

TOY MODELS FOR BLACK HOLES

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TOPICS:

- GENERAL REMARKS.
- SYK
- NEARLY- AdS_2 .
- WORM HOLES

L1 A TOY MODEL FOR A BLACK HOLE:

①

- MODEL THAT CAPTURES SOME ASPECTS OF BLACK HOLES.

• MOST OF THE MODELS LOOK AT THE BLACK HOLE FROM THE OUTSIDE. AND CAN ANSWER QUESTIONS POSED FROM THE OUTSIDE.

• SIMPLE EXAMPLE: 2 BLACK HOLES ORBITING EACH OTHER



→ CAN BE REPLACED BY TWO MASSIVE PARTICLES IN FLAT SPACE + CORRECTIONS.

• WE WANT MODELS THAT CAPTURE:

• QUANTUM EFFECTS → T_H , $S = \text{ENTROPY}$ → e.g. BPS BLACK HOLE

• FALLING OBJECTS ARE ABSORBED (THERMALIZATION)

(APPARENT INFORMATION LOSS)

• EXACT UNITARY DYNAMICS FROM OUTSIDE.

• CHADS

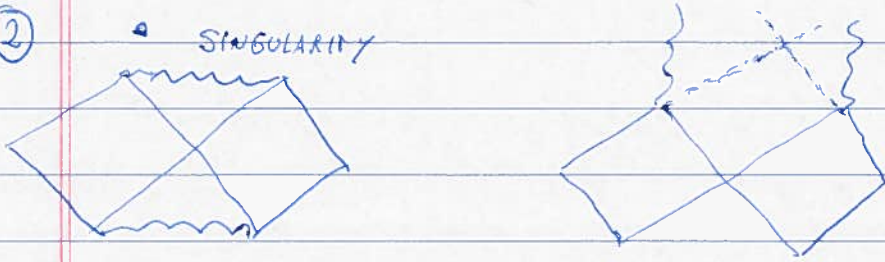
• NEAR HORIZON DYNAMICS

• LOCAL PHYSICS NEAR THE HORIZON W/ EINSTEIN GRAVITY

• UNDERSTAND THE INTERIOR & THE SINGULARITY.

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LIKE A BIG CRUNCH.

→ COULD UNDERSTAND THE BIG BANG -

WHY NOT TRY TO UNDERSTAND THE BIG BANG DIRECTLY?

→ WOULD BE GOOD

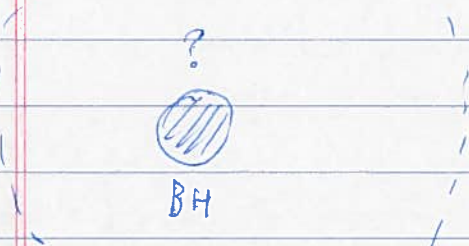
→ SEEMS VERY CONFUSING

→ ANY IDEA YOU HAVE: ASK WHETHER IT IMPLIES ANYTHING FOR COSMOLOGY !!

WHY ARE BLACK HOLES SIMPLER.?

→ FROM OUTSIDE:

→ FAR AWAY ~ "SOLID" PLATFORM", TIME IS WELL DEFINED & CONVENTIONAL QUESTIONS: - S-MATRIX - CORRELATORS.



FAR AWAY → SMALL QUANTUM EFFECTS
→ FIXED "FRAME"

L1

TOY MODEL

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- A BLACK HOLE \approx GAS OF WEAKLY INTERACTING PARTICLES. \rightarrow LARGE NUMBER, OF PARTICLE TYPES $O(N)$.
- ENTROPY IS LARGE

VASILIEW GRAVITY LIKE GRAVITY IF INTERACTIONS ARE WEAK
?



$$x^\pm = r e^{\pm \tau}$$

PERIOD $\sim \beta_\tau = 2\pi$.

TO CONVERT TO OTHER TIMES.

$$\tau \rightarrow \frac{2\pi t}{\beta}$$

PERTURBATIONS DECAY EXPONENTIALLY $\sim e^{-(\text{const})\tau}$.

IF THEY START IN THE NEAR HORIZON REGION.

(FOR ~~FLAT~~ BLACK HOLES IN FLAT SPACE WE CAN HAVE POWER LAW TAILS FROM LONG WAVELENGTH FIELDS)

\rightarrow RAPID "THERMALIZATION" \rightarrow TIME $\sim \beta$

\rightarrow THERE CAN BE A MORE COMPLICATED STORY \rightarrow ORBITING THE BLACK HOLES, ETC

L1

SYMMETRIES OF THE NEAR HORIZON GEOMETRY

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τ TRANSLATIONS \rightarrow BOOSTS.

CAN IT BE AN EXACT SYMMETRY?

\rightarrow TIME TRANSLATIONS $S \rightarrow e^{-iHt} \rho e^{iHt}$.
 (EXTERIOR) \rightarrow

\rightarrow IN TFD $\rightarrow H_R - H_L$



$$| \rangle = \sum_m | E_m \rangle | E_m \rangle e^{-E_m \beta / 2}$$

W. ISRAEL : 1976

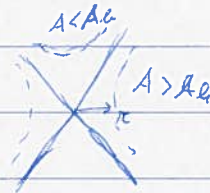
WE HAVE MORE :

APPROXIMATE TRANSLATIONS (POINCARÉ SYMMETRY)
 OF THE FLAT SPACE REGION.

\leadsto SLIGHTLY BROKEN.

\leadsto IN PARTICULAR BY THE SIZE OF THE
 TRANSVERSE DIMENSIONS (AREA)

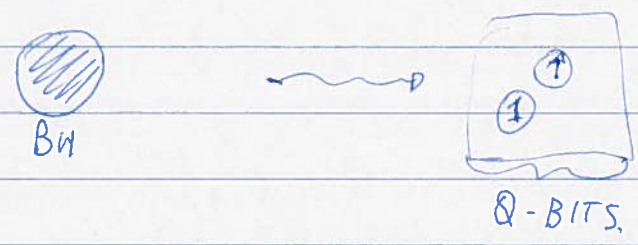
$$A = A_0 + \alpha \pi^2$$



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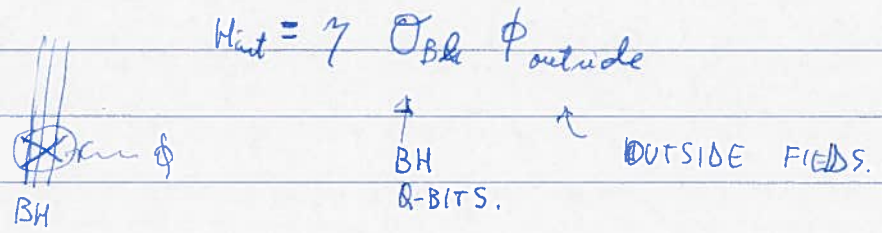
CAN WE GET AN EXACT DESCRIPTION FROM OUTSIDE?

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- CAN WE SEPARATE THE BH Q-BITS FROM THE OUTSIDE?

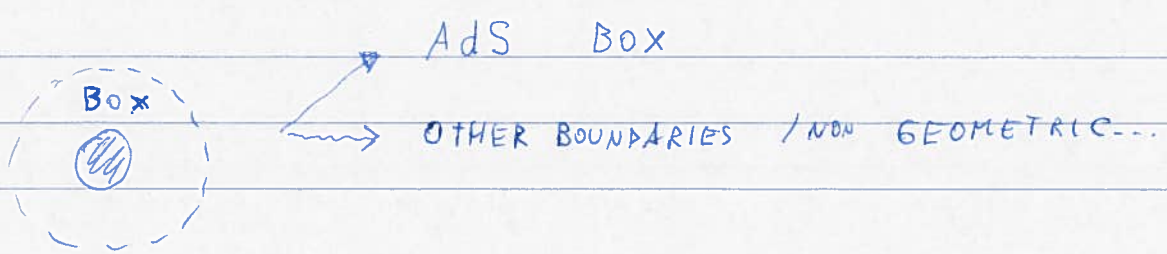
• STUFF CAN FALL IN → WE HAVE SOME COUPLING.



CORRECTIONS TO THE BH THAT ARE LARGE!

LARGE COMPARED TO LEVEL SPACINGS $\sim e^{-S}$.

→ NEED TO INCLUDE MORE OF THE SPACE AROUND OR CHANGE THE SPACETIME AROUND TO DECOUPLE THE REST.



L1

⑦ $S = \text{ENTROPY} \propto \frac{1}{G_N} \gg 1$ WHEN GRAVITY IS A GOOD APPROXIMATION.

→ HARD TO SEE ^{MICROSTATES} CLASSICALLY

$$g_{\text{eff}}^2 \propto \frac{r_s^2}{G_N} \sim \frac{1}{S}$$

. BUT "EASY" TO SEE AS A EUCLIDEAN SOLUTION.

DO WE HAVE ANY ANALOG?

MECHANICS FOR THERMODYNAMICS / HYDRODYNAMICS.

FREE ENERGY $F(T) \rightsquigarrow \begin{cases} S \\ E \end{cases}$

* LAGRANGIAN: $\mathcal{L}_E(\psi') = F(\psi')$; $\psi \sim \psi + 1$ PERIODIC VARIABLE, β FIXED PERIOD.

§ EUCLIDEAN SOLUTION.

$$\psi' = \text{CONST} \rightarrow \psi = t/\beta = \frac{T}{T} t$$

ψ -SHIFTS → SYMMETRY

$$S = \int -\frac{\partial \mathcal{L}}{\partial \psi'} = -\frac{\partial F}{\partial T}$$

NOETHER CHARGE

↓ ACTION
 $\int_0^\beta dt \mathcal{L}(\psi) = \beta F$

t -SHIFTS → ENERGY.

$$E = U = H = \mathcal{L}(\psi') - \psi' \frac{\partial \mathcal{L}}{\partial \psi'} = F + TS$$

REPRODUCES THERMODYNAMICS → NO MICROSTATES.
→ COULD CONSIDER IT IN LORENTZIAN TIME...