. (eg orbifolds) are relatively well-understood.

Spacelike (e.g cosmological, BH) are difficult.

We attempt to look at null singularity (mass inflation, colliding plane-waves) in the hope it is easier...

Also... in the process we'll have to look behind horizons, which is interesting by itself; we'll have to refer to horizon complementarity (or complex analyticity in this context).

Experience suggests that generically (maybe always) non-pert. physics is required → try to use AdS/CFT.

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More detail: spherically symmetric, charged solution (BH) which is asymptotically AdS_5

$$ds^2 = -f(r)\,dt^2 + f^{-1}(r)\,dr^2 + r^2\,d\Omega_3^2$$

$$A_0 = \left(-\frac{\sqrt{3}}{2}\frac{Q}{r^2} + \Phi\right)$$

A is Maxwell field, coming from one of the isometries of S^5 in the maximally susy context. Φ is a constant.

$$f(r) = 1 + r^2 - \frac{M}{r^2} + \frac{Q^2}{r^4}$$

M = mass
Q = charge
ℓ = Ads radius = 1.

---

horizons: roots of

$$\Delta(r) = r^6 + r^4 - Mr^2 + Q^2 \equiv (x+r_0)(x-x_+)(x-x_-)$$

(where $x = r^2$)

absence of naked singularity enforced $x_+ > x_- > 0$, so for fixed M the charge Q is bounded from above. [extremal solution has $T \neq 0$]

[susy solutions are naked singular].

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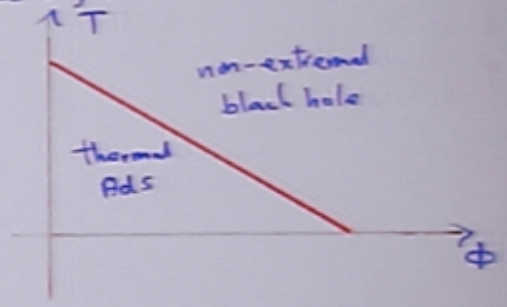
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Chamblin, Emparan, Johnson, Myers
PRD 60, 064018 (1999)

Field theory dual:

The field theory is in grand-canonical ensemble. The fixed temp is Hawking temperature of BH, the chemical potential, conjugate to one of the R-charges, is the constant Φ.

Phase diagram is interesting:



For small enough Φ the Schwartzschild ($\Phi=0$) feature continue: there's Hawking-Page transition at some critical temp., interpreted as a version of deconfinement in the gauge theory.

For large enough Φ, this transition disappears. We will see other qualitative changes as one move away sufficiently from the Schw. case.

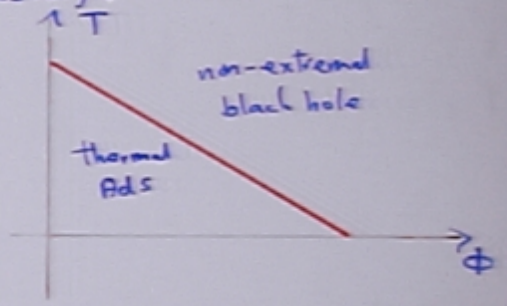
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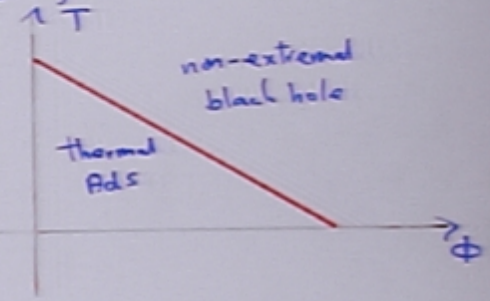
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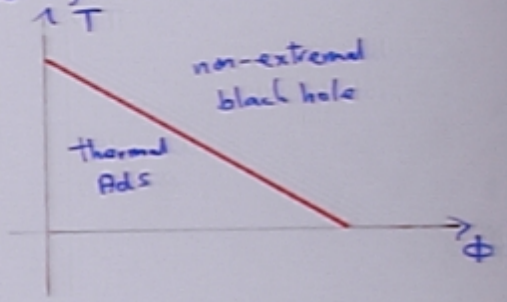
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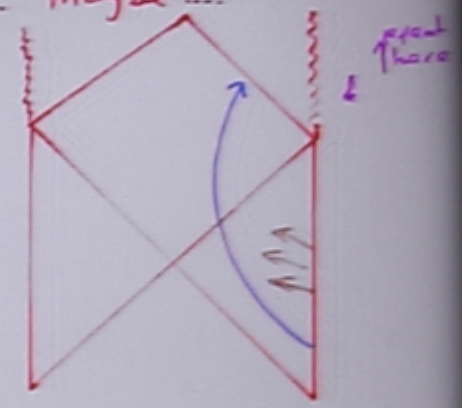
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Inner horizon instability:

Chandrasekhar + Hartle
Proc. Royal Soc. A384, 1982
Chan. Math. Th. of BH.

Can one cross the inner horizon? maybe ....



- the moment before crossing the Cauchy horizon, the observer will see the entire history of the universe flash before their eyes.

observer dependant statement: because of blue shifting, the observer crossing will see huge amplification of any signal sent from the outside world.

More detailed analysis shows some surprises.

Poisson + Israel
PRD 41, 1796(1990)

In classical GR one can add null perturbations

$$T_{ab} = \rho^{in}\, m_a m_b + \rho^{out}\, n_a n_b$$

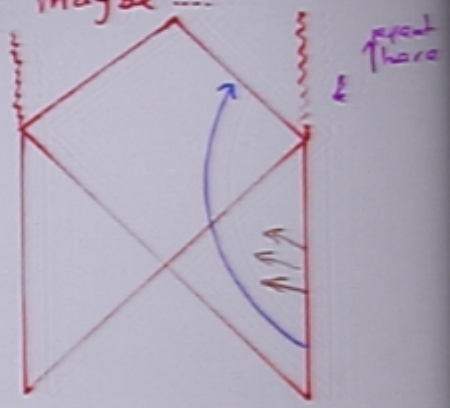
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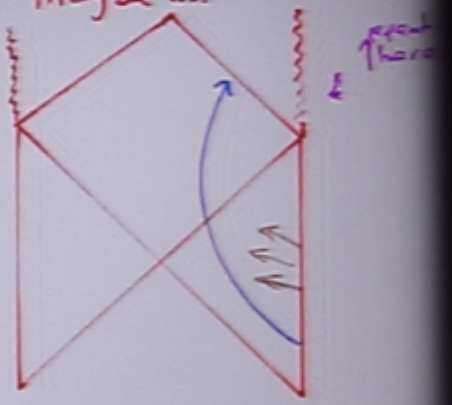
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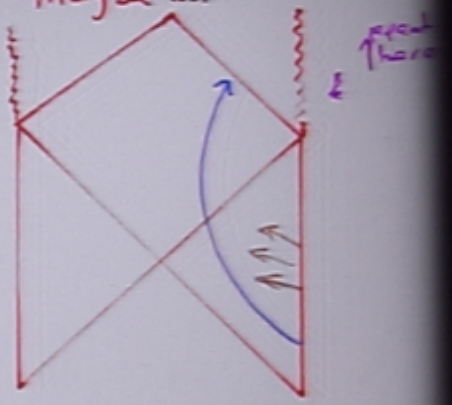
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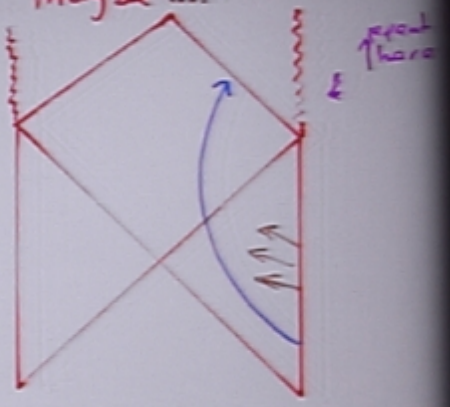
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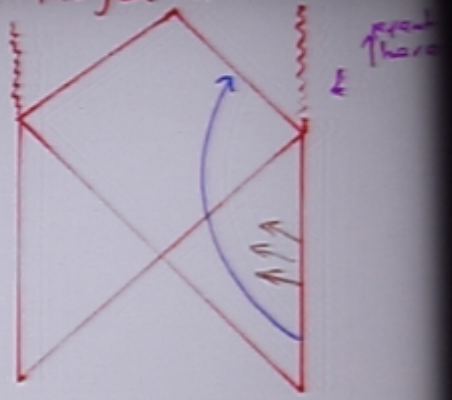
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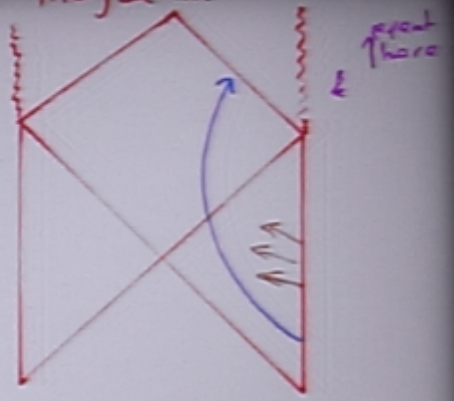
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In classical GR one can add null perturbations

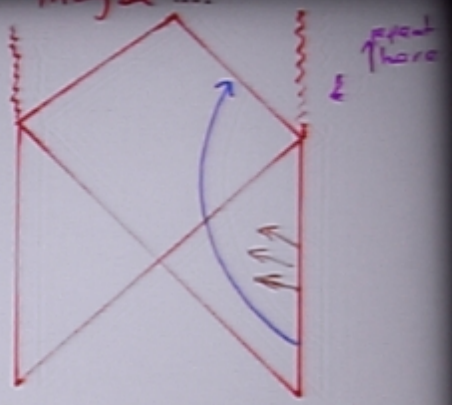
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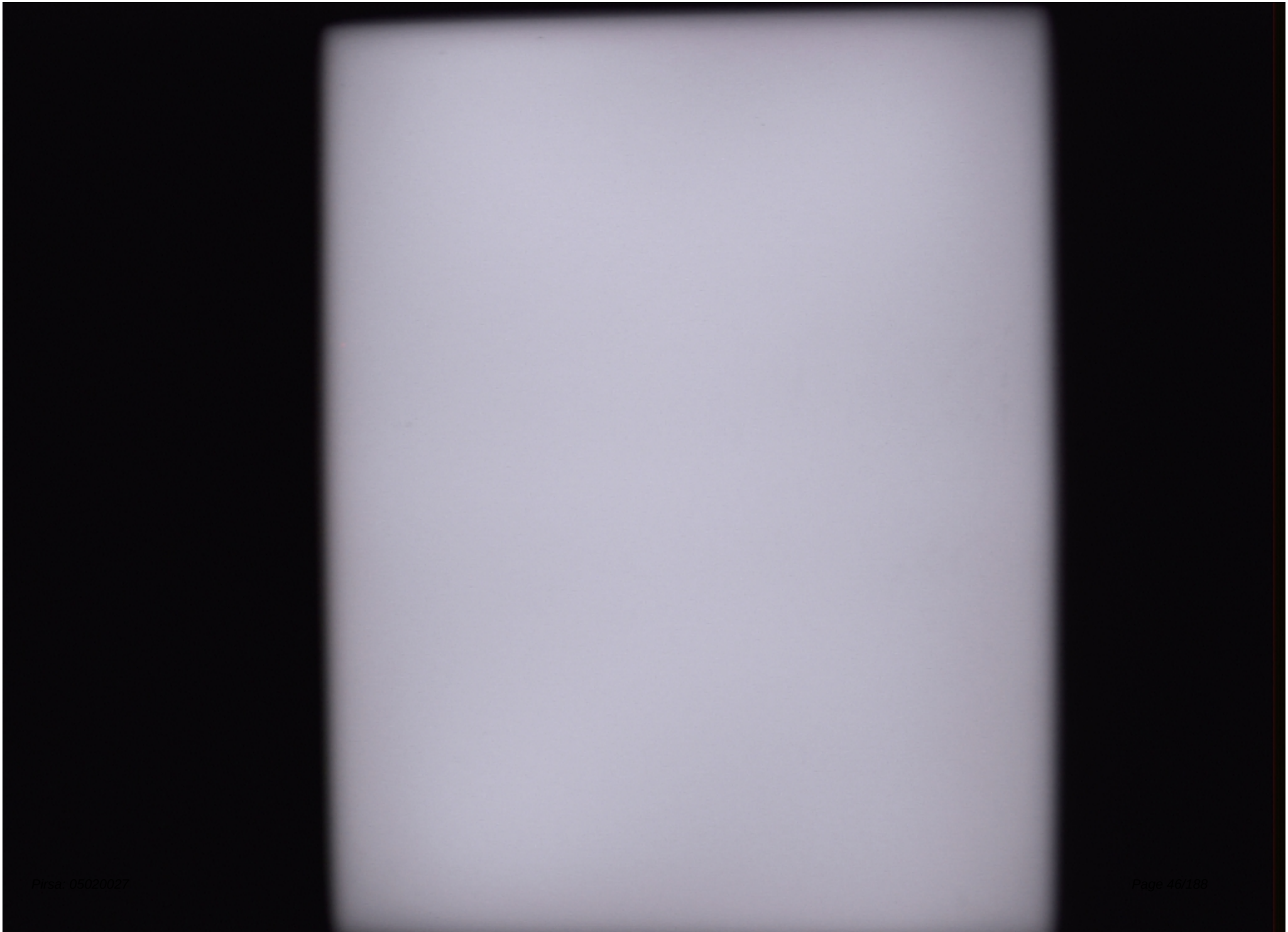
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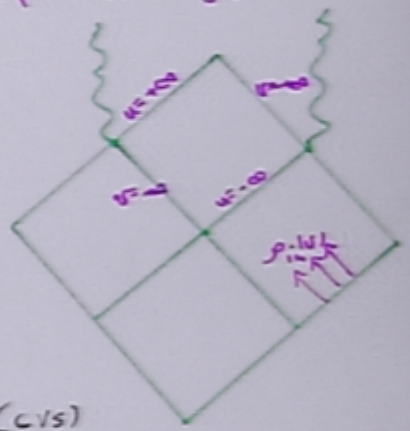
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Pirsa: 05020027



Single "chiral" perturbation

For incoming/outgoing perturbations only, one can re-solve Einstein-Maxwell eqn. exactly.



work in (adim) asym. flat space, with Eddington-Finkelstein coordinates.
(generalizatn to AdS$_5$ is trivial)

The charge Vaidya solution: (cvs)

$$ds^2 = du\,(2dr - f_{in}(u)\,du) + r^2\,d\Omega_3^2 \qquad (r = r(u,v))$$

solve the Einstein-Maxwell eqn with additional $T_{uu} = \rho_{in}(u)$

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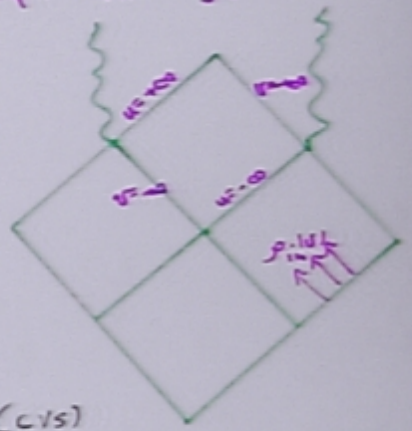
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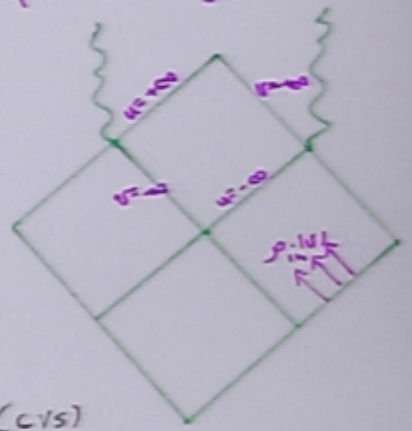
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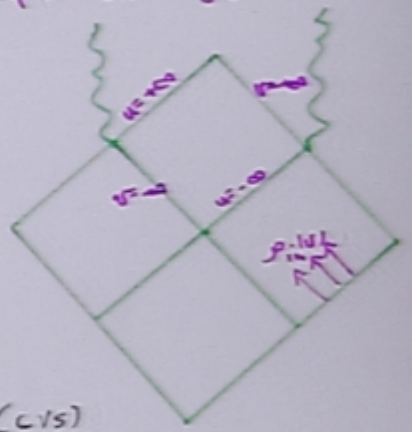
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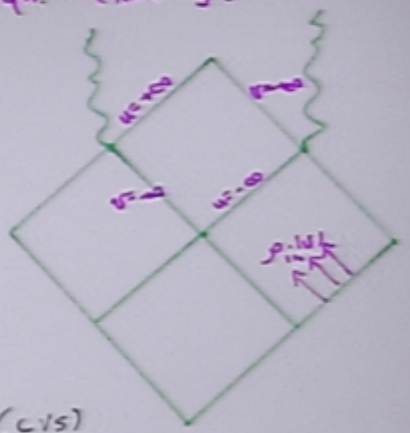
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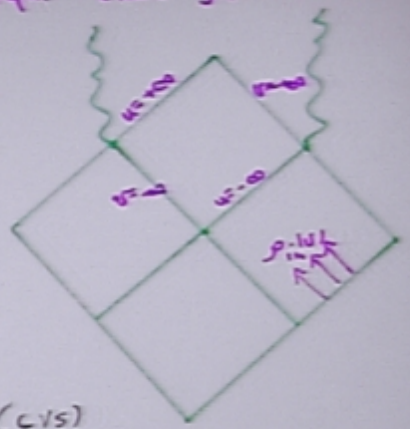
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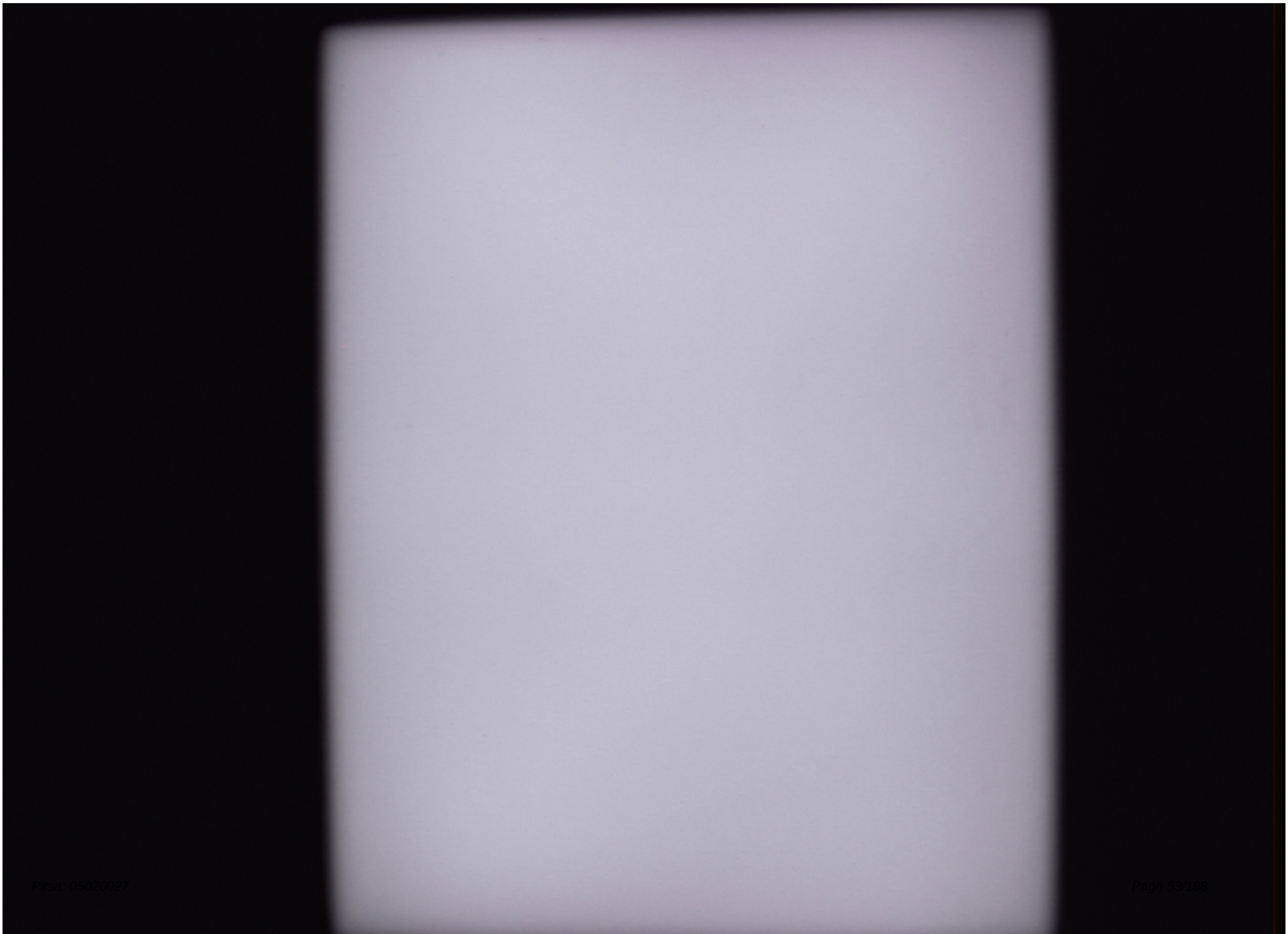
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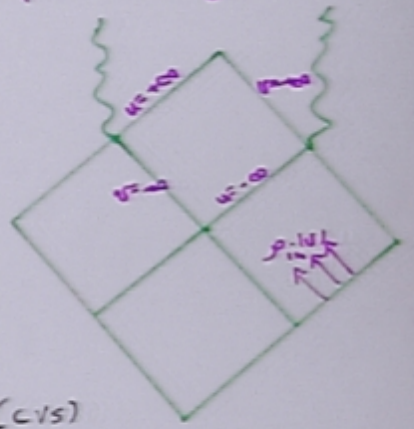
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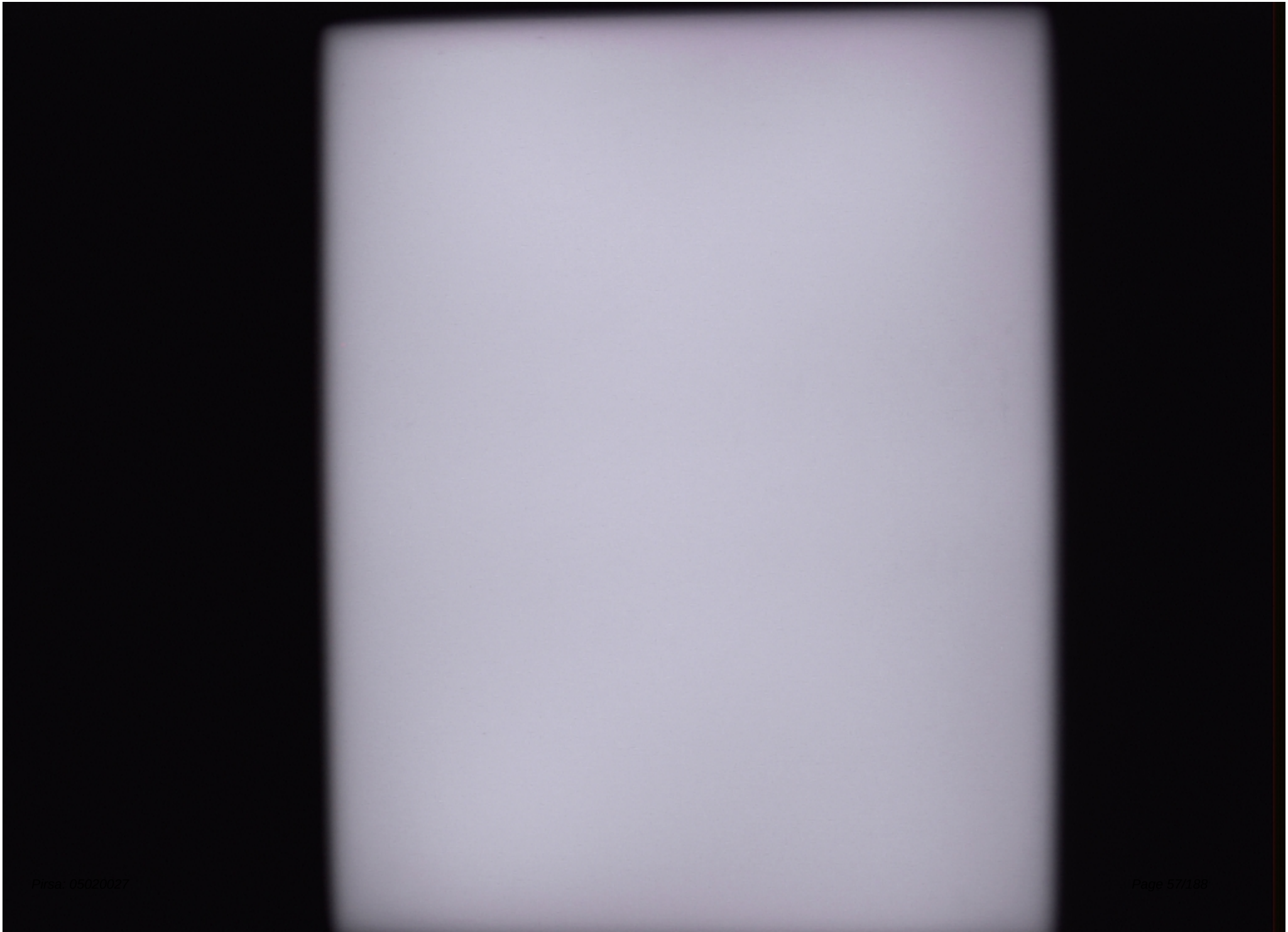
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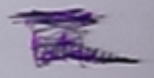
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Probing Thermal Spacetimes: (looking behind horizons)

The boundary:

At finite temp the observables are correlation functions

$$\frac{1}{Z} e^{-\beta E_n} \langle n | T\, \phi(\vec{x}_1, t_1) \cdots \phi(\vec{x}_N, t_N) | n \rangle$$

which one can calculate using path integral

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when one sums over paths with $\phi(t) = \pm \phi(t - i\beta)$.

Already we are considering $t = t_L + i t_E$ as complex.

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Already we are considering $t = t_L + i t_E$ as complex.

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This is the Matsubara formalism, good for calculating static properties.

Probing thermal spacetimes

The boundary:

At finite temp. the observables are correlation functions

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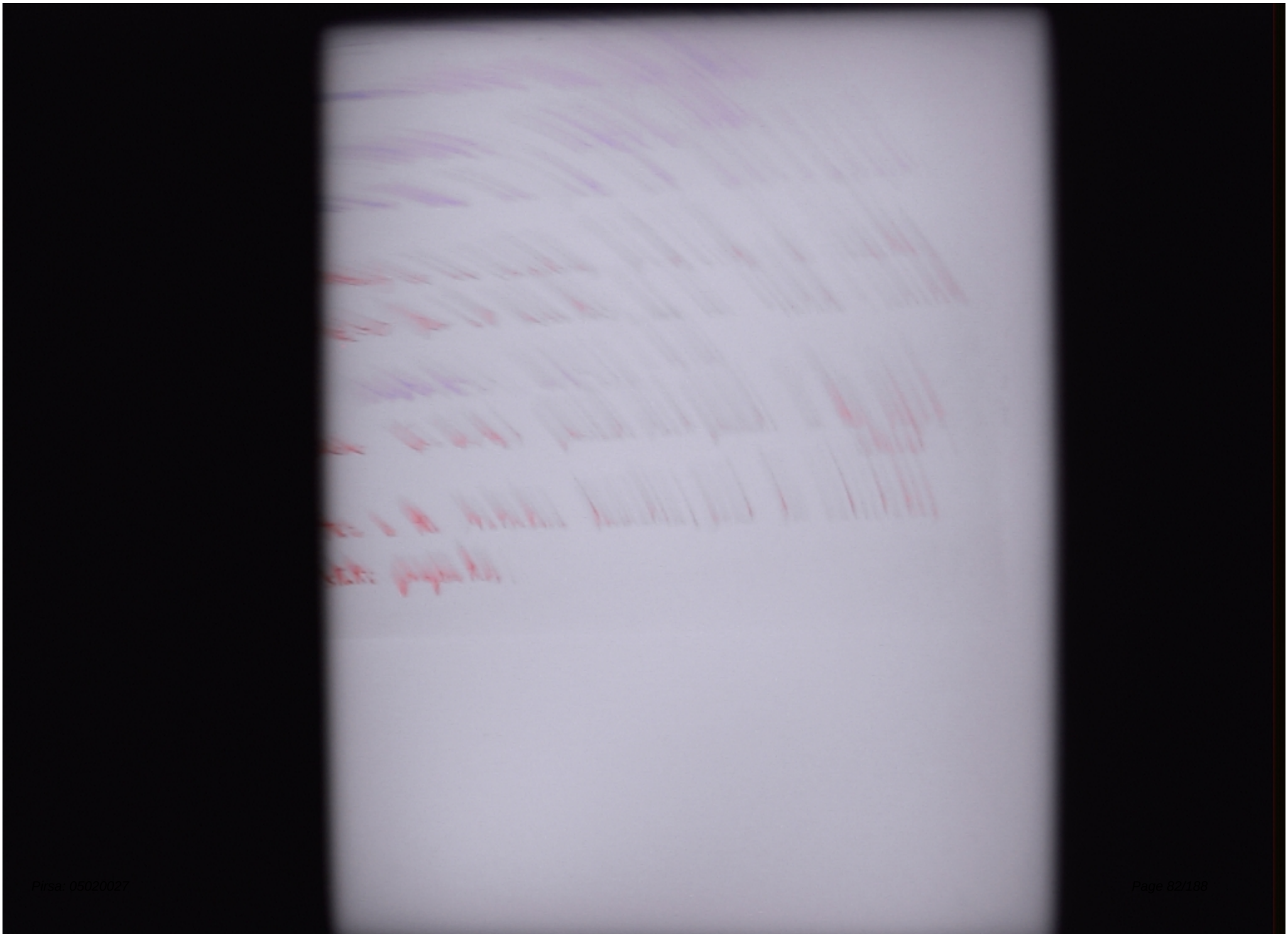
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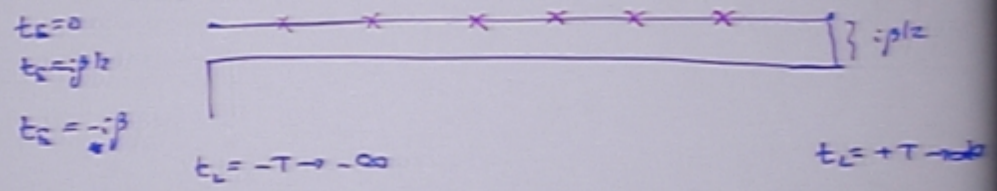
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More generally $S(\phi)$ has t integration which has to be interpreted as contour integration. There are two requirements:

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[thermofield dynamics]

$|n\rangle$: original theory; $|\tilde{n}\rangle$: thermal double

The thermal double roughly lives on the second real line, where time runs backwards.

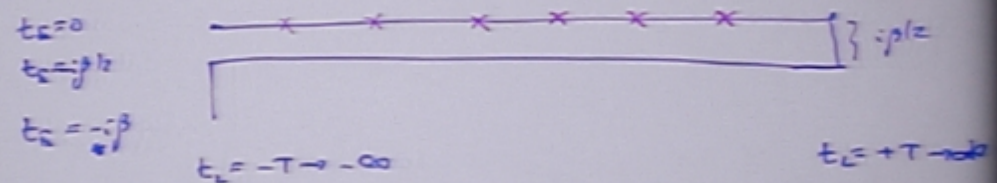
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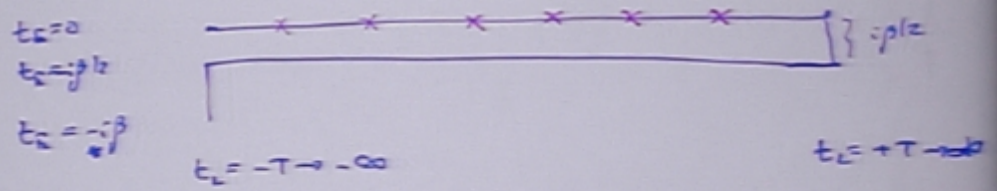
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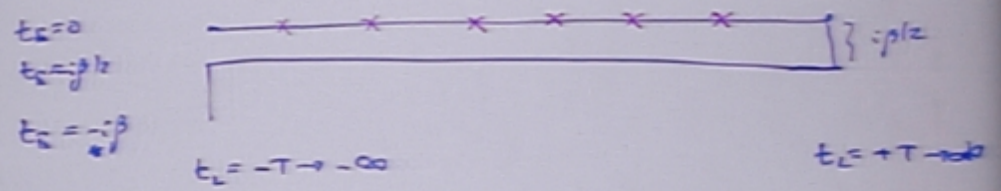
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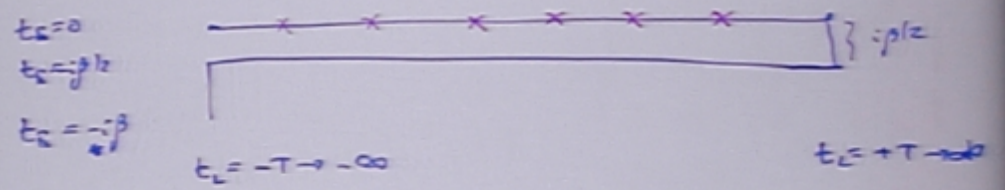
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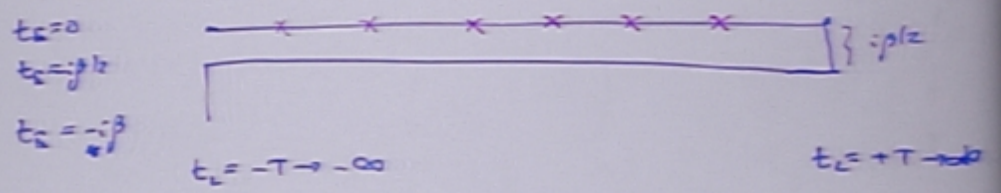
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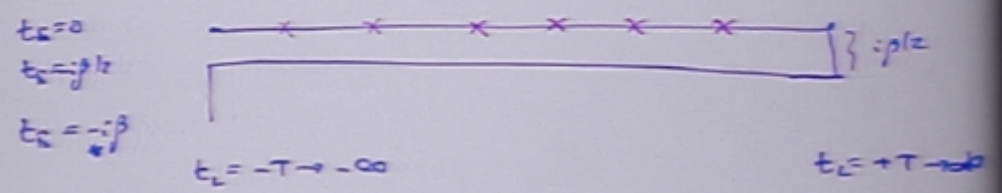
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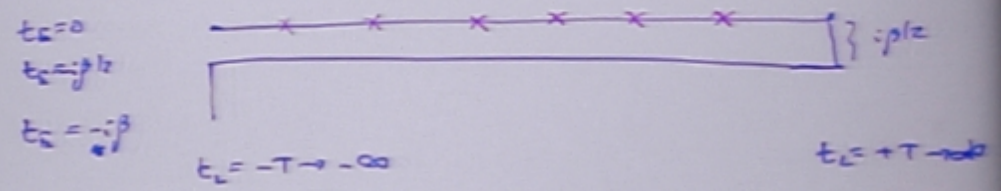
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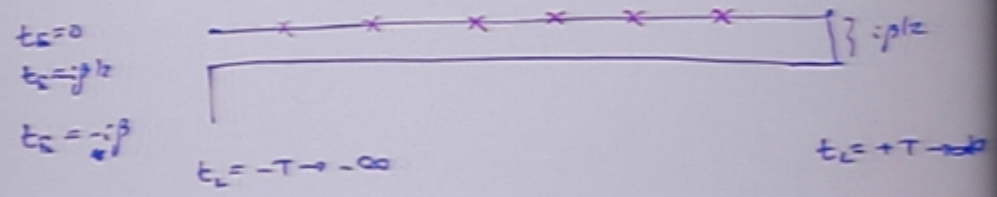
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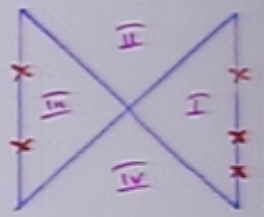


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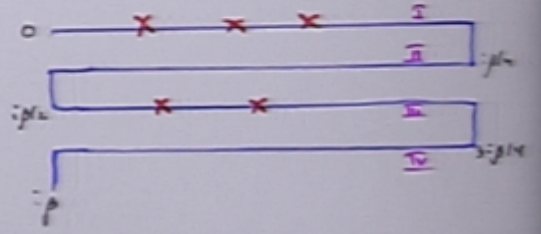
[Israel, Maldacena]

The Bulk:

Eternal BH have 2 bdy components, which maps to the thermofield doubling.



To make this precise complexify the Schw. coordinates of region I (outside the horizon), so that t_E jump by $\frac{i\beta}{4}$ when horizon is crossed. The field theory contour is:



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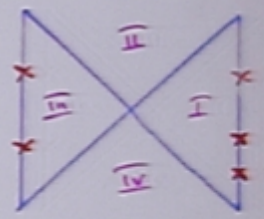
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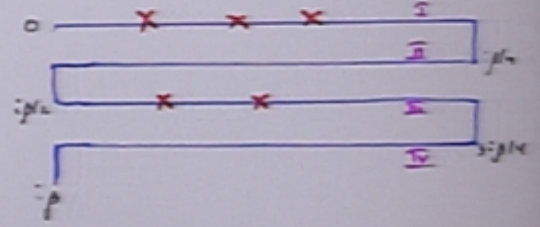
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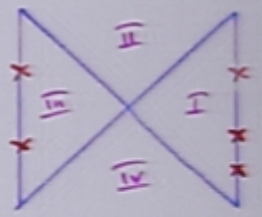
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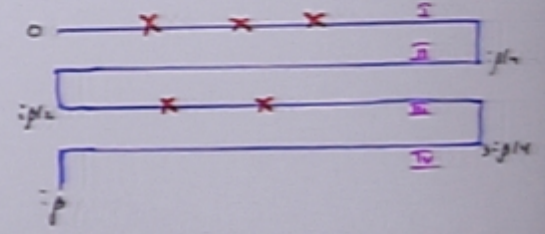
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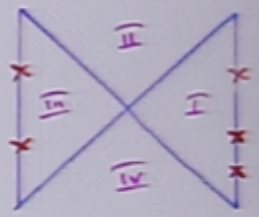
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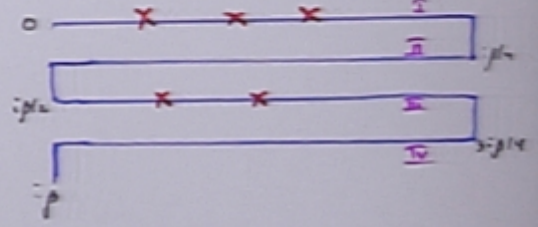
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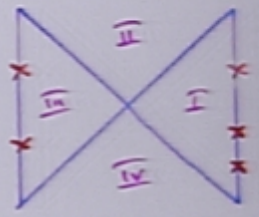
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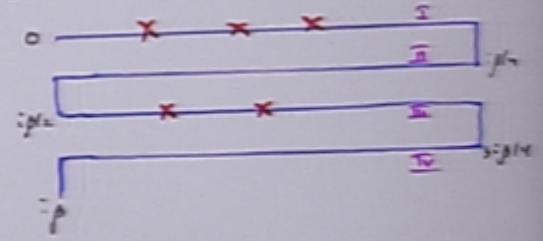
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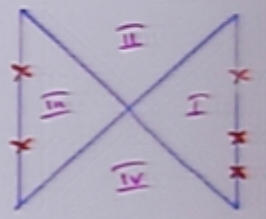
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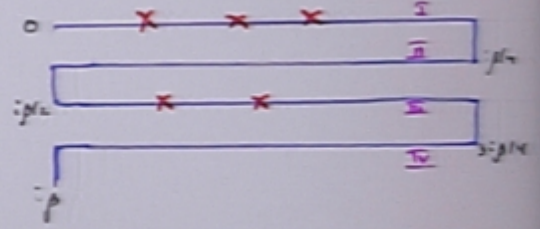
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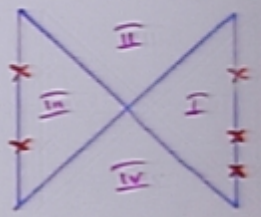
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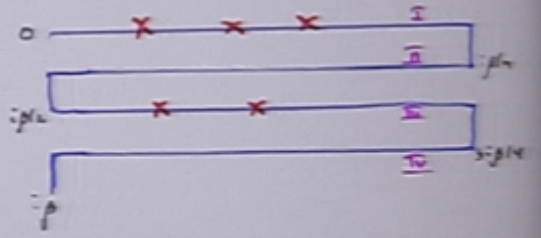
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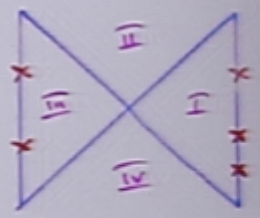
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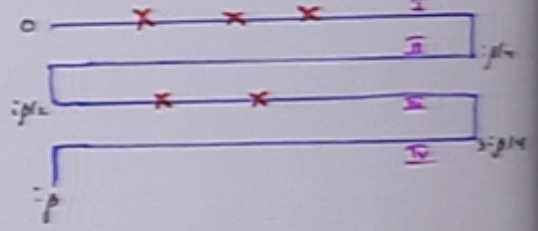
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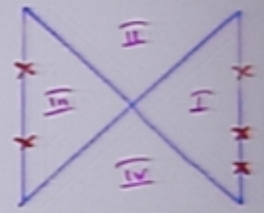
(vertical lines = horizons).

(insertions schematically shown.).



The Bulk:

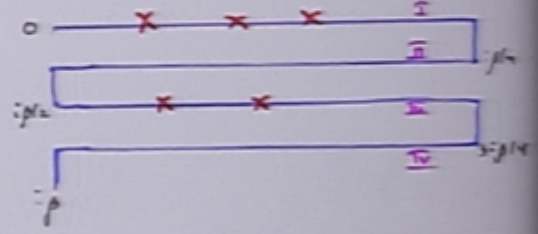
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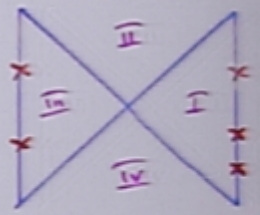


be a nice probe inside the horizon.

[Israel, Maldacena]

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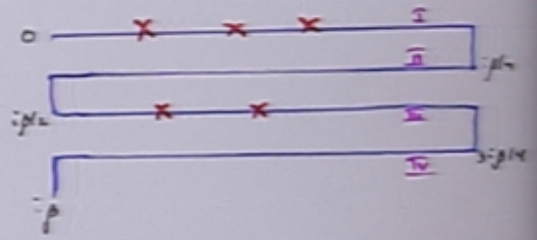
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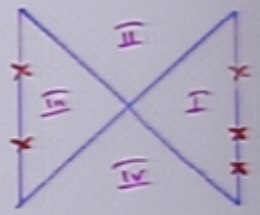
Pirsa: 05020027

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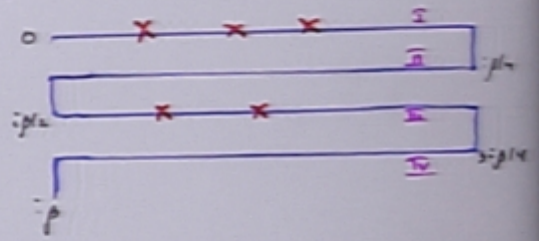
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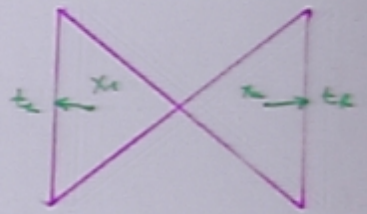


Bulk calculation: concentrate on 2 pt. function

$\langle \phi(t_L)\, \phi(t_R - \frac{iL}{2}) \rangle$; this is extracted from the bulk Green's function $G(x_1, x_2)$ for two points x_1, x_2 which are spacelike separated and approach the bdy.

(Fidkowski, Hubeny, Kleban, Shaher)

subtraction (renormalization) is needed for these, more later...



Finally: Green's function are tricky, but for high mass (= conformal dim., eg 0-particles) they have heat kernel expansion

$$\frac{1}{\Box + m^2} \sim \int \mathcal{D}x(\lambda)\, e^{\frac{i}{\hbar} S(x)}$$

with the first quantized action $S = m \int g_{\mu\nu} \dot{x}^\mu \dot{x}^\nu$

dominated by saddle points (= spacelike geodesics).

(Some subtleties later).

~~Kleban, Left for more general cases, Kleban stopped~~

~~Comparison of features...~~

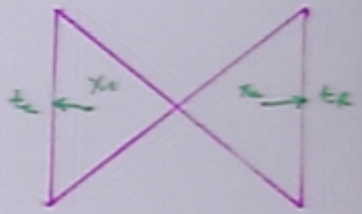
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~~this work for more general cases~~
~~comparison of results~~

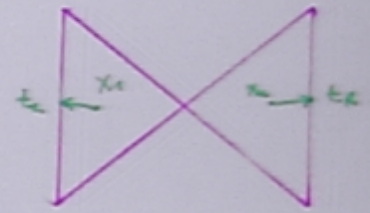
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$$\frac{1}{\Box + m^2} \sim \int \mathcal{D}x\, |x|\, e^{-\frac{1}{a} S(x)}$$

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[Some subtleties later.] ~~[illegible]~~

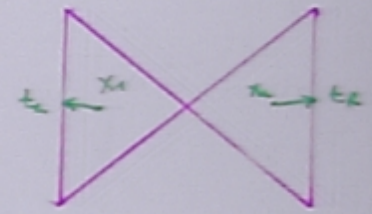
Print: 05020027

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[Some subtleties later.] ~~Method for more general cases, Higher dimensions, Comparison of Features...~~

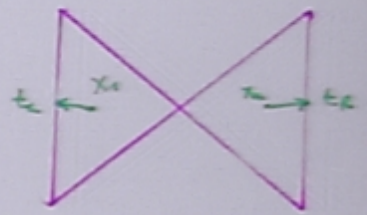
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~~Kleban's talk for more~~ ~~details~~

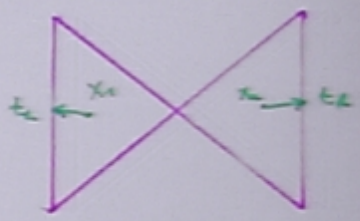
~~Comparison of teachers~~

Pirsa: 05020027

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[Some subtleties later.]

~~[illegible] for more general [illegible]~~

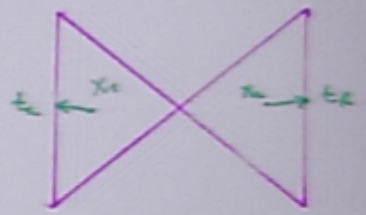
~~comparison of [illegible]...~~

Pirsa: 05020027

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[Some subtleties later].

~~Motivation for more general [illegible]~~

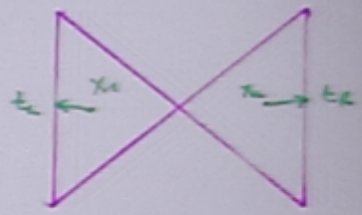
~~Comparison of theories...~~

Pirsa: 05020027

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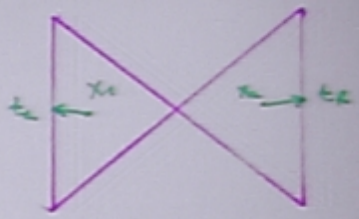
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Pirsa: 05020027

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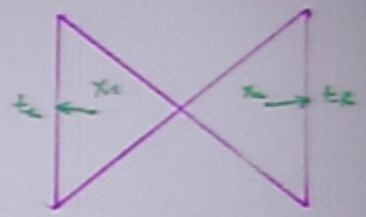
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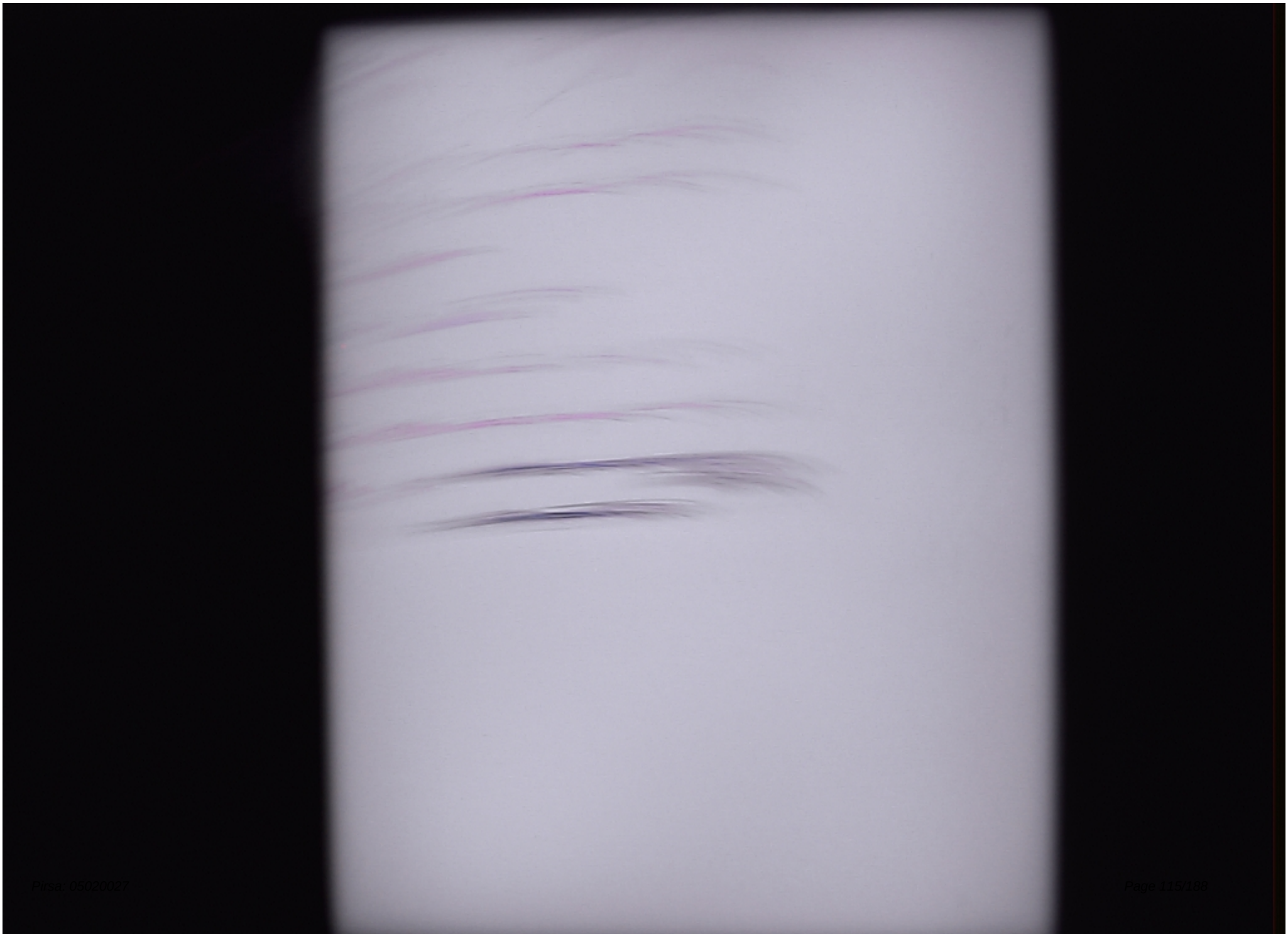
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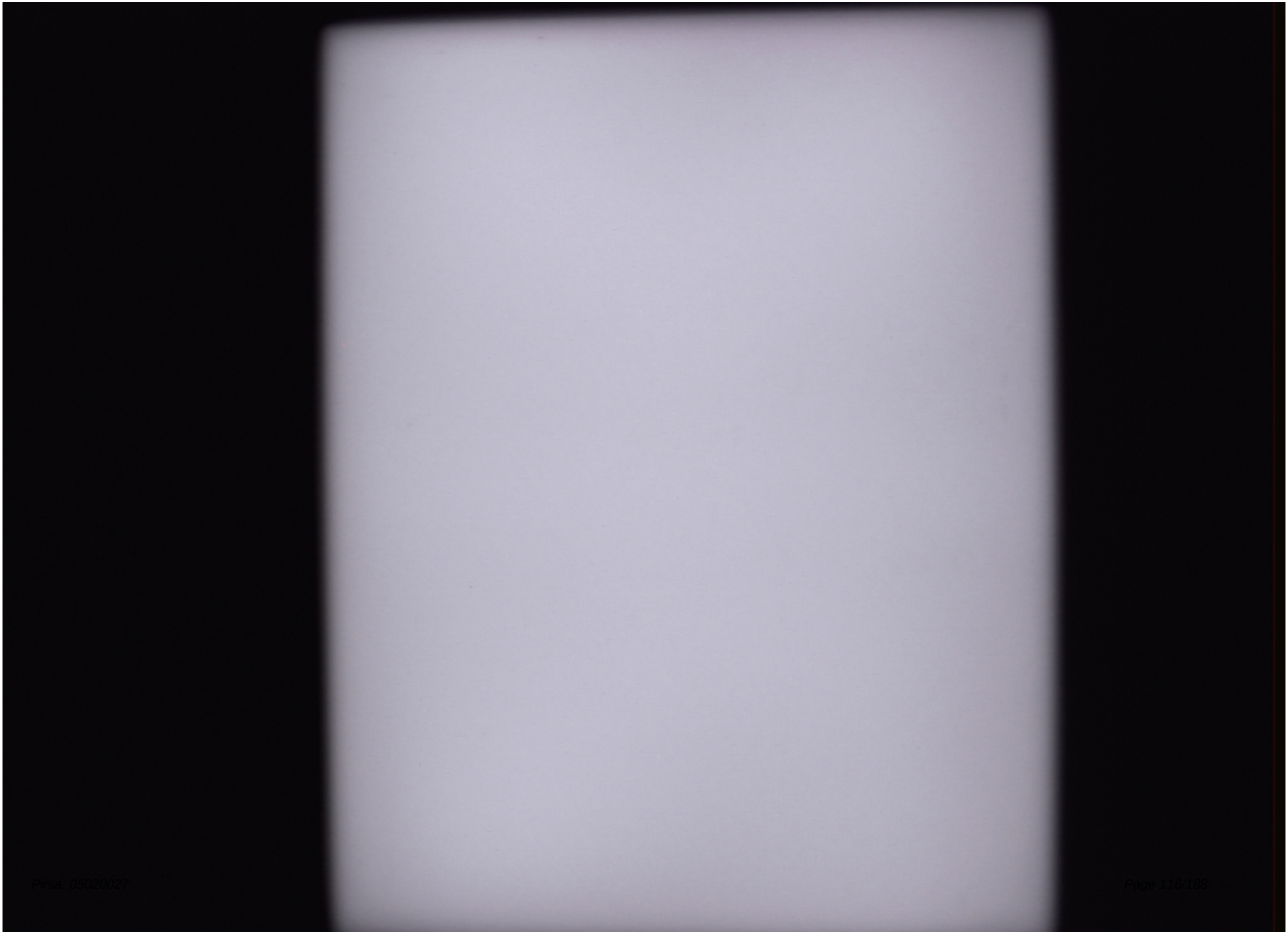
[Some subtleties later].

~~[illegible]~~

~~Comparison of [illegible]...~~

Pirsa: 05020027





Spacelike Geodesics:

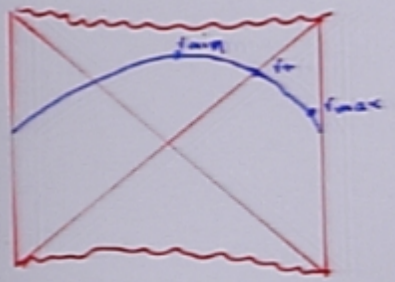
For spherically symmetric spacetime, world line action

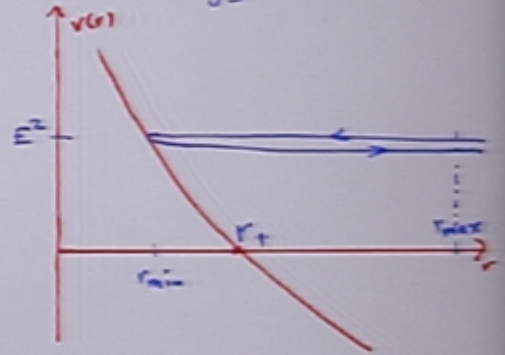
$$\mathcal{L} = -f(r)\dot{t}^2 + \frac{\dot{r}^2}{f(r)} = 1$$

geodesic eqn. for $t(\lambda)$, $r(\lambda)$ are:

$$\begin{cases} \dot{t} = \dfrac{E}{f(r)} & \text{(static spacetime} \rightarrow E \text{ is conserved energy)} \\ \dot{r}^2 + U(r) = E^2 & \text{with} \quad V(r) = -f(r) \end{cases}$$

Features of $r(\lambda)$ visible from $V(r)$: look like motion of particle in potential $V(r)$ with energy $E^2 > 0$.





simplest example in Schwarzschild geometry

$$f(r) = 1 - \frac{M}{r^2} + \frac{r^2}{l^2}$$

note $r_{min} \to 0$, singularity visible.

Pirsa: 05020027

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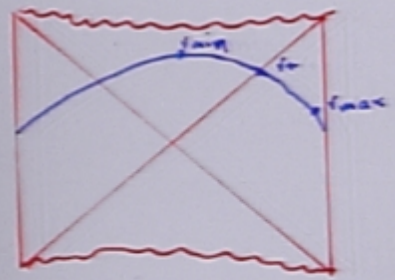
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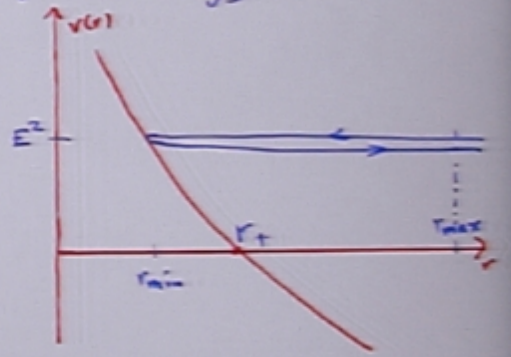
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Pirsa: 05020027

Spacelike Geodesics:

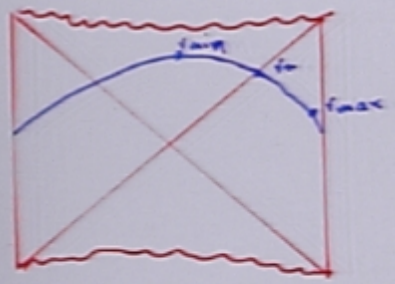
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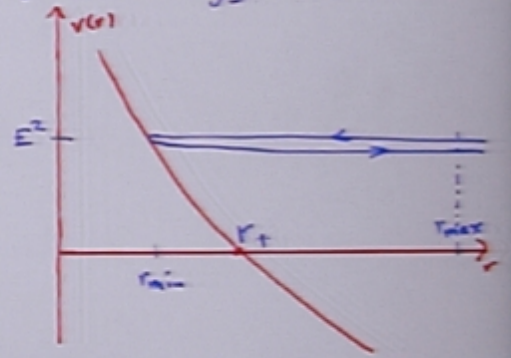
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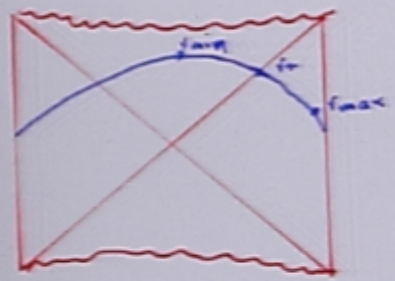
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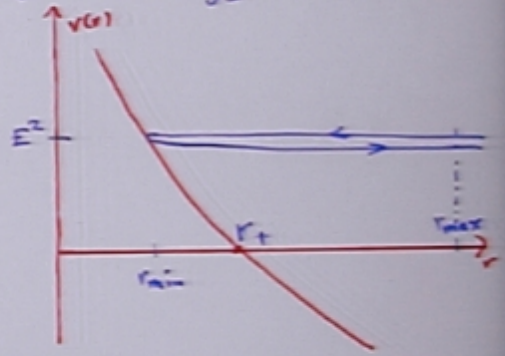
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$$f(r) = 1 - \frac{M}{r^2} + \frac{L^2}{r^4}$$

note $r_{min} \to 0$, singularity visible.

Pirsa: 05020027

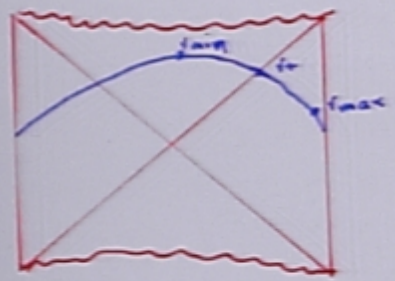
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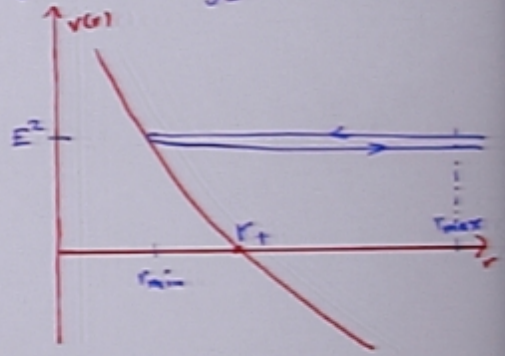
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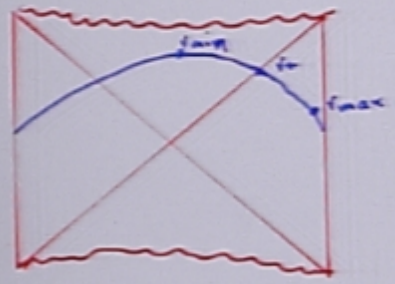
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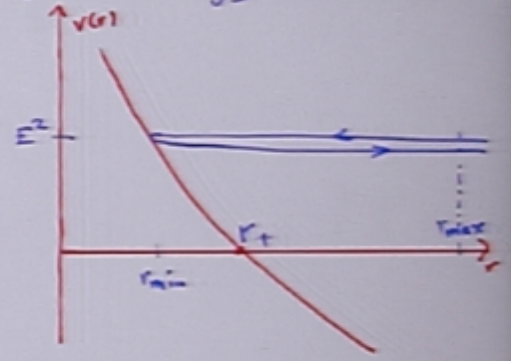
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Features of $r(\lambda)$ visible from $V(r)$: look like motion of particle in potential $V(r)$ with energy $E^2 > 0$.





simplest example in Schwarzschild geometry

$$f(r) = 1 - \frac{M}{r^2} + \frac{r^2}{l^2}$$

note $r_{min} \to 0$, singularity visible.

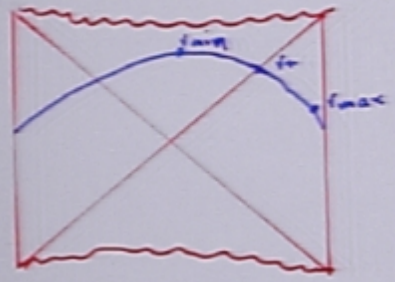
Pirsa: 05020027

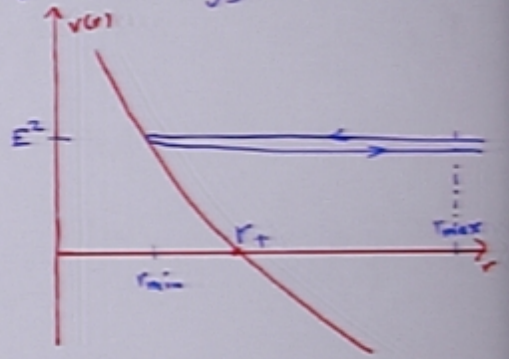
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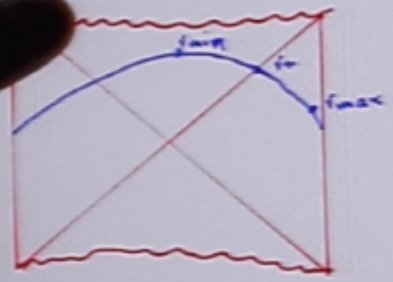
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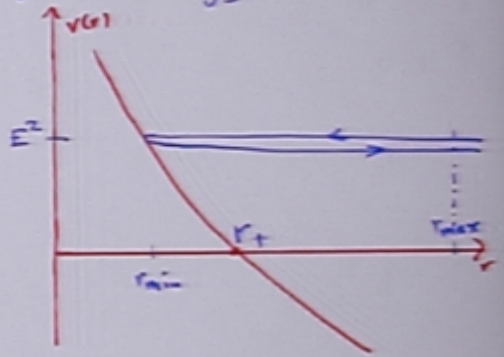
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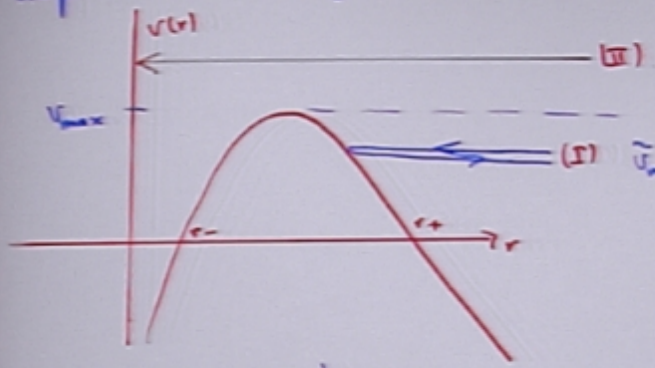
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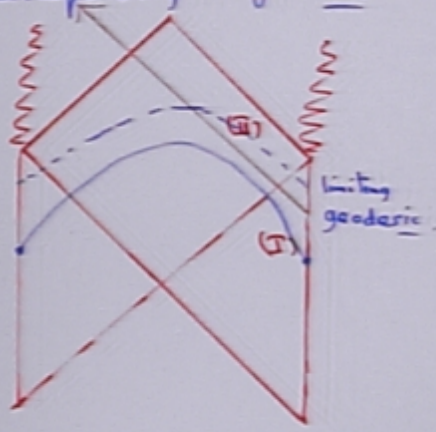
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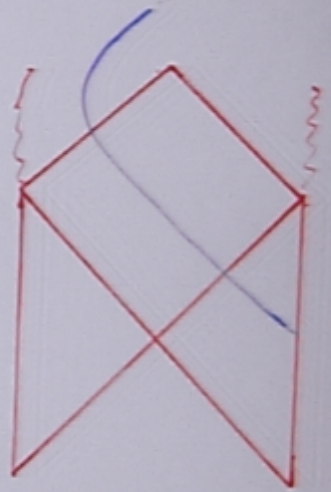


(with rotation)

roots are r_+, r_-, L^2.

The corresponding trajectories:



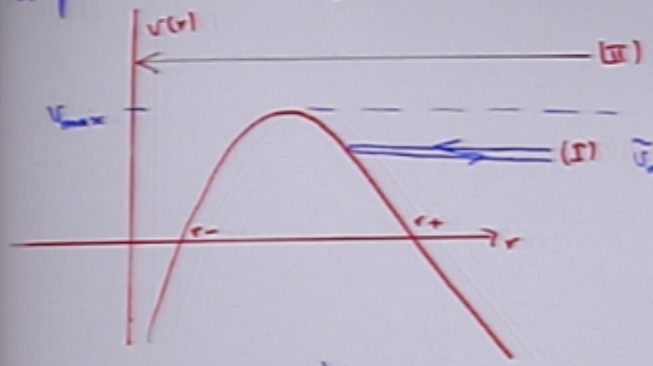


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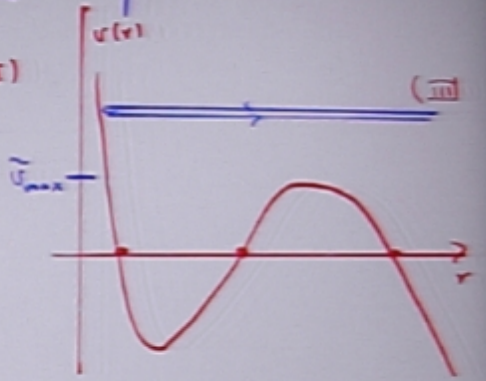
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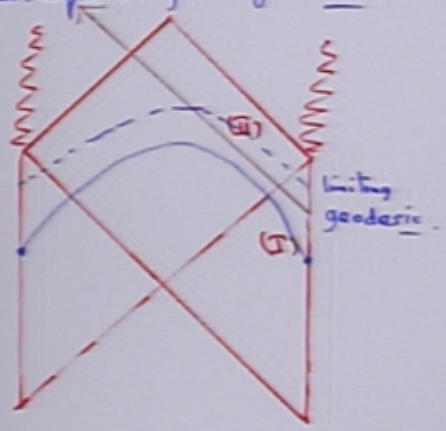
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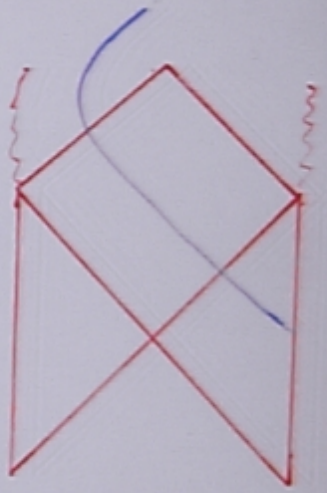


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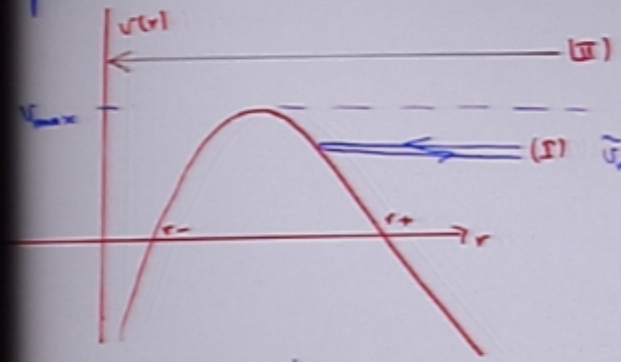


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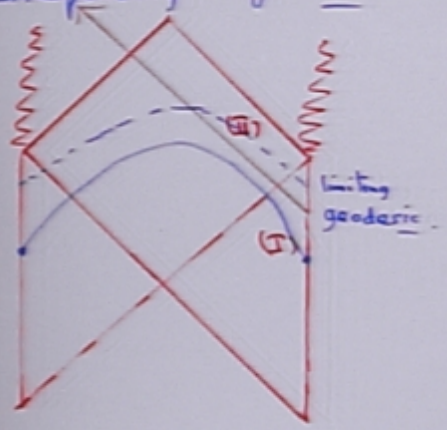
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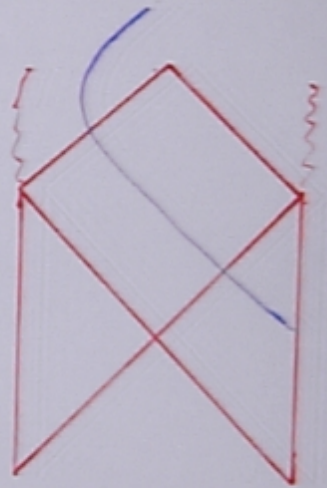


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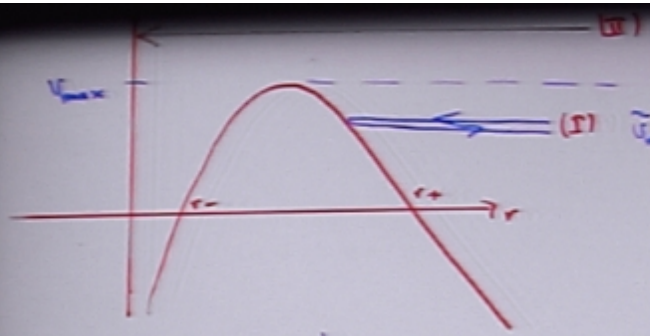




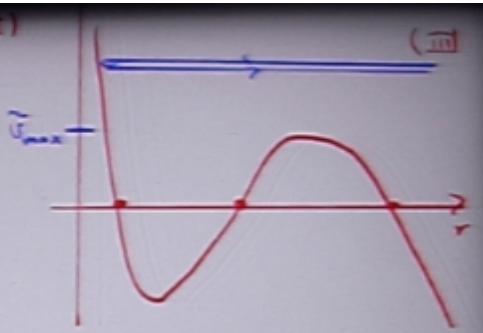
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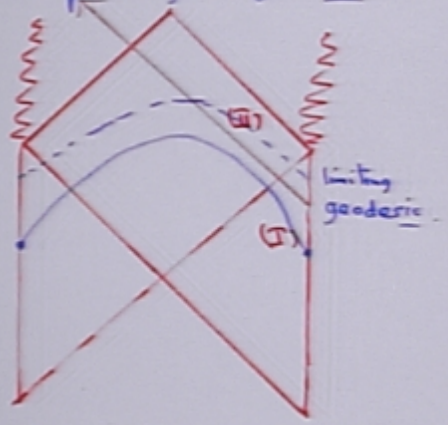
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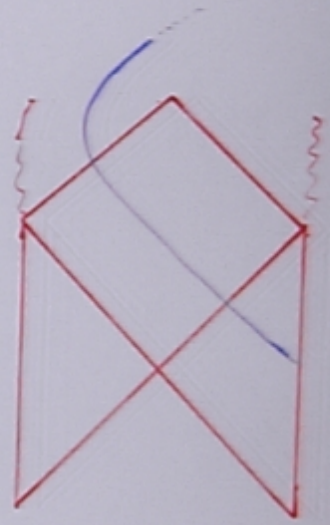


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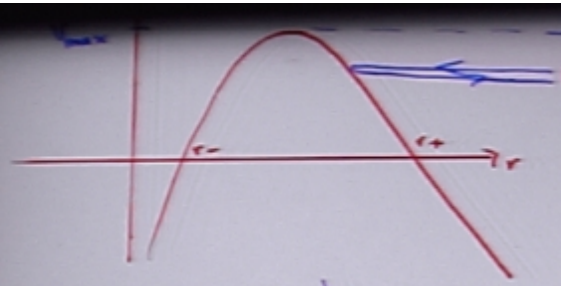




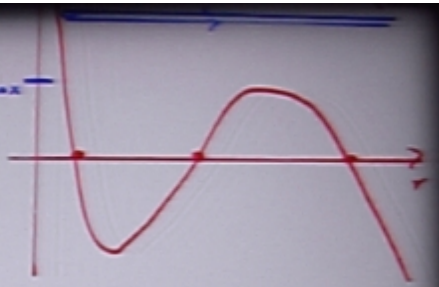
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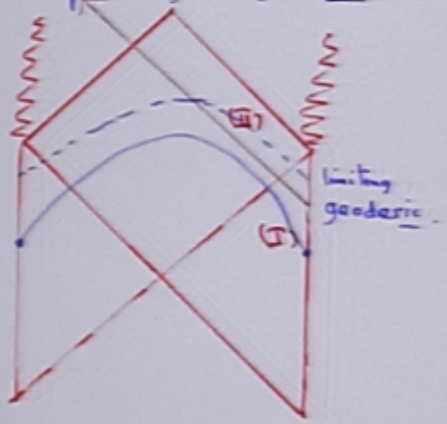
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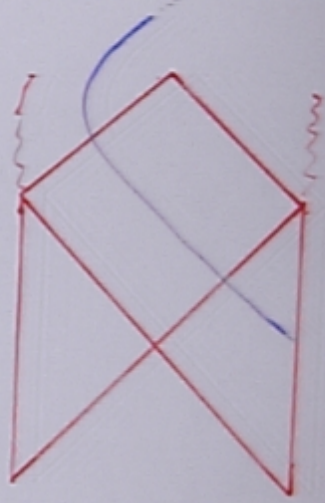


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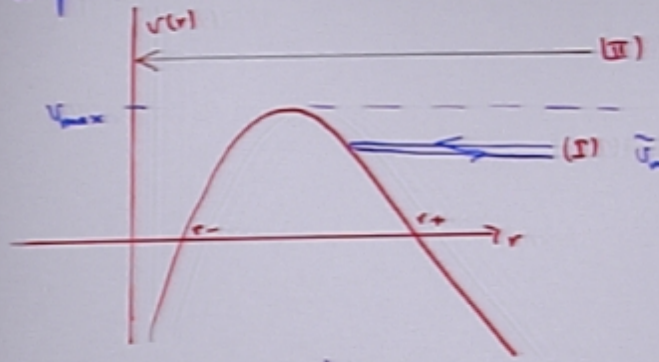
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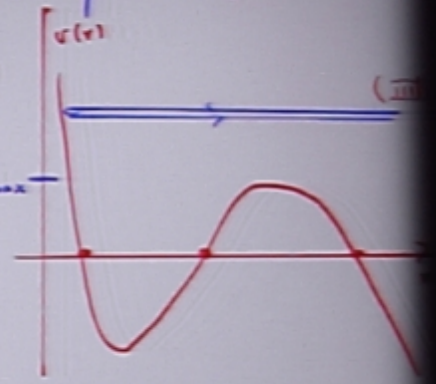
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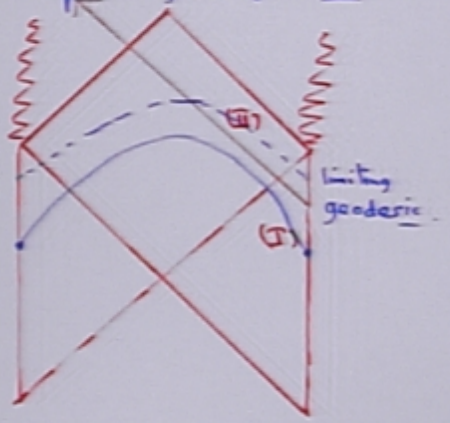
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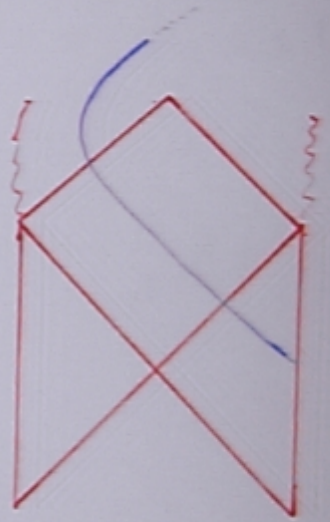


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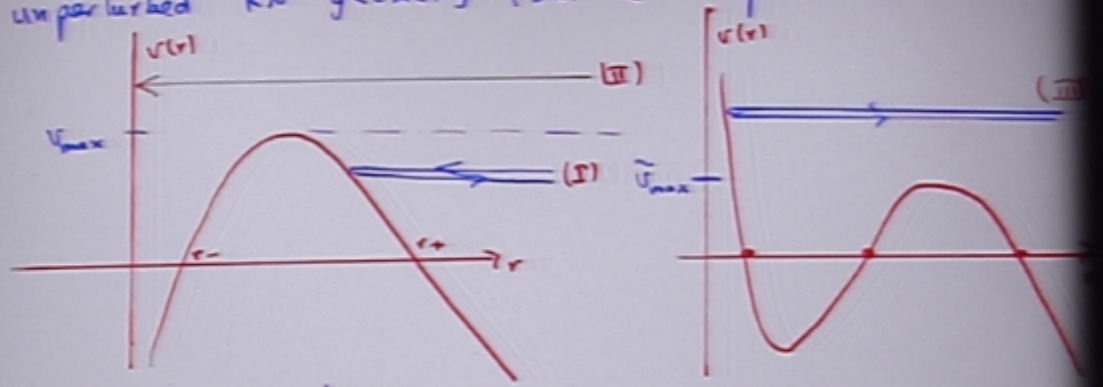


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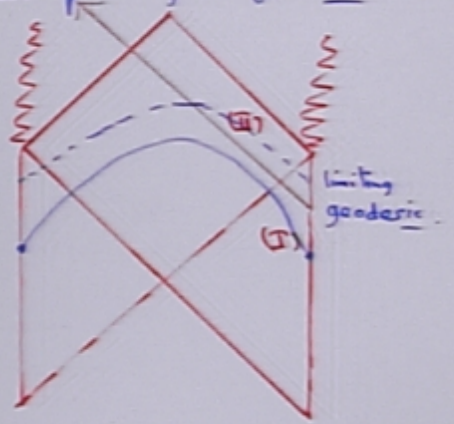


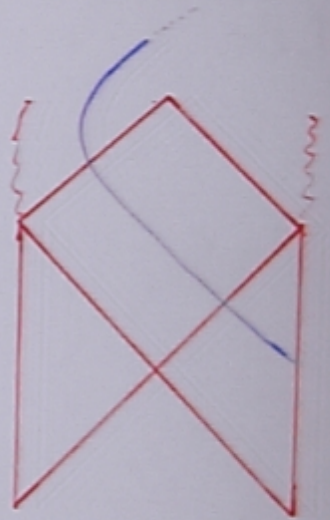
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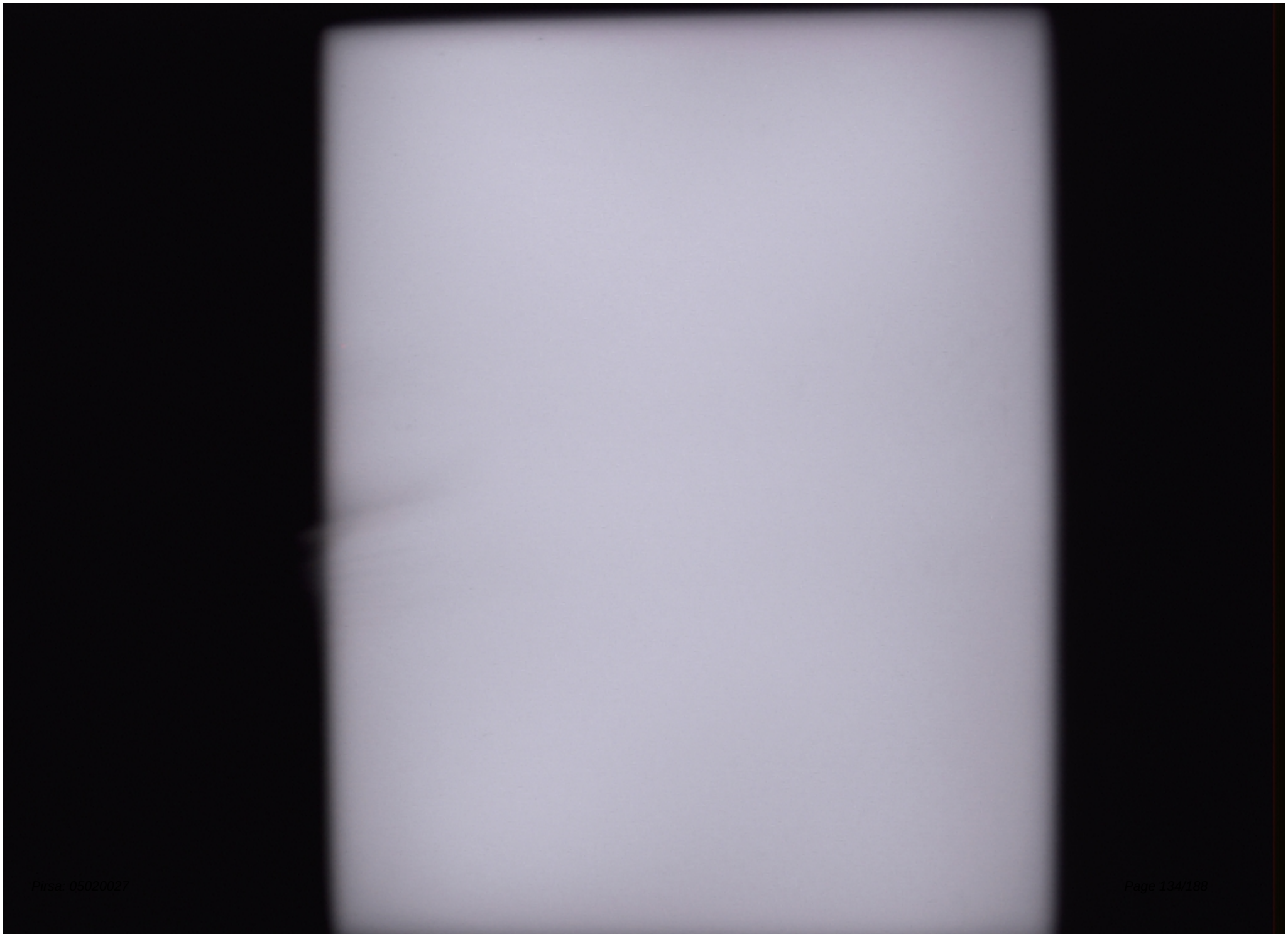




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Calculating Correlation Functions:

For simplicity focus on neutral non-rotating geodesics.

We see 2 types of behavior, depending on BH parameters.

Schwartzschild + far from extremal cases:

$$\langle \phi(t_L)\,\phi(t_R)\rangle \sim e^{-\ell(t_L,t_R)}$$

$\ell(t_L,t_R)$ is the length (appropriately renormalized) of the shortest geodesic connecting boundary points t_L, t_R.

In the unperturbed case things only depend on t_L+t_R.

First step: trade (t_L+t_R) for E, the conserved energy; for many reasons it would be nice to avoid this step (e.g. do initial value problem).

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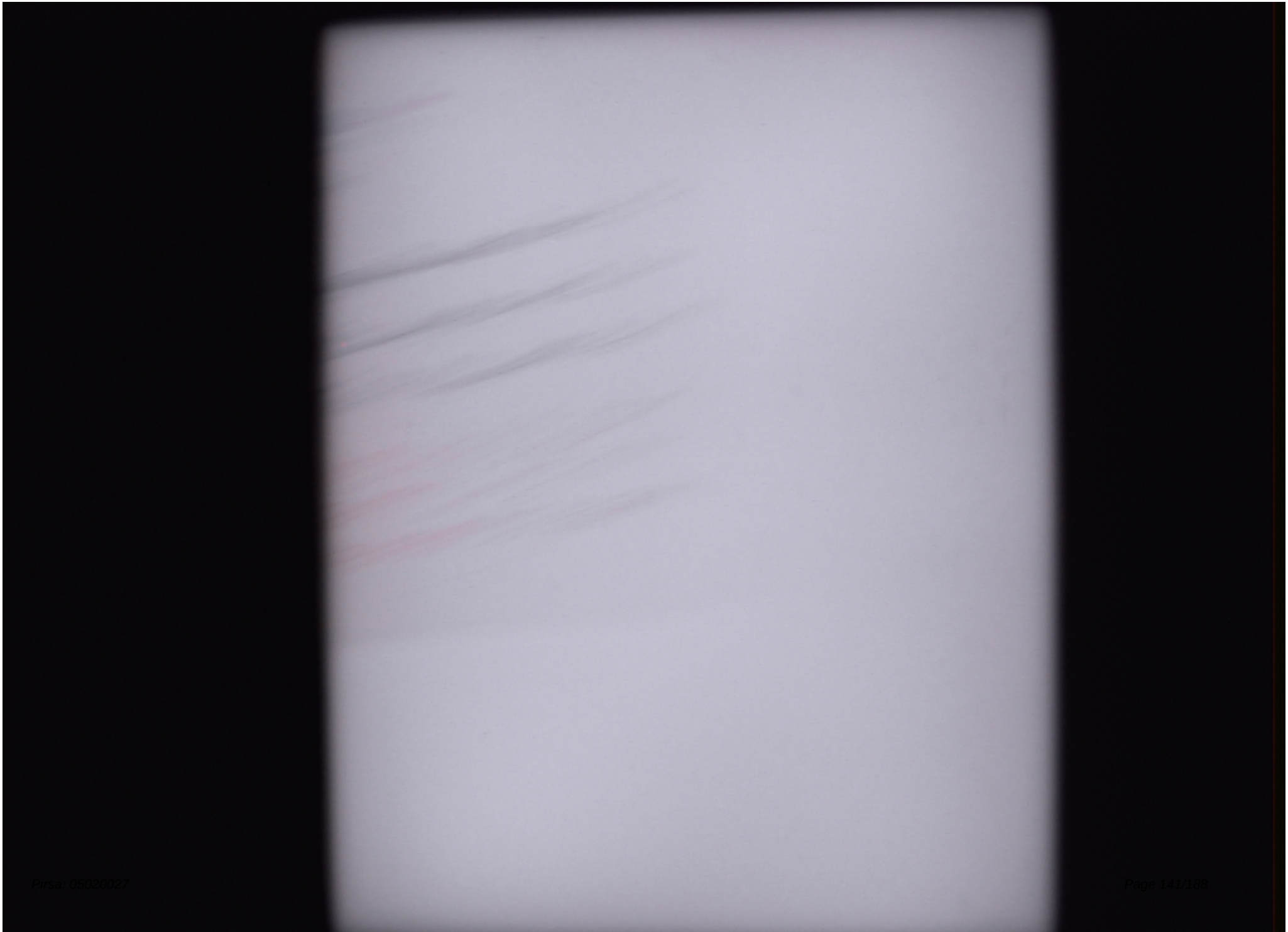
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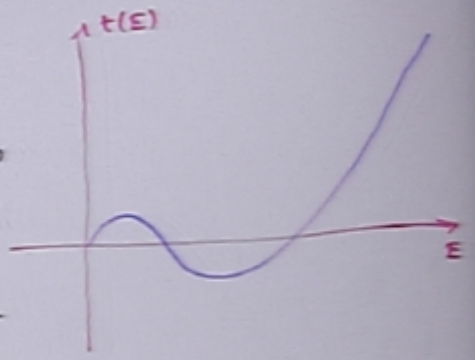
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because:

For neutral + near neutral BH the plot is roughly.



more than one geodesic, need to decide which one dominates, based on ~~#~~ which one lies on the (unknown) steepest descent path.

In the neutral case this was used to "hide" the signature of the singularity (which leads to contradiction in gauge theory language); it is only revealed by analytic cont.

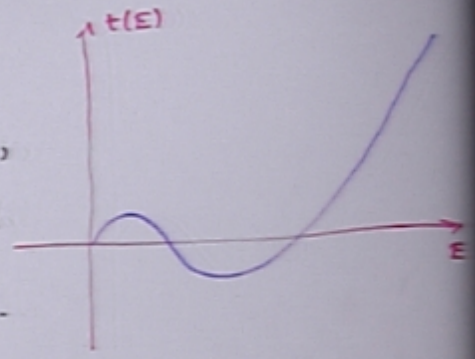
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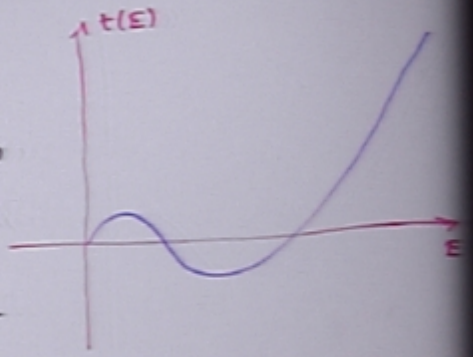
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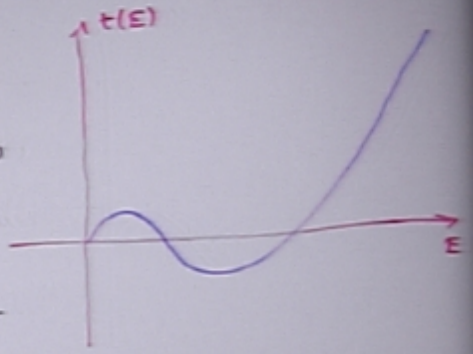
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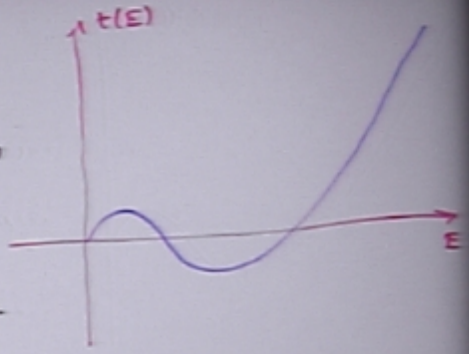
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for neutral + near neutral BH the plot is roughly.



more than one geodesic, need to decide which one dominates, based on ~~$\frac{3}{2}$~~ which one lies on the (unknown) steepest descent path.

In the neutral case this was need to "hide" the signature of the singularity (which leads to contradiction in gauge theory language); it is only revealed by analytic cont.

More direct way to observe the late-time geodesics, which we are interested in, is needed in these cases. (currently, elaborate procedure based on cat. from the Euc. slice is needed).

Luckily, this is simpler for us.

Pirsa: 05020027



Near extremal case $(r_+ \simeq r_-)$

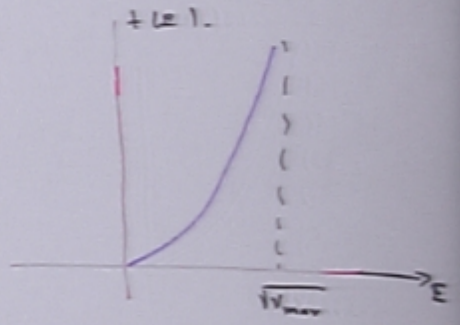
Boundary Time vs. Energy:

Trajectory of energy E^2 has turning point defined by $E^2 + V(r_E) = 0$

Then:

$$t_L + t_R = \int_{r_E}^{\infty} \frac{E\, dr}{V(r)\sqrt{E^2 - V(r)}}$$

The integral can be calculated in terms of elliptic integral, it has the feature



- it is monotonic → no competing saddles.
  (similar on the Euc. slice).
- $t(E)$ diverges as $E^2 \to V_{max}$; all paths with $E^2 > V_{max}$ must be irrelevant then.
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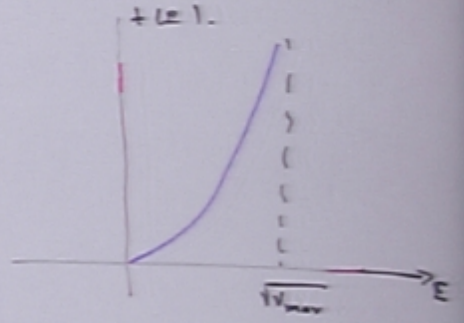
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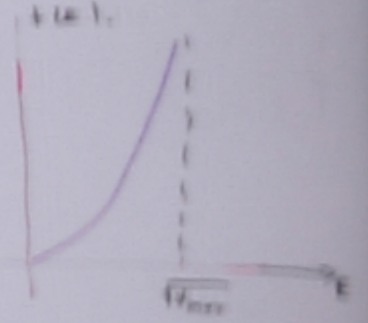
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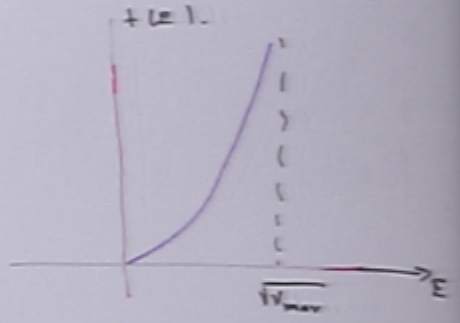
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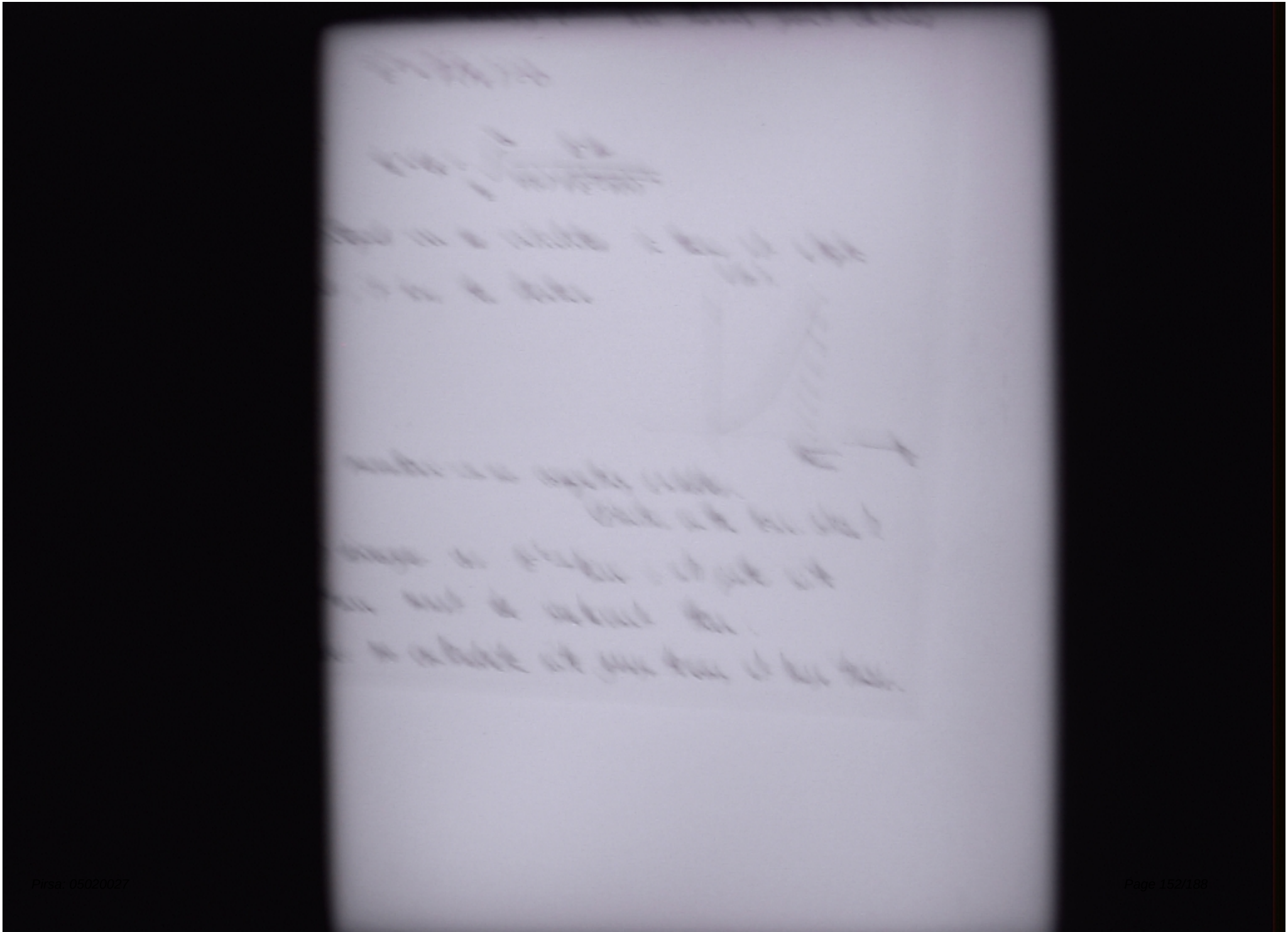
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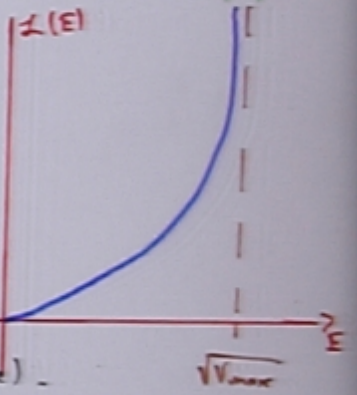
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Plot $\mathcal{I}(E) - \mathcal{I}(E=0)$ instead (exact result in paper).



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* The set of relevant geodesics accumulate at some finite distance away from CH, important later.
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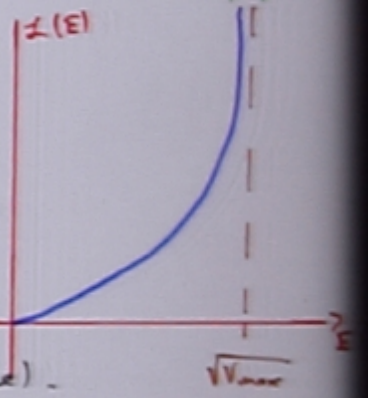
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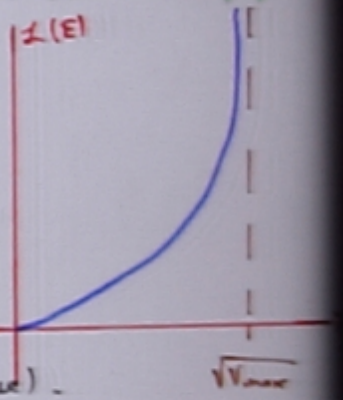
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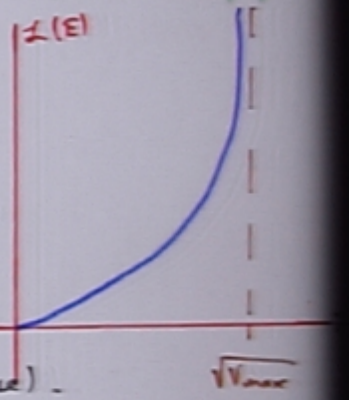
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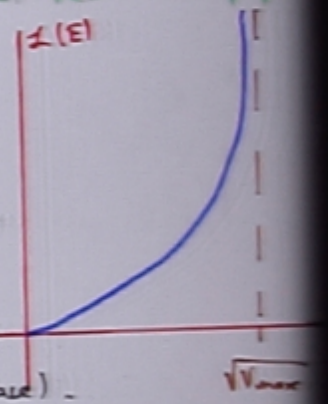
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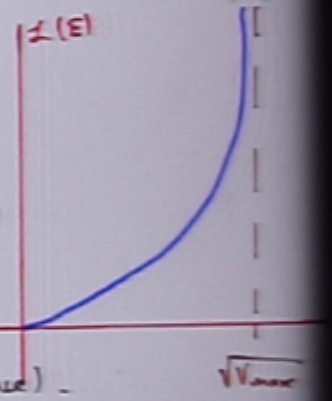
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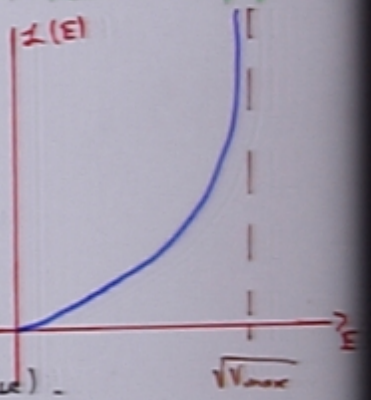
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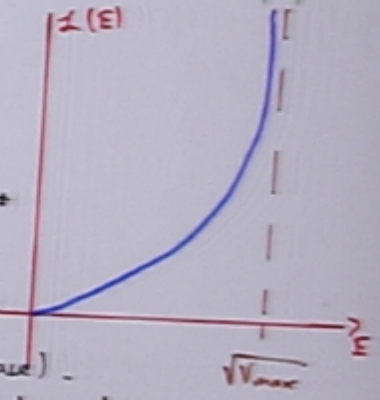
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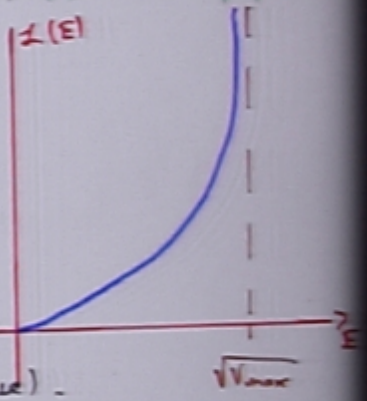
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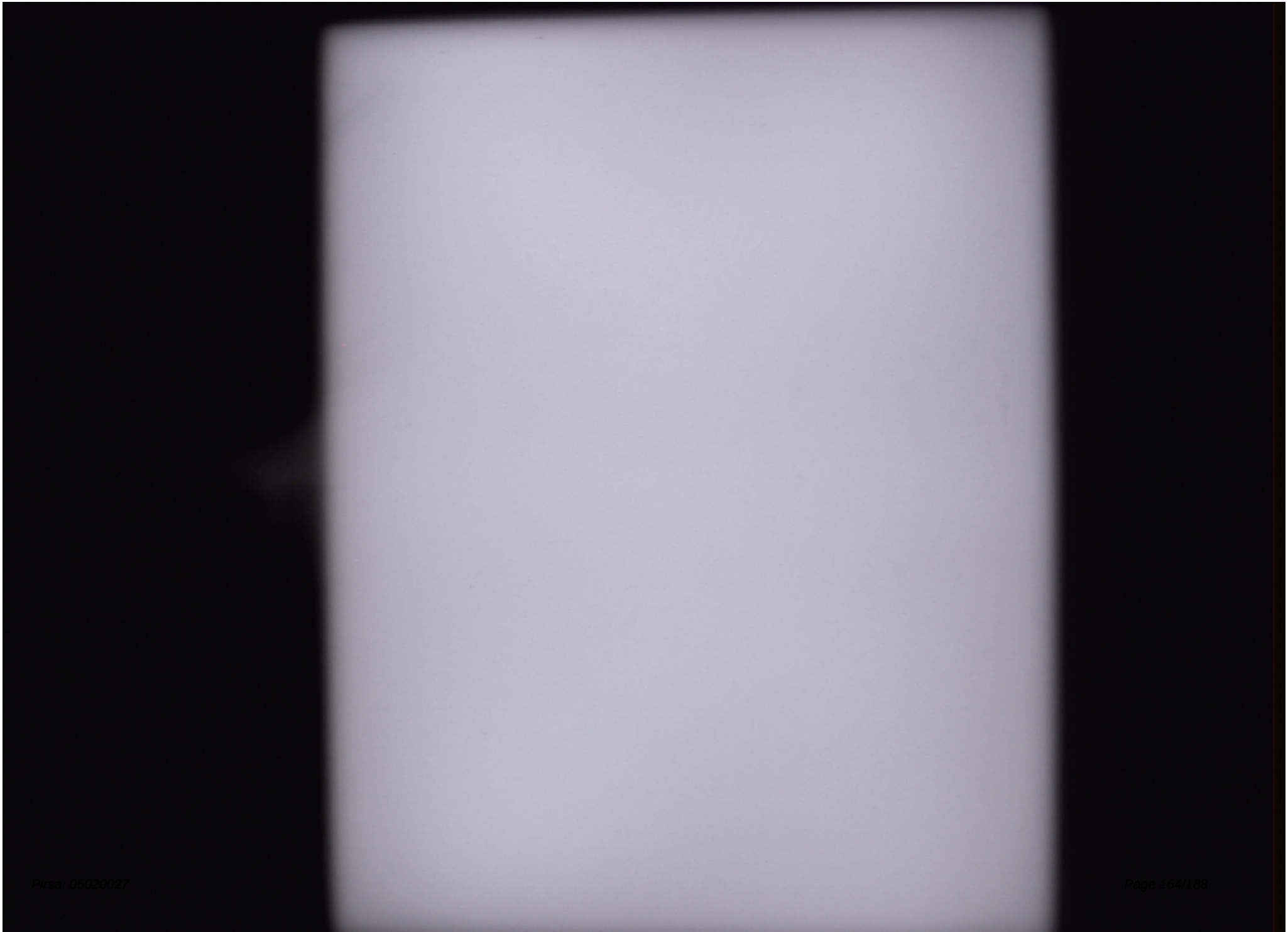
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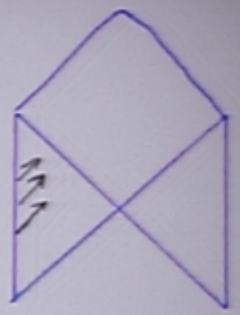
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Scanning Behind the Horizon:



The phenomena we are interested in are localized behind the horizon, can one see such localized events?

Toy problem: add perturbation as drawn, it's effect is purely behind the horizon, and can be arbitrary local. Can the observables discern it's effect?

For example, send infinitely thin pulse at time t_p, one can plot the correlators as function of t_p.

Before we do that, what is the expected answer? perturbation effect does not diminish as its strength goes to zero.

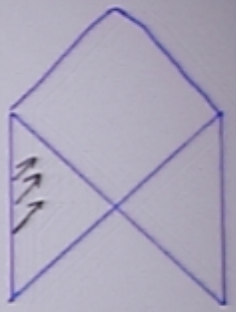
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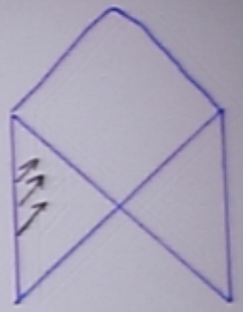
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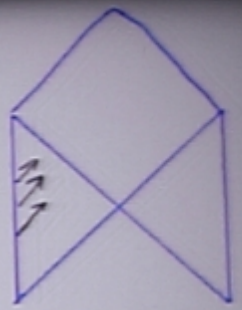
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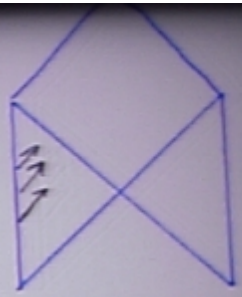
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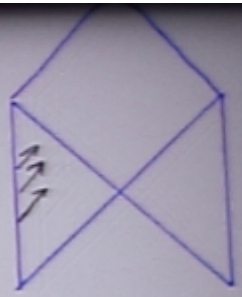
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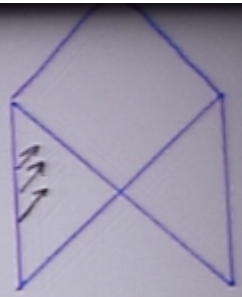
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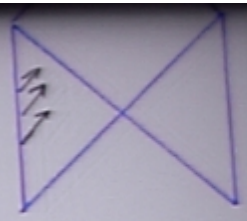
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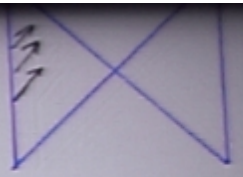
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Pirsa: 05020027

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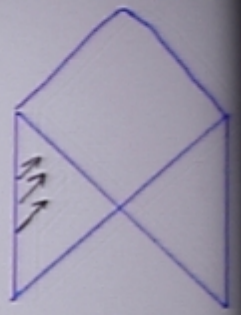
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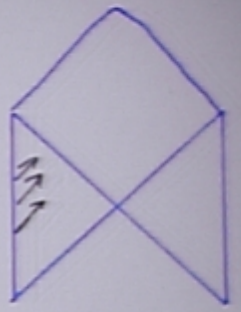
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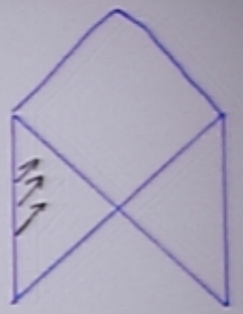
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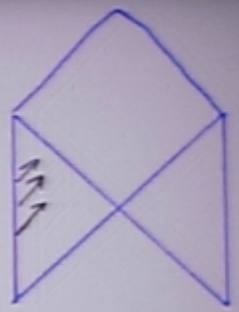
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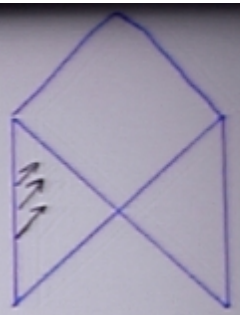
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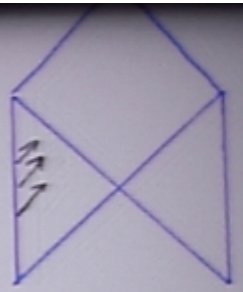
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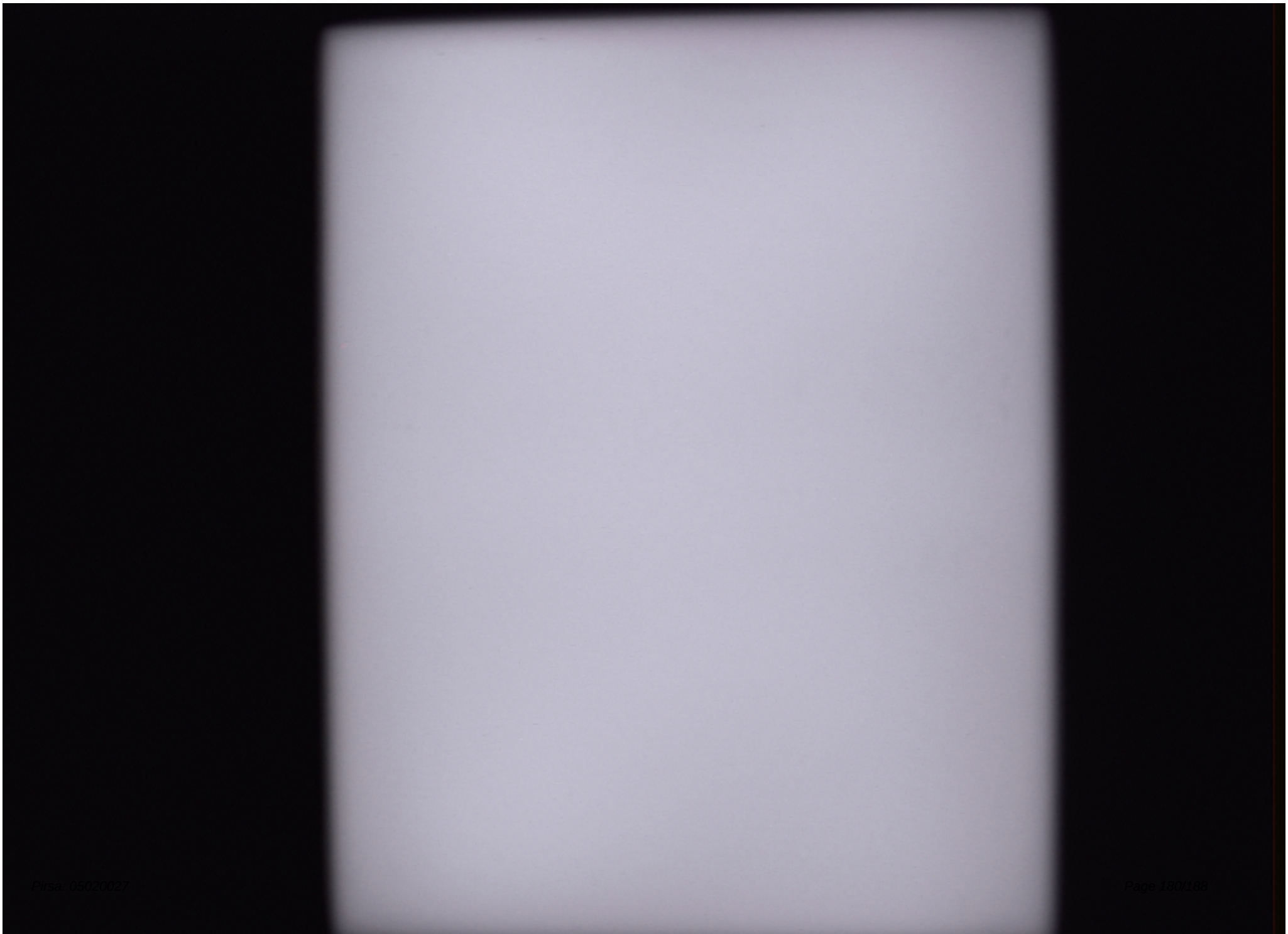
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The calculation

Add pulse perturbation, the CVS can be easily generalized to 5 dim AdS space.

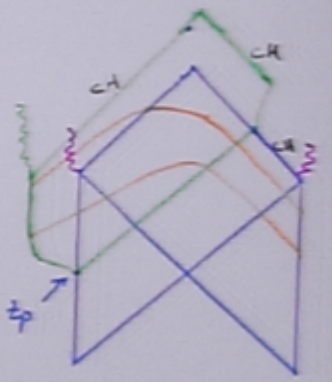
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blue - before
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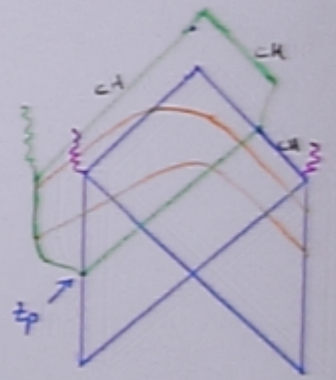
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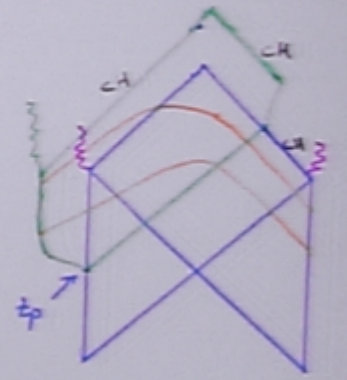
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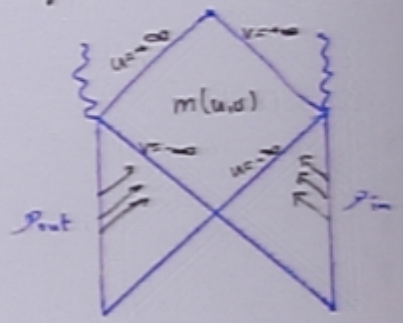


Conclusions: the next step...

- Find better correlators: trade boundary value problem for initial value one, better relation with gauge theory, easier to calculate in genuine spacetime.

- Cross flow spacetimes:

$\rho_{in}, \rho_{out} \neq c$



In Kruskal coordinates

$$ds^2 = -2e^{2\delta} du\,dv + r^2(u,v)\,d\Omega^2$$

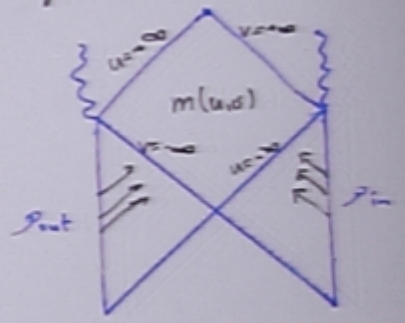
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