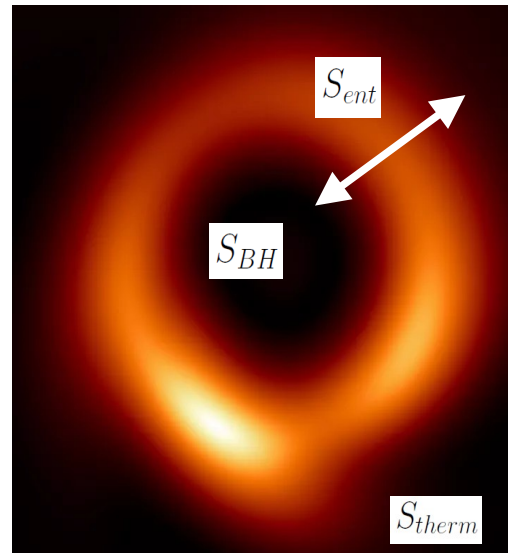


Testing quantum gravity on quantum devices

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Prague



INFN meeting
Quantum Architectures for Analogs and Theory Applications
Trento - February 13th, 2024

PLAN

- * **General strategy:** the road to HELIOS
 - analogies and equivalences
 - the smoking guns of quantum gravity
- * **Focus (theory):** fermions in low d
 - $(2+1)d$ analogy: graphene
 - $(1+1)d$ equivalence: SYK/JT
- * **Focus (experiments):** hyperbolic lattices for
 - $(2+1)d$ analogy: improved graphene
 - $(1+1)d$ equivalence: the JT side of SYK/JT
- * **Roadmap**

* General strategy: the road to HELIOS

Analogies are useful, but have limitations.

H rad from Analog BHs (**S**) is genuine, but it does not prove that Astro BHs (**T**) emit H rad. Experiments are not confirmatory.

We need:

- to 'simulate' a physical system not a theory;
- full dynamical **equivalence**: *same action/Hamiltonian, same vacuum structure, same SSB.*

Candidates for correspondence/equivalence: SYK(**S**) / JT(**T**).

Indirect experiments could eventually become confirmatory.

To test **nonunitarity** we need quantum devices that allow for many vacua.

(E.g., Unruh-Wald for QG and Umezawa for framework).

Such Unconventional QC can settle open questions.

E.g., do neutrino oscillations obey Pontecorvo formula (one vacuum) or QFT-based formulae (two vacua)?

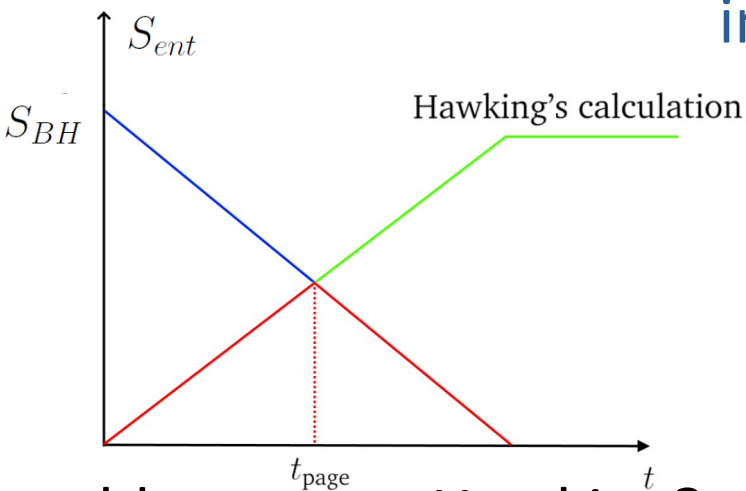
$$\begin{aligned} & \langle \alpha_{k,e}^r(t) | N_{\alpha_e}^{k,r} | \alpha_{k,e}^r(t) \rangle \\ &= 1 - \sin^2 \theta \underbrace{|V_k|^2}_{\mathbf{0}} - \underbrace{|U_k|^2}_{\mathbf{1}} \sin^2 2\theta \sin^2 \left(\frac{\Delta\omega_k}{2} t \right) \end{aligned}$$

W Unruh, R Wald, 1703.02140.

H Umezawa, *Advanced field theory*, AIP 1993.

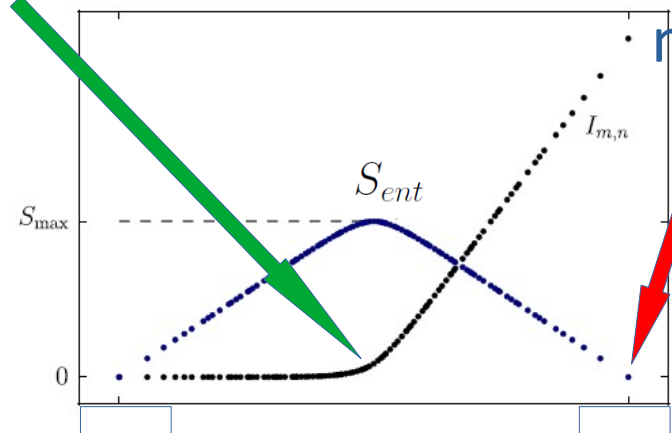
E Alfinito, M Blasone, A I, G Vitiello, hep-ph/9510213.

- smoking guns of QG



info leaking

BH death, no residue



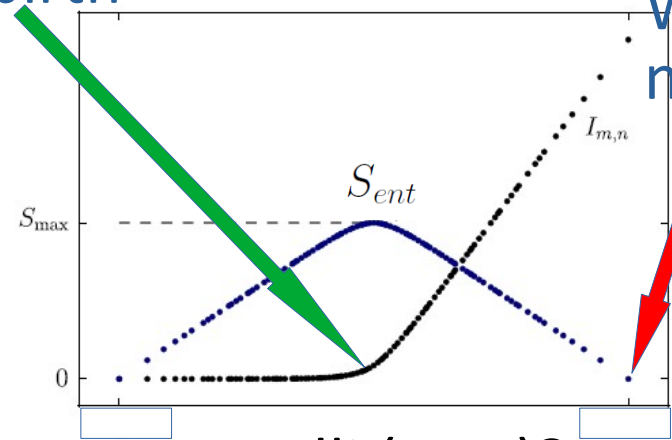
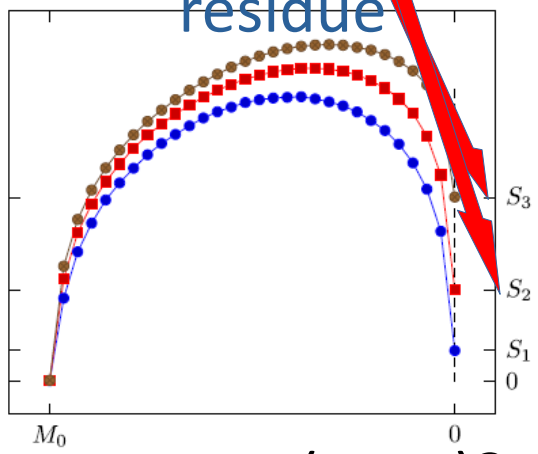
old or young Hawking?

Page ('central dogma')?

BH death, residue

BH death/WH birth

WH death, no residue



new Page (Xons)?

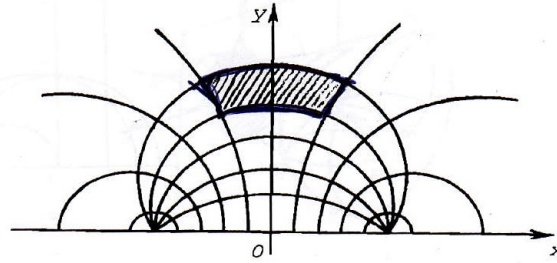
Rovelli (LQG)?

... ?

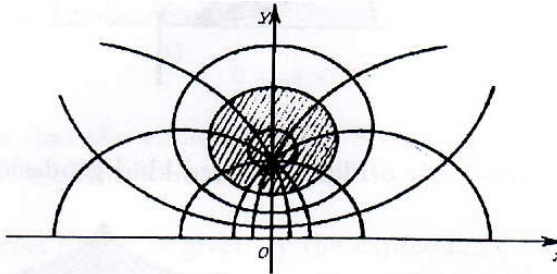
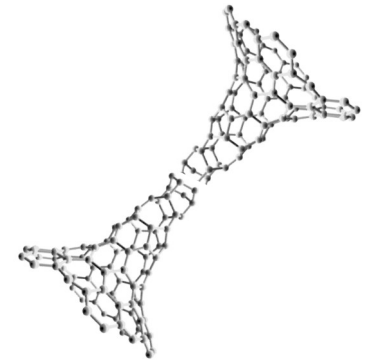
* Focus (theory): (2+1)d analogy, graphene

Shape graphene as shown. **Conformal** symmetry and **Lobachevsky** geometry tell us that the **Dirac** quasi-particles, the π -electrons, leave in (portions of) interesting (2+1)d spacetimes.

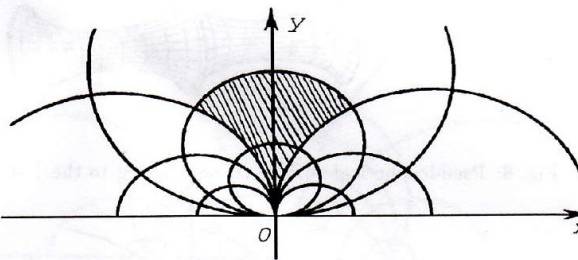
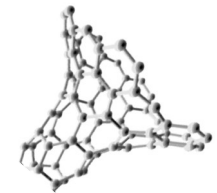
Realization of QFT in curved space.



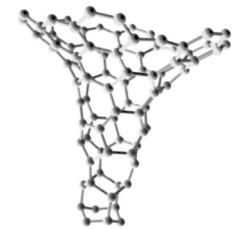
BTZ



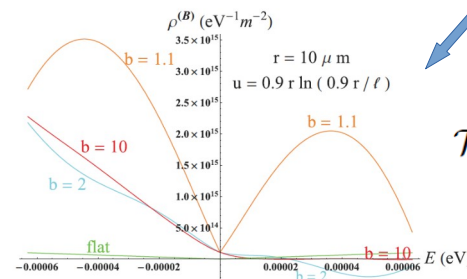
de Sitter



Rindler



⋮



$$\mathcal{T}(r \ln(r/\ell)) = \frac{\hbar v_F}{k_B} \frac{1}{2\pi r}$$

Hawking T

Focus (theory): (1+1)d equivalence, SYK/JT

$$H_4 = \frac{1}{(2N)^{3/2}} \sum_{i,j,k,l=1}^N U_{ij;kl} c_i^\dagger c_j^\dagger c_k c_l$$

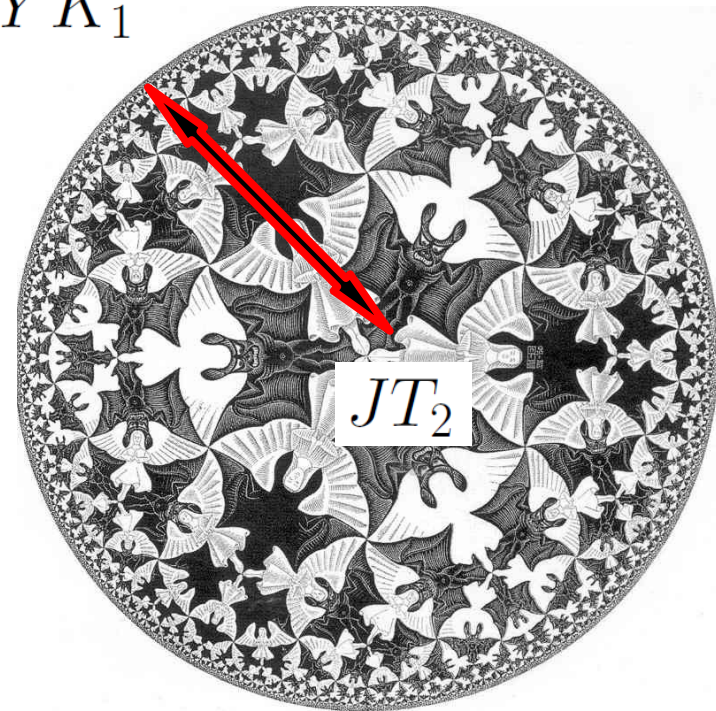
large N \longleftrightarrow small E

$$-\frac{1}{16\pi G_N} \int_{\mathcal{M}} d^2x \sqrt{g} \Phi (R - \Lambda)$$

$$ds^2 = V(r) dt^2 - \frac{1}{V(r)} dr^2$$

with $V(r_h) = 0$ and $T = V'(r_h)/(4\pi)$

*SYK*₁



SL(2, *R*)

G Sarosi, 1711.08482. Sachdev et al, 2109.05037.

A. Kitaev, <http://online.kitp.ucsb.edu/online/entangled15/kitaev/>;

<http://online.kitp.ucsb.edu/online/entangled15/kitaev2/>.

Good candidate for a full equivalence.

On both sides:

same SSB (full conf $\rightarrow SL(2, R)$)

same vacuum structure

same action

$$I_{\text{Schw}}[\phi] = -\frac{1}{g} \int d\tau \text{Schw}\{\tan(\phi/2), \tau\} \leftarrow$$

with $\text{Schw}\{f, t\} = f'''/f' - \frac{3}{2} (f''/f)^2$

(many ingredients common to graphene analog:

conformal symmetry

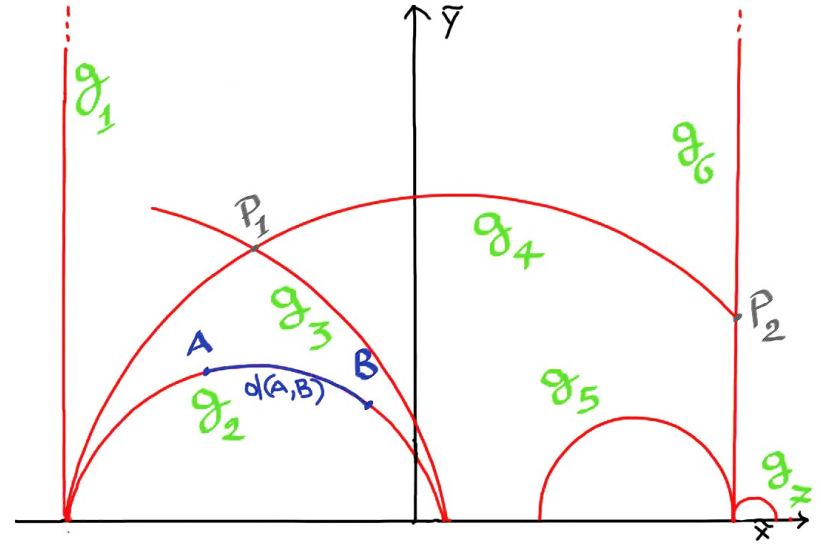
fermions

Lobachevsky geometry

low d)

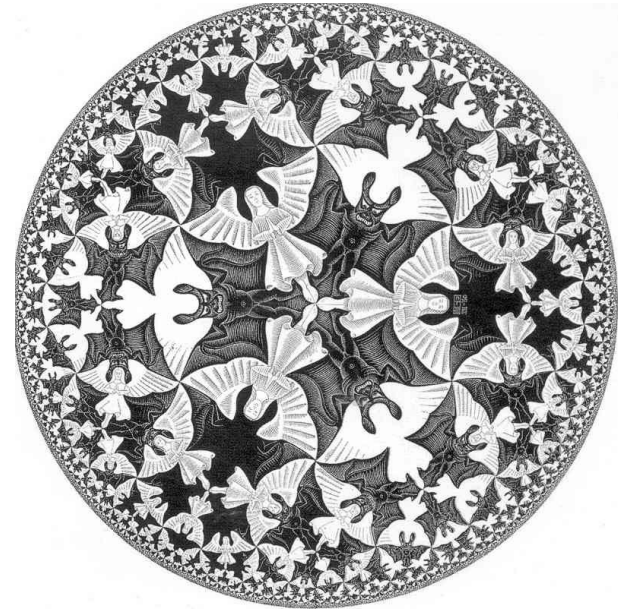
* Focus (experiments): hyperbolic lattices

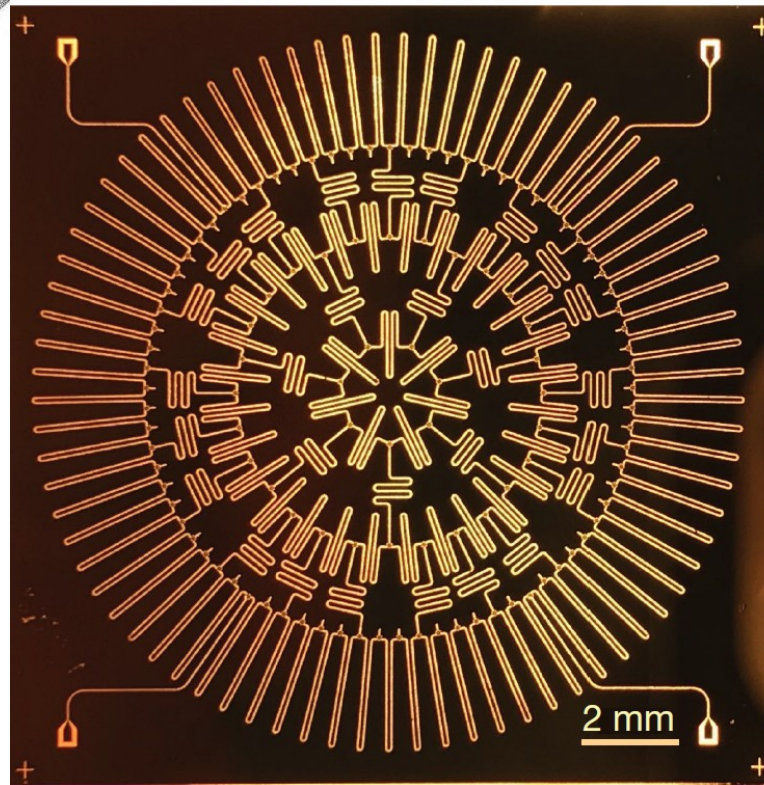
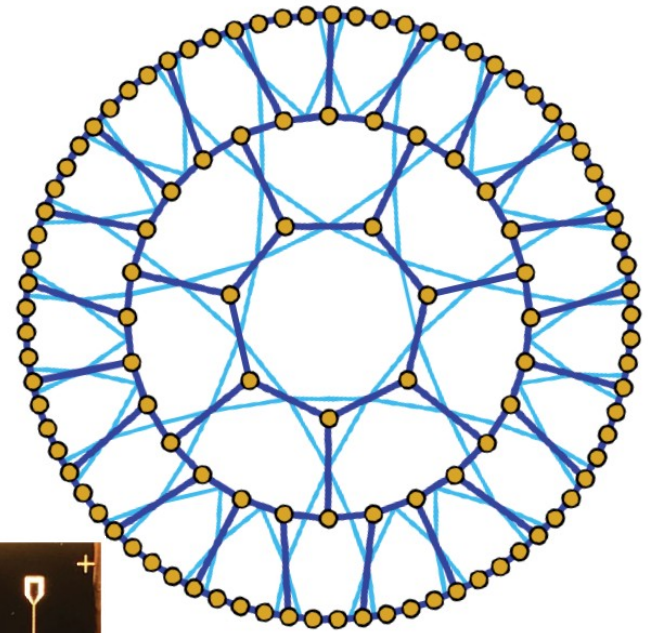
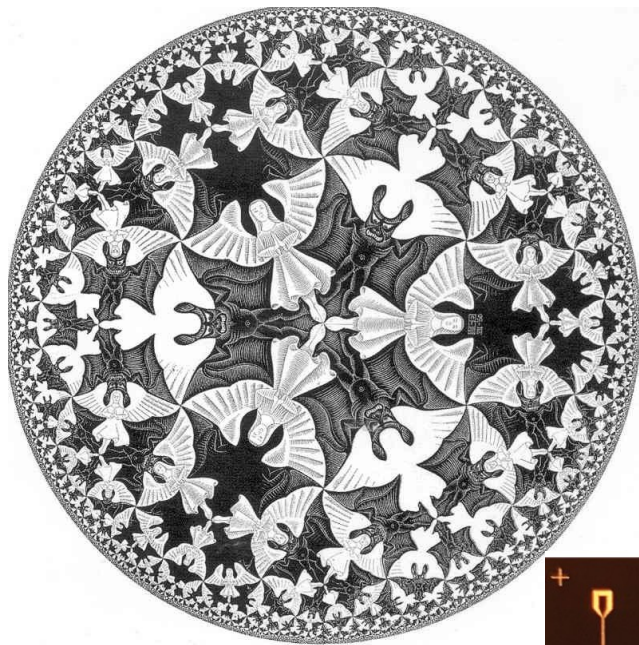
$$dl^2 = \frac{1}{\tilde{y}^2}(d\tilde{x}^2 + d\tilde{y}^2)$$



Lobachevsky geometry

$$dl^2 = \frac{d\tilde{x}^2 + d\tilde{y}^2}{(1 - \tilde{x}^2 - \tilde{y}^2)^2}$$





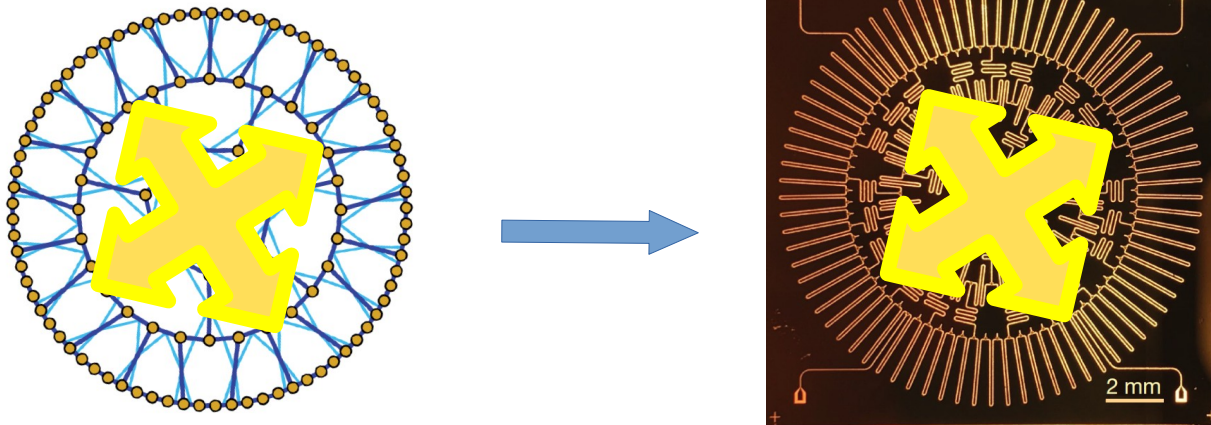
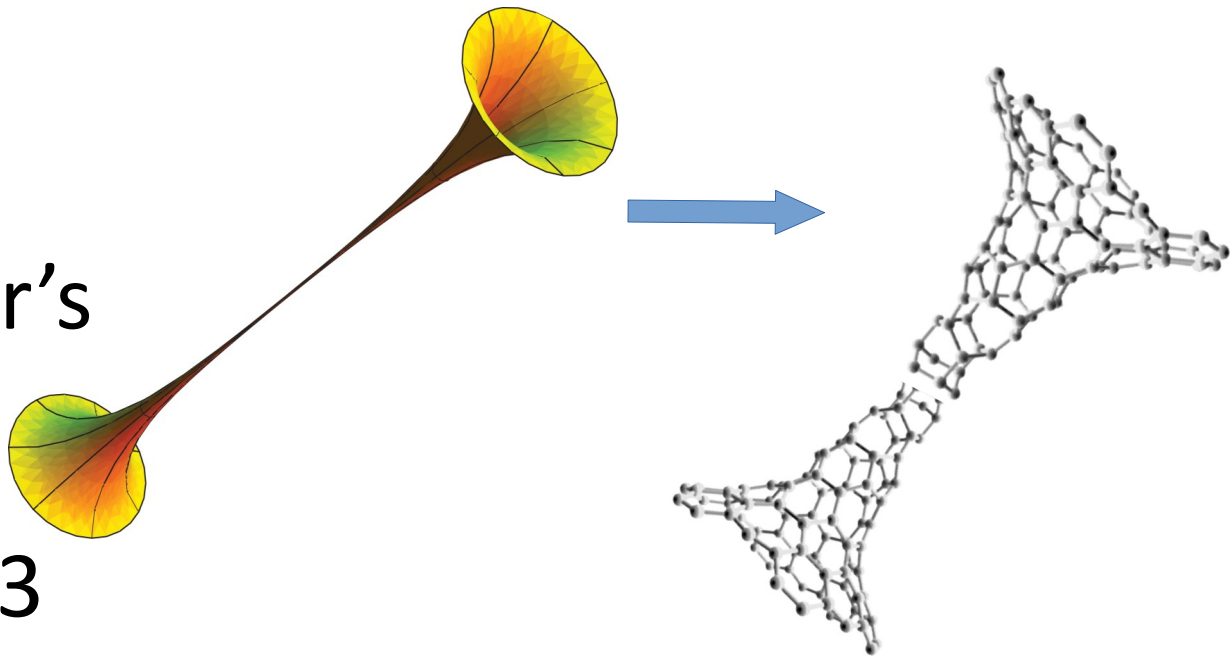
A J Kollár, M Fitzpatrick and A A Houck, Nature 571 (2019) 45.

- (2+1)d analogy: improved graphene

Dirac/other fields on (full!) BTZ BH spacetime!

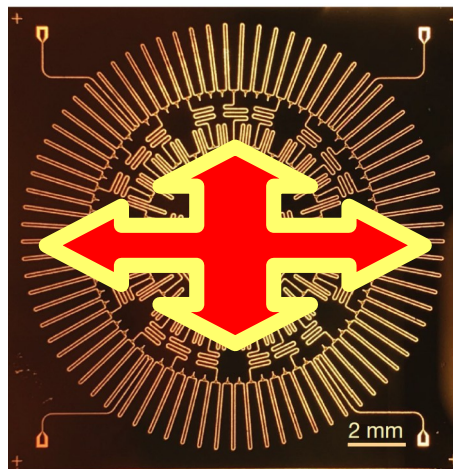
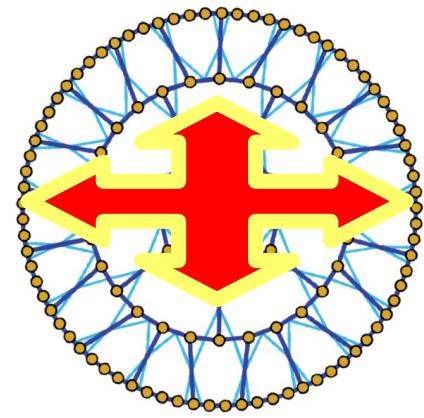
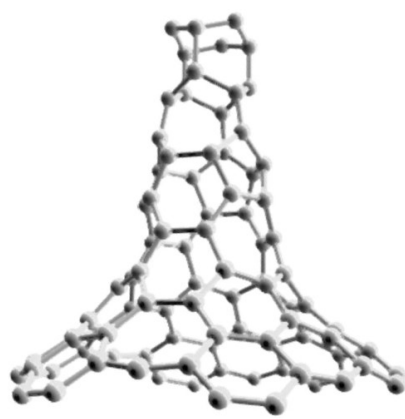
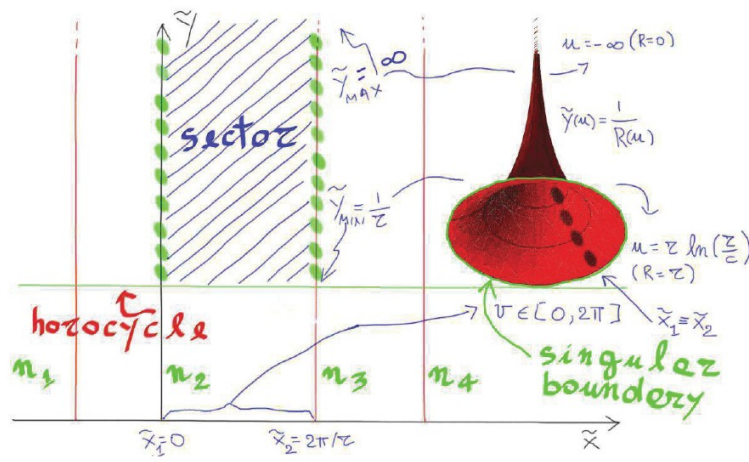
“The BTZ is the result of a tailor’s work”, Jorge Z.

Identifications turn trivial AdS3 into BTZ.

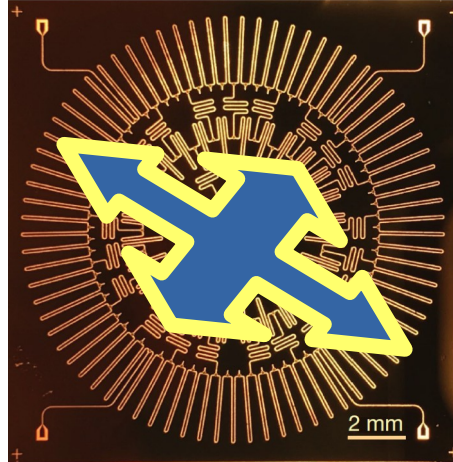
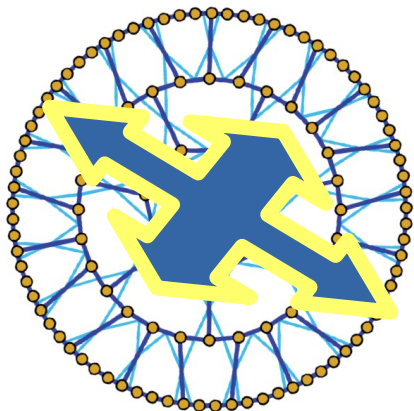
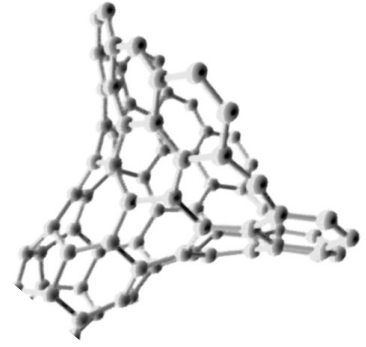
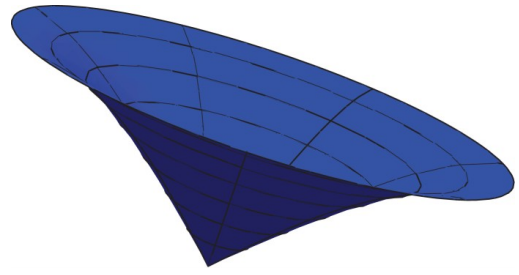


A I, V Tynianska, in progress.

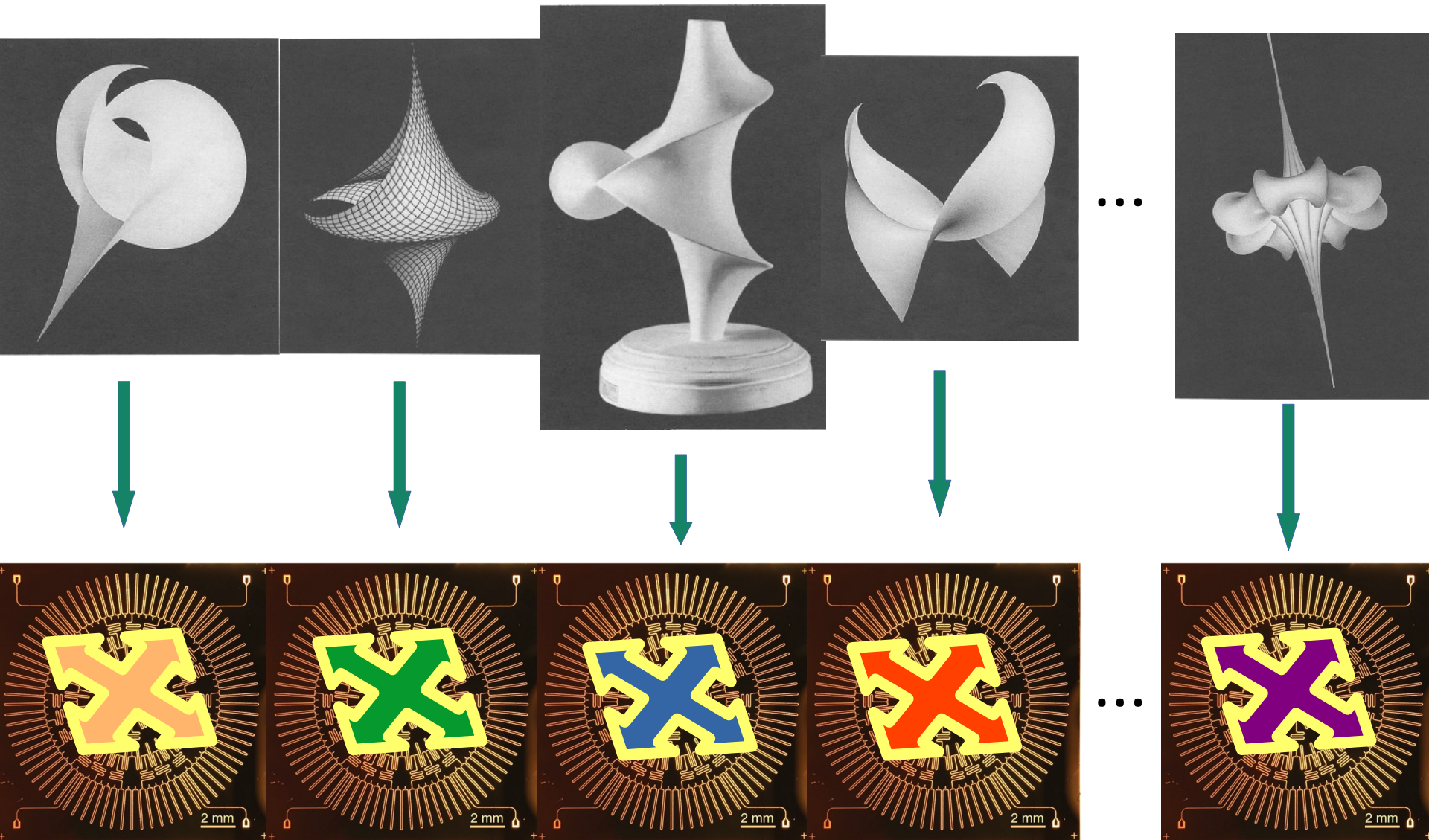
Dirac/other fields in (full!) Rindler spacetime.



Dirac/other fields in (full!) de Sitter spacetime.



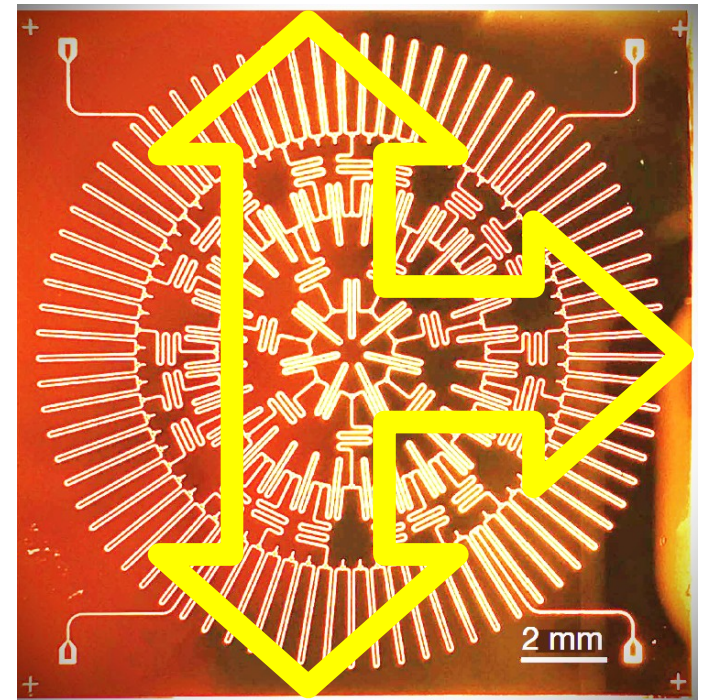
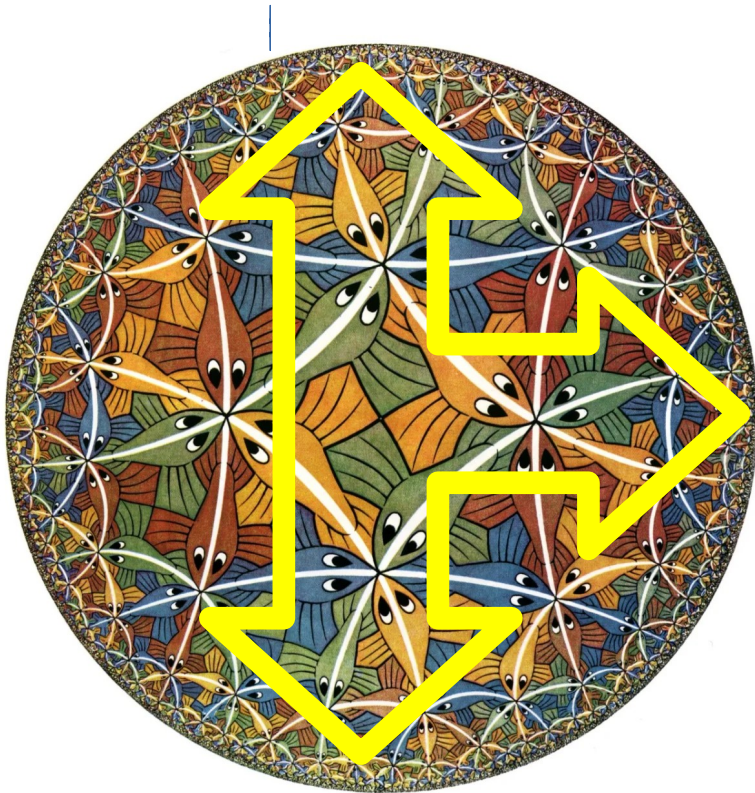
A factory of (2+1)d QFTs in curved spaces.



- (1+1)d equivalence: the JT side

Use the know-how built for the BTZ.

Engineer a novel hyperbolic lattice.



A I, P Pais, in progress.
P Castorina, D Grumiller, A I, in progress.

With this we should:

realize a JT BH

obtain the emergence of $I_{\text{Schw}}[\phi]$

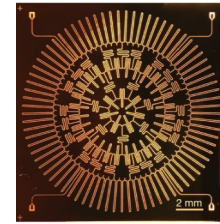
together with results from SYK, test AdS/CFT

implement the JT BH evaporation
(till t Page, then full?)

realize a (1+1)d BH factory

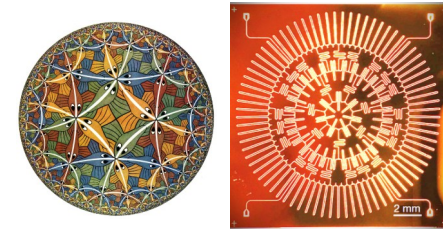
* Roadmap

- (e) build the “magic” circuit



- (t,e) realize the BTZ BH + the QFTinCS factory

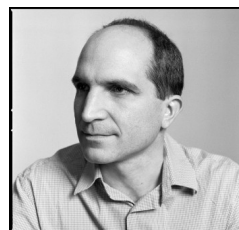
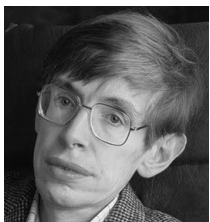
- (t,e) build new (hyperbolic) lattices



- (t,e) realize the JT BH

...

- (e) eventually decide who is right:



... ?