Putting String Theory to Work

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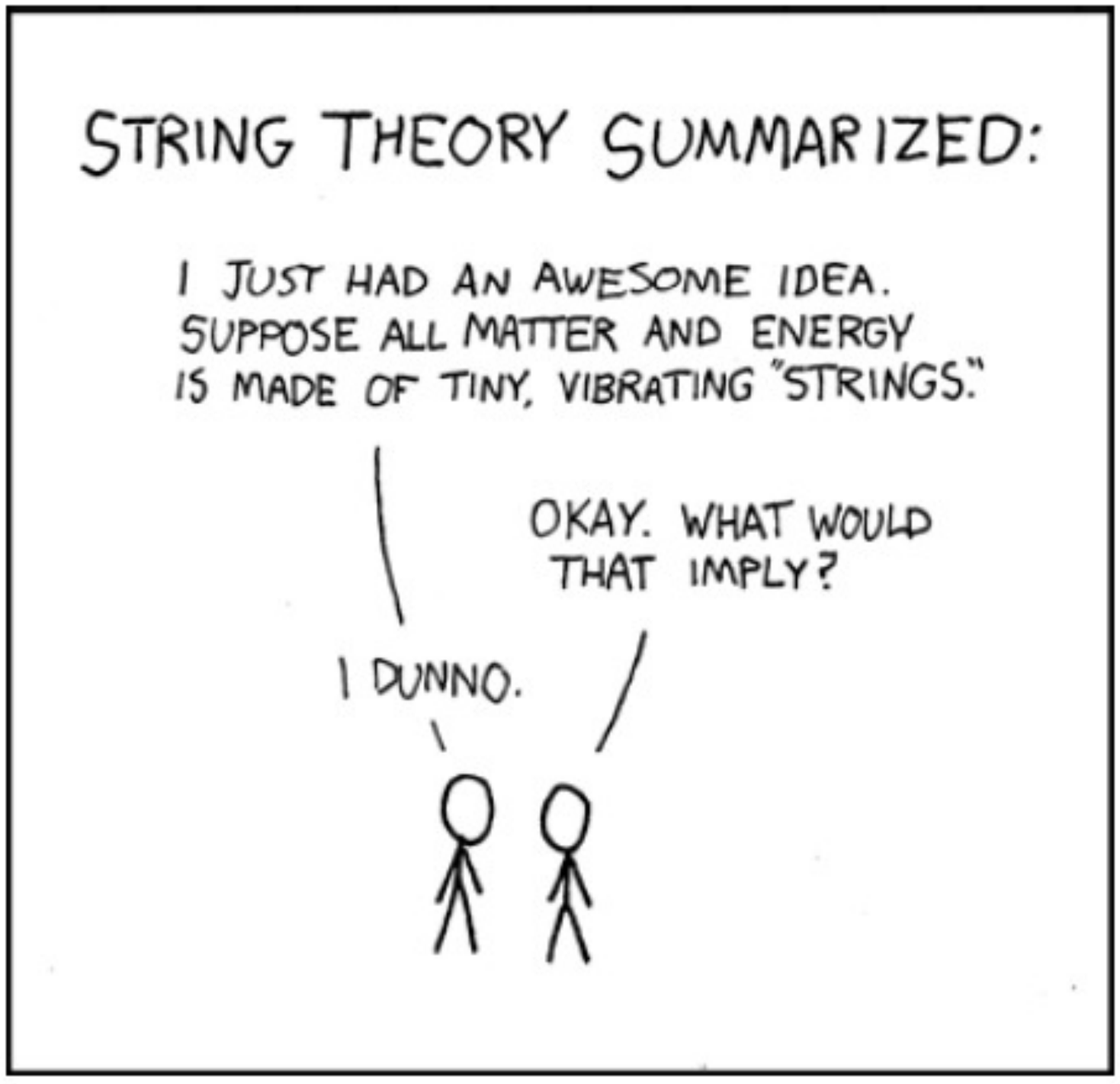
String Theory


STRING THEORY SUMMARIZED:
I JUST HAD AN AWESOME IDEA. SUPPOSE ALL MATTER AND ENERGY IS MADE OF TINY, VIBRATING "STRINGS."
OKAY. WHAT WOULD THAT IMPLY?
I DUNNO.

xkcd.com

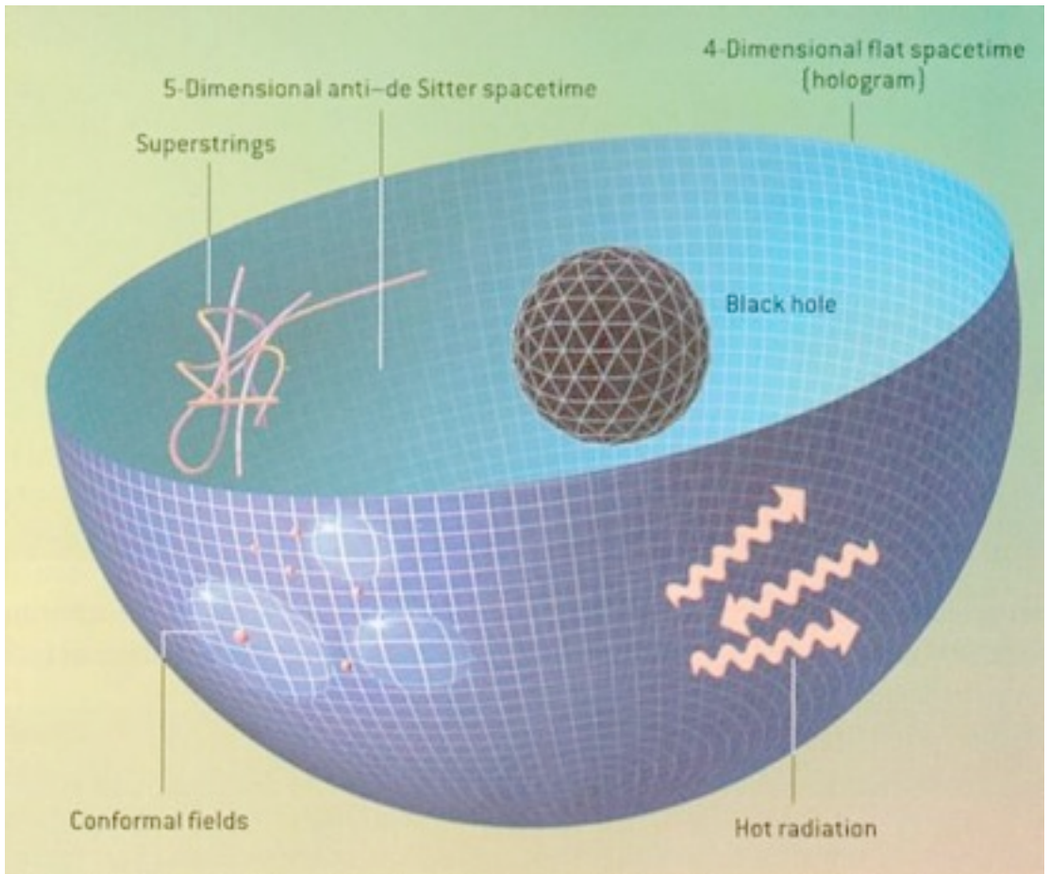
The Basics of AdS/CFT

The AdS/CFT Correspondence

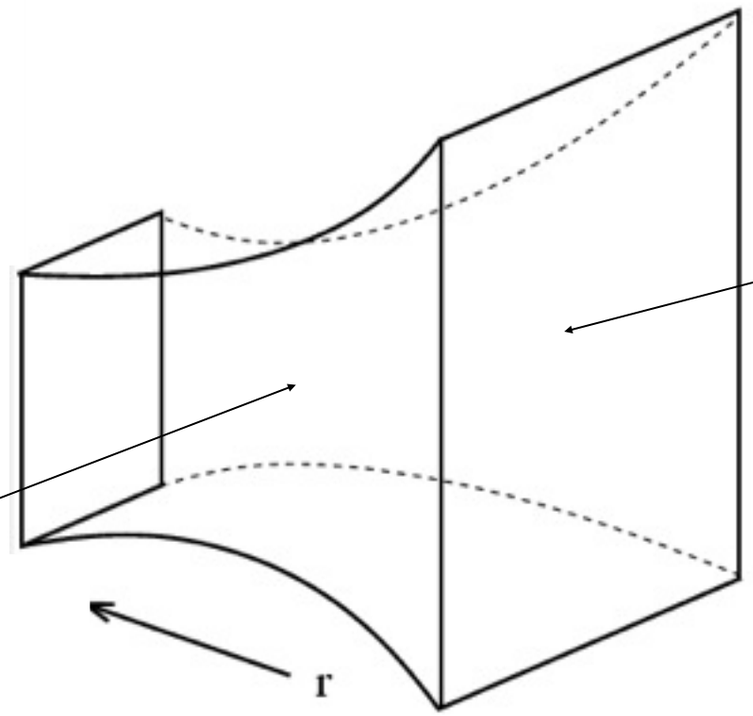
Strongly interacting QFT
in d-dimensions

$\Longleftrightarrow$

General relativity in (at least)
(d+1)-dimensions



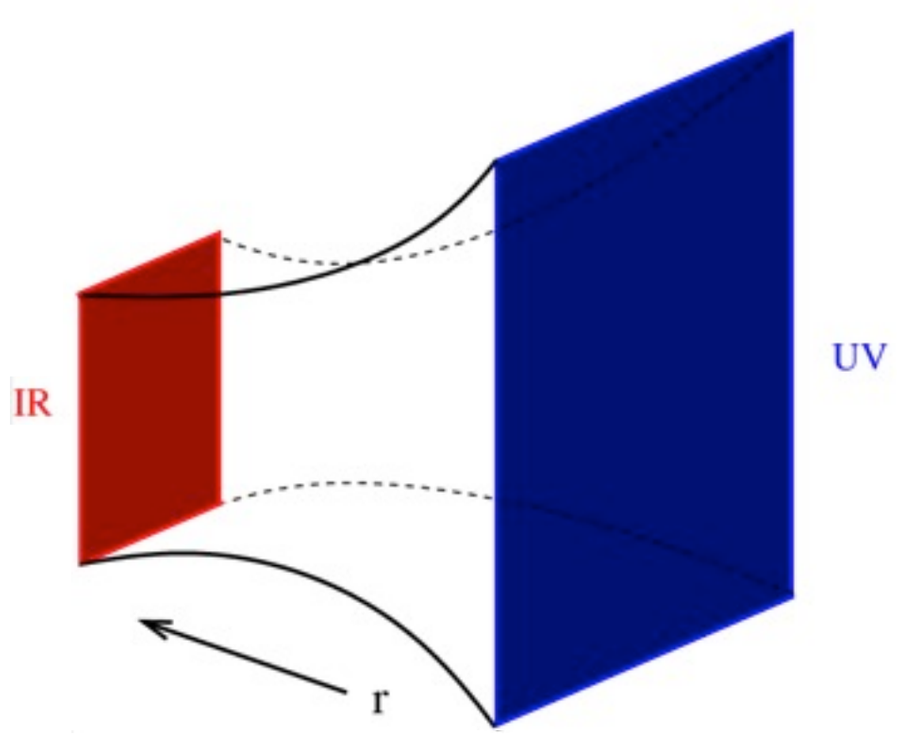
The AdS/CFT Correspondence



$$ds^2 = \frac{L^2}{r^2}\left(dr^2 + \eta_{\mu\nu}dx^\mu dx^\nu\right)$$

[G,R]=0

- The extra direction, r, should be thought of as *energy scale*.
- Objects occurring on different scales live in different *r*-slices of bulk
- AdS/CFT is the geometrization of Wilsonian RG flow.



Generating Function

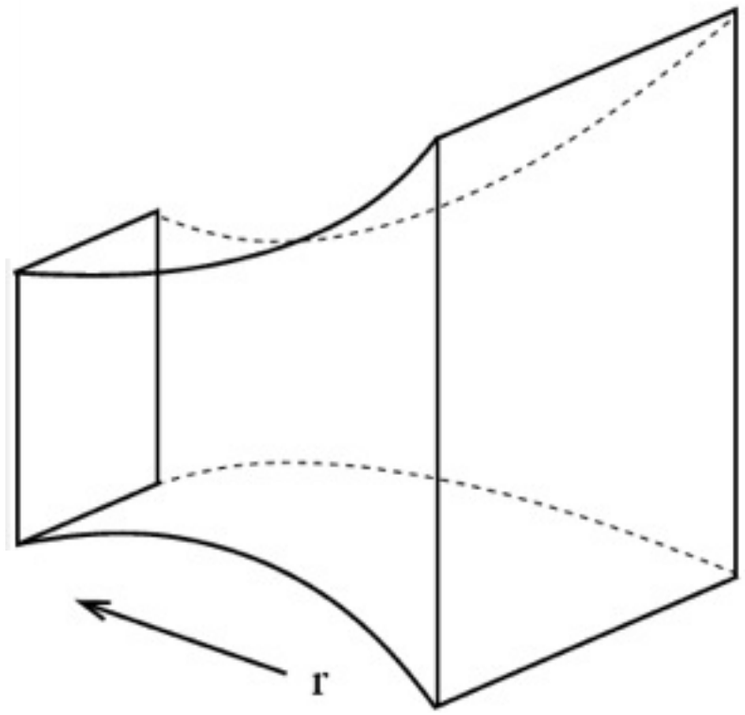
$$Z_{\mathrm{QFT}}[\phi_0] = \int \mathcal{D}A \exp\left(\frac{i}{\hbar} S_{\mathrm{QFT}}[A] + \phi_0 \mathcal{O}(A)\right)$$

source

operator

Idea: Make the Sources Come Alive

$$\phi(\vec{x}, r) \rightarrow \phi_0(\vec{x})$$



How to Calculate: GKPW Formula

(Gubser, Klebanov, Polyakov; Witten)

$$Z_{\mathrm{QFT}}[\phi_0] = e^{iS_{\mathrm{Gravity}}(\phi)}\Big|_{\phi\to\phi_0}$$

on-shell action for AdS bulk

boundary conditions

AdS/CFT Will Not Solve Your Favourite Theory

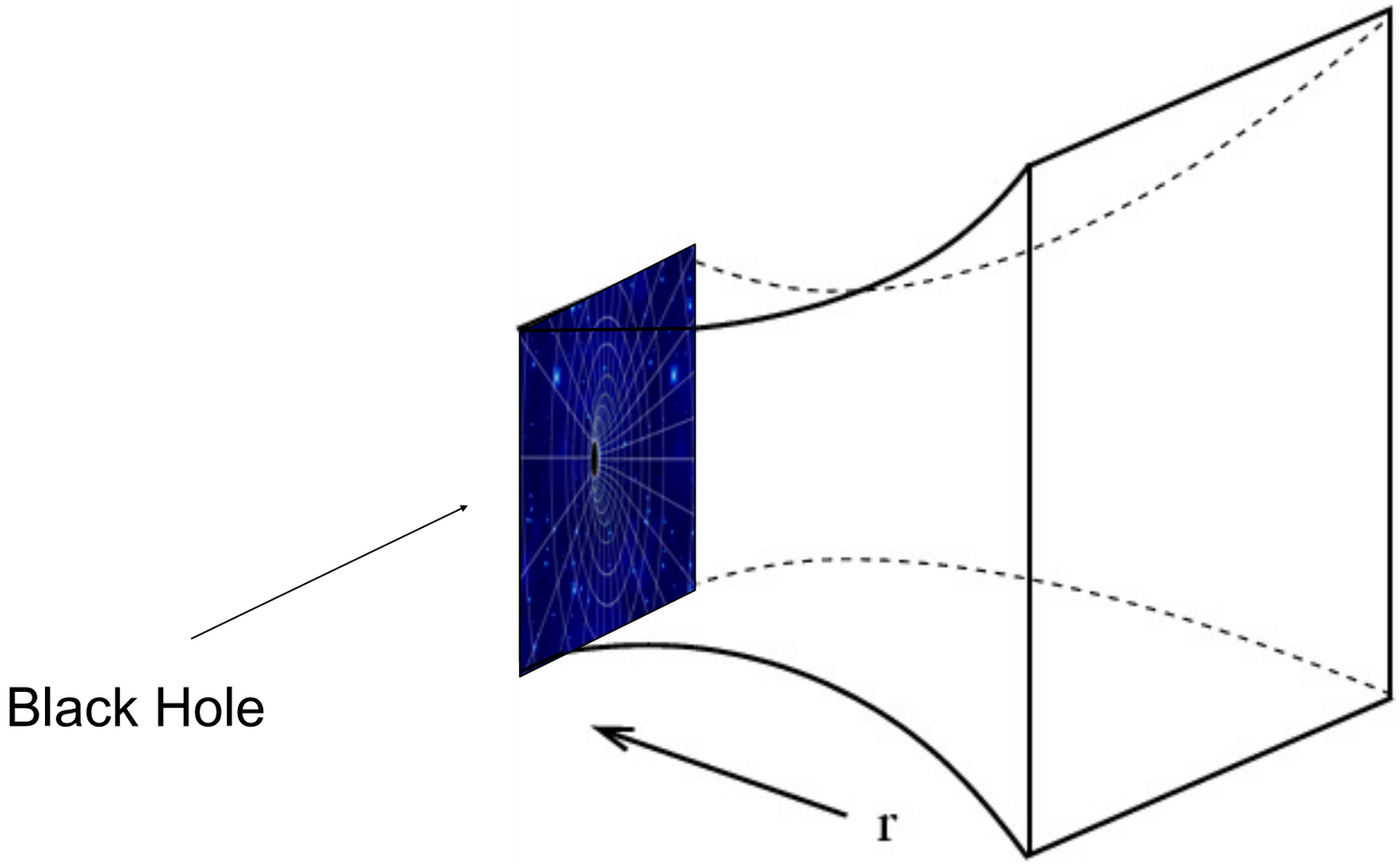
- Tricky Part: Find the map

$$S_{\mathrm{QFT}} :\to S_{\mathrm{gravity}}$$

- We have several well explored examples, but no proof.
  - e.g. Maximally supersymmetric Yang-Mills = IIB string theory on $\mathrm{AdS}_5 \times \mathrm{S}^5$

- To make progress: use gravity to *define* the boundary theory
  - Tractable class of strongly interacting theories
  - We can ask the question: "*What can strongly interacting matter do?"*

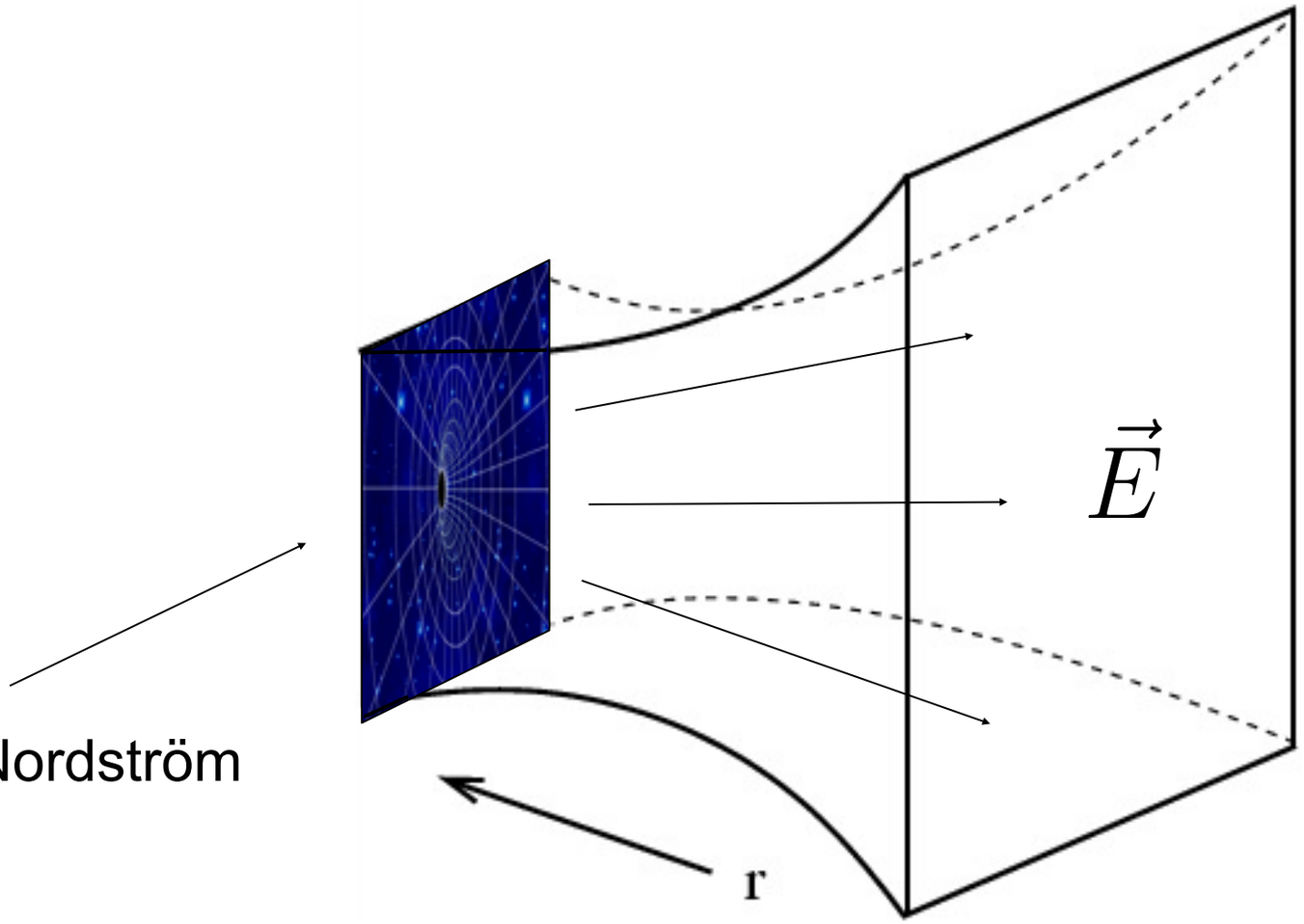
Finite Temperature



Boundary theory at
Hawking temperature, *T*

Euclidean and *Lorentzian* signatures

Finite Density



Reissner-Nordström
Black Hole

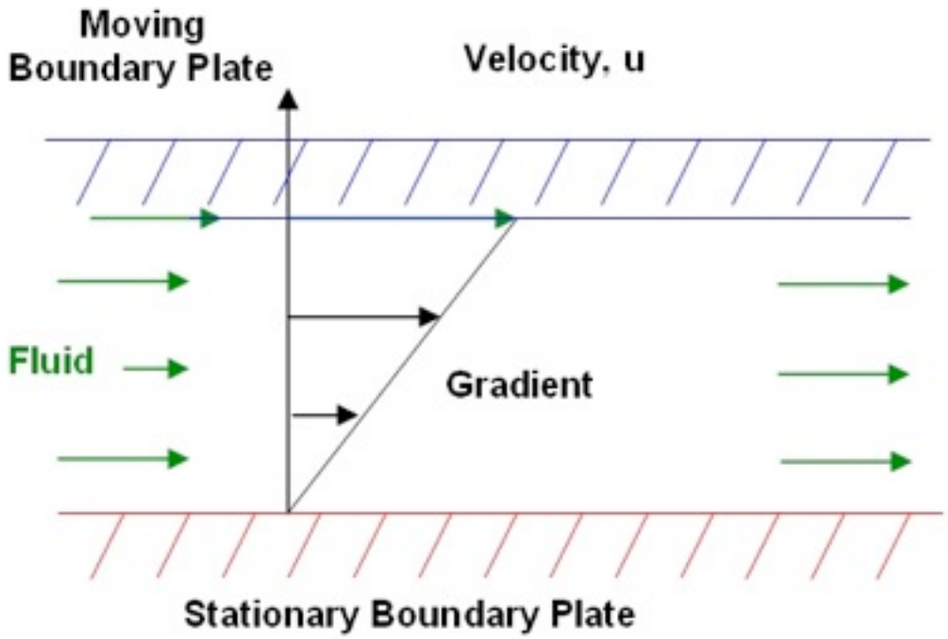
Temperature, *T*
Chemical Potential, μ

What's it Good For?

Transport

Shear Viscosity

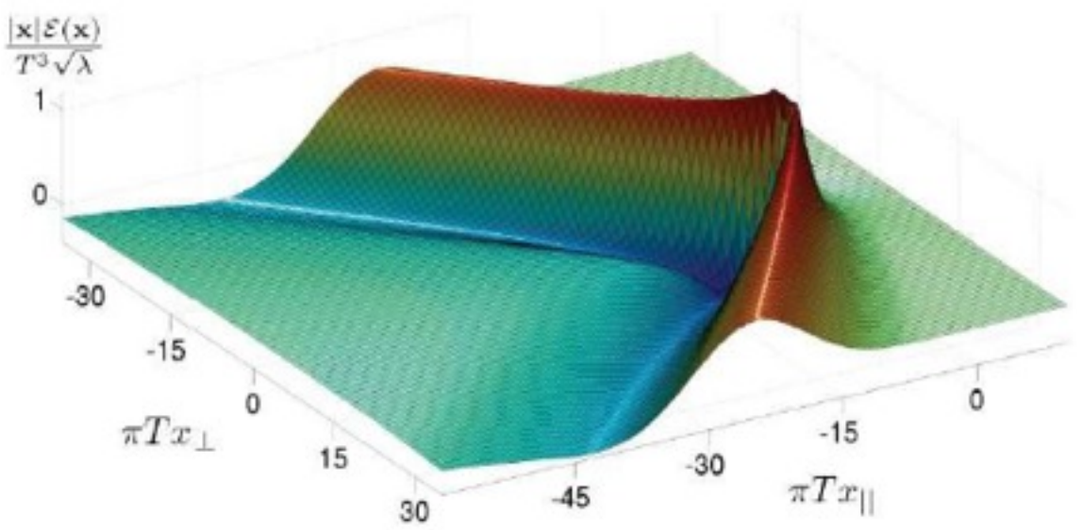
Kovtun, Policastro, Son, Starinets



$$\frac{\eta}{s} = \frac{1}{4\pi}\frac{\hbar}{k_B}$$

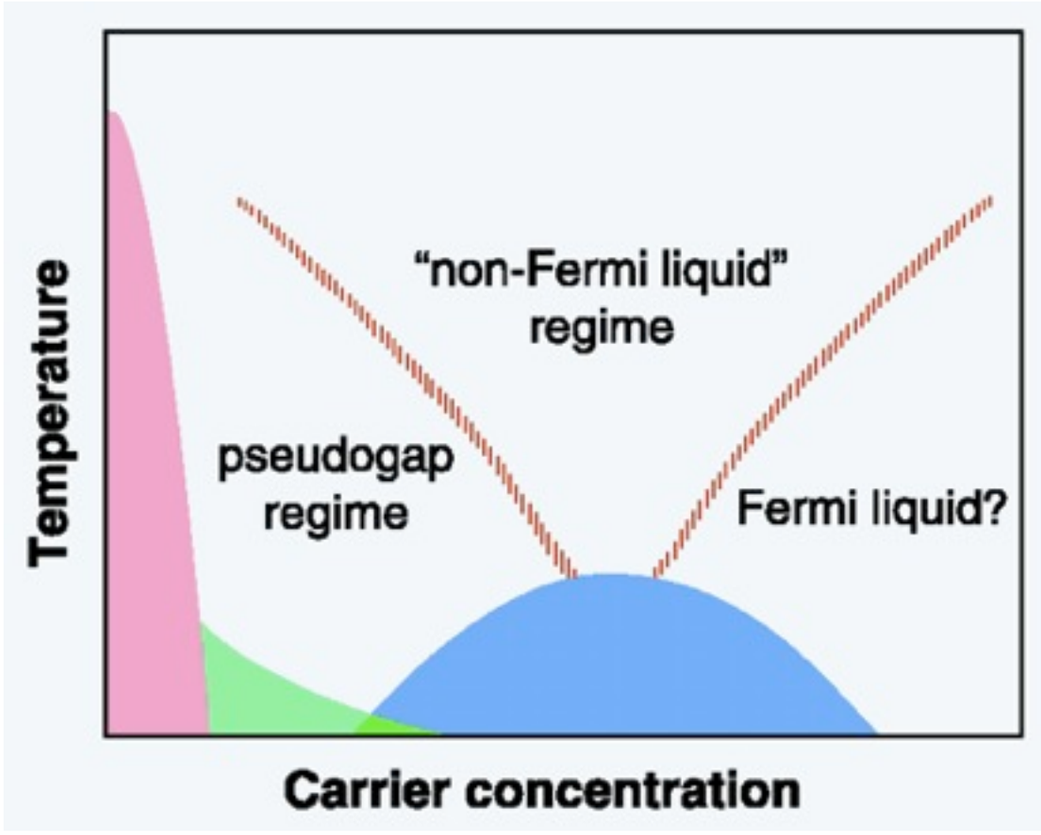
Application to Quark Gluon Plasma

Jet Quenching vs String Dragging



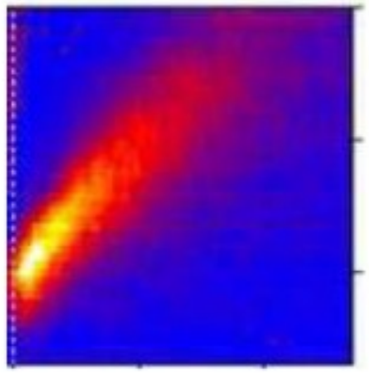
Gubser et al, Seattle Group

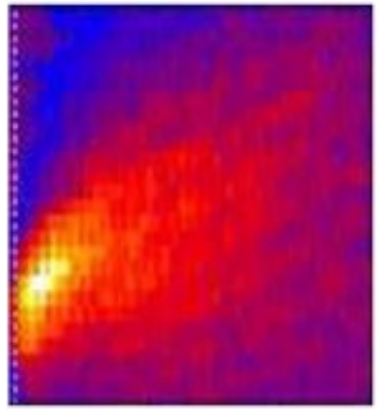
Application to Strange Metals



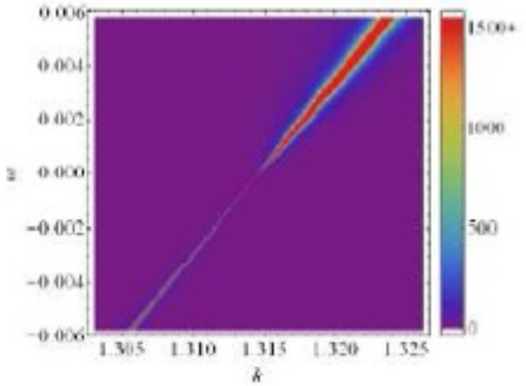
Non-Fermi Liquid

Schalm, Zaanen et al (Leiden)
Liu, McGreevy et al. (MIT)
de Boer, Verlinde et al. (Amsterdam)

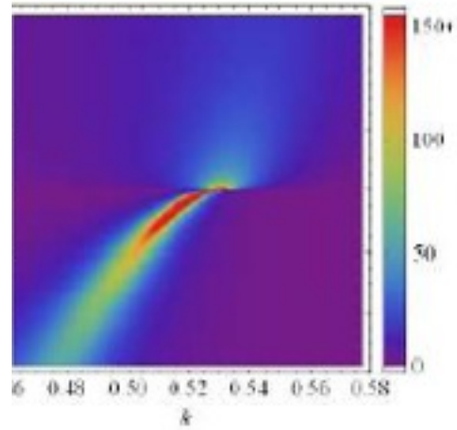




energy



momentum



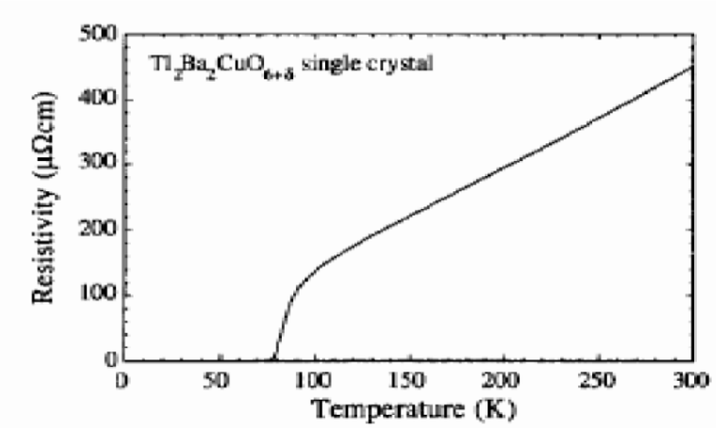
Landau Fermi Liquid: $\Gamma \sim \omega^2$

Non-Fermi Liquid: $\Gamma \sim \omega^{2\nu}$

Anomalous Conductivities

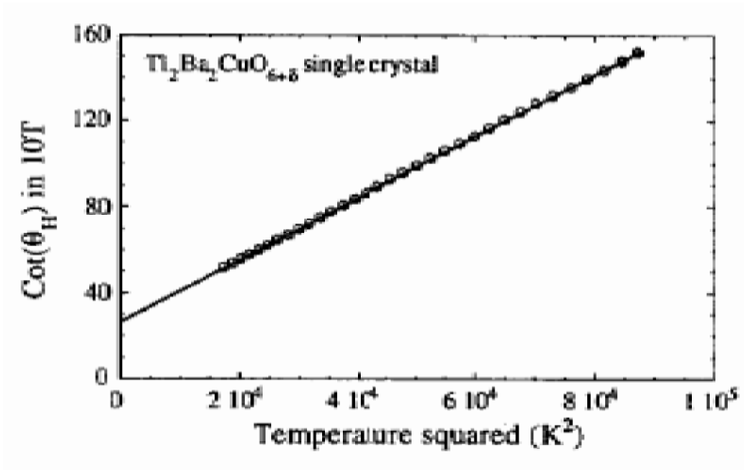
DC Resistivity: $\rho \sim T$

(Expect $\rho \sim T^2$)



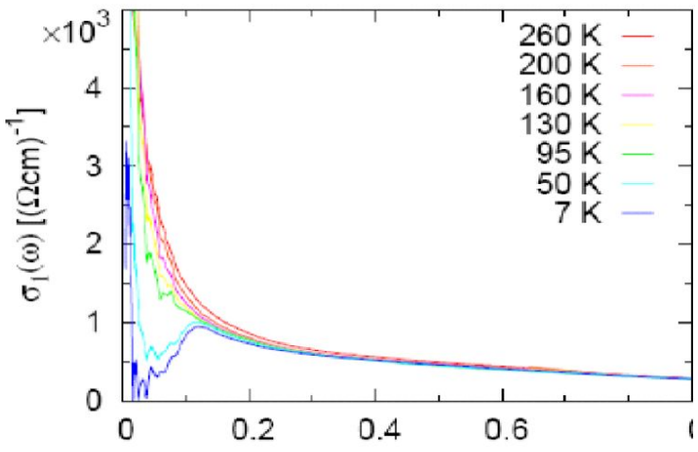
Hall Conductivity: $\frac{\sigma_{xx}}{\sigma_{xy}} \sim T^2$

(Expect $\frac{\sigma_{xx}}{\sigma_{xy}} \sim \rho$)



Optical Conductivity: $\sigma(\omega) \sim (i/\omega)^{0.65}$

(Expect $\sigma(\omega) \sim (i/\omega)$)



Mackenzie; van der Marel et al.

Conductivities from Lifshitz Scaling

Lifshitz Scaling: $\vec{x} \to \lambda \vec{x}$

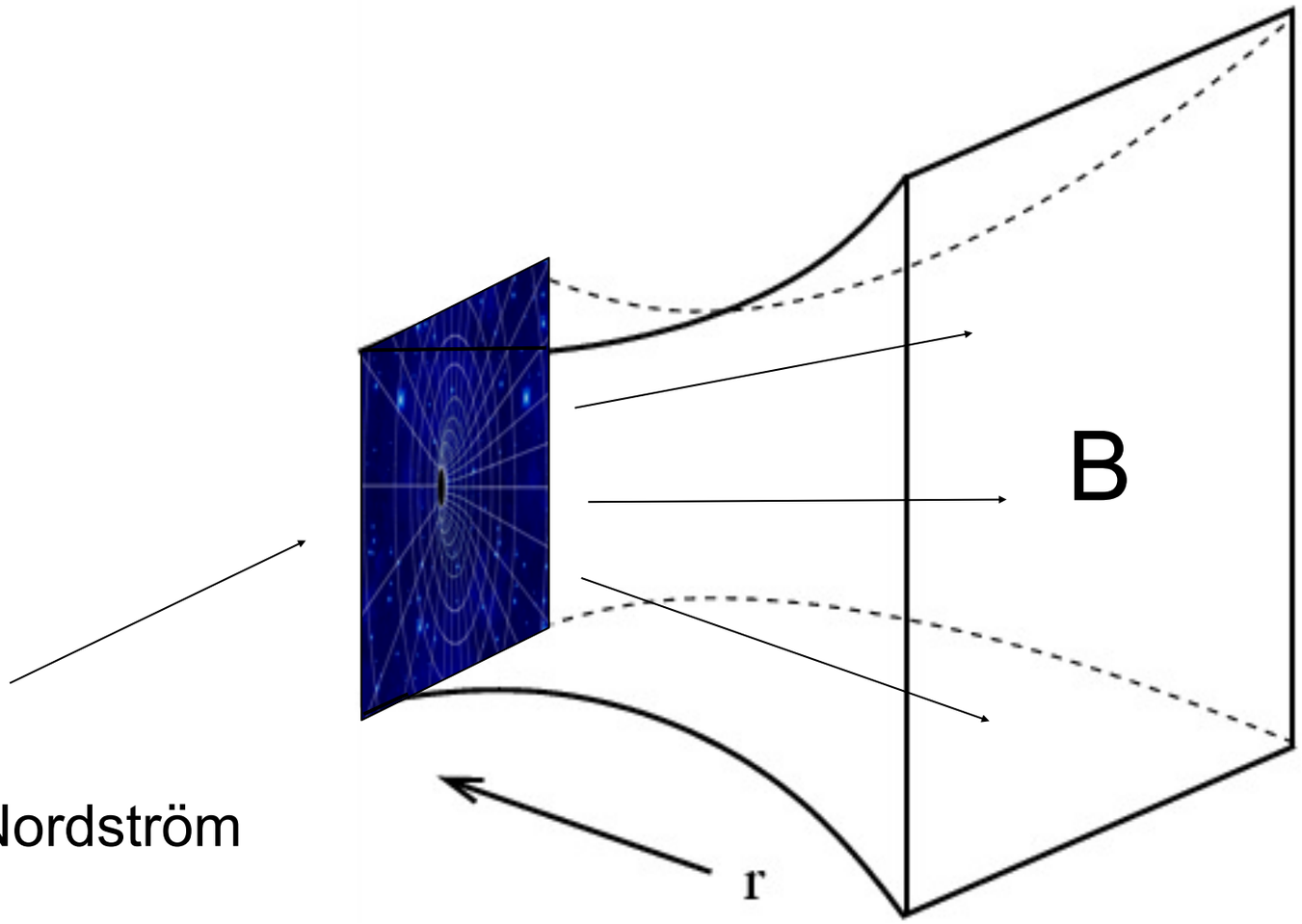
$t \to \lambda^z t$

$$\sigma(\omega) \sim \begin{cases} \rho^{z/2}\,(i/\omega) & z < 2 \\ \rho\,(i/\omega)^{2/z} & z > 2 \end{cases}$$

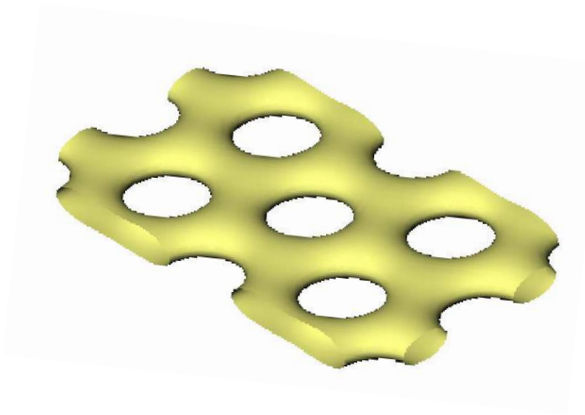
z=3 consistent with data, but....

Hartnoll, Polchinski, Silverstein, Tong

Dynamical Lattice Formation



Magnetic
Reissner-Nordström
Black Hole

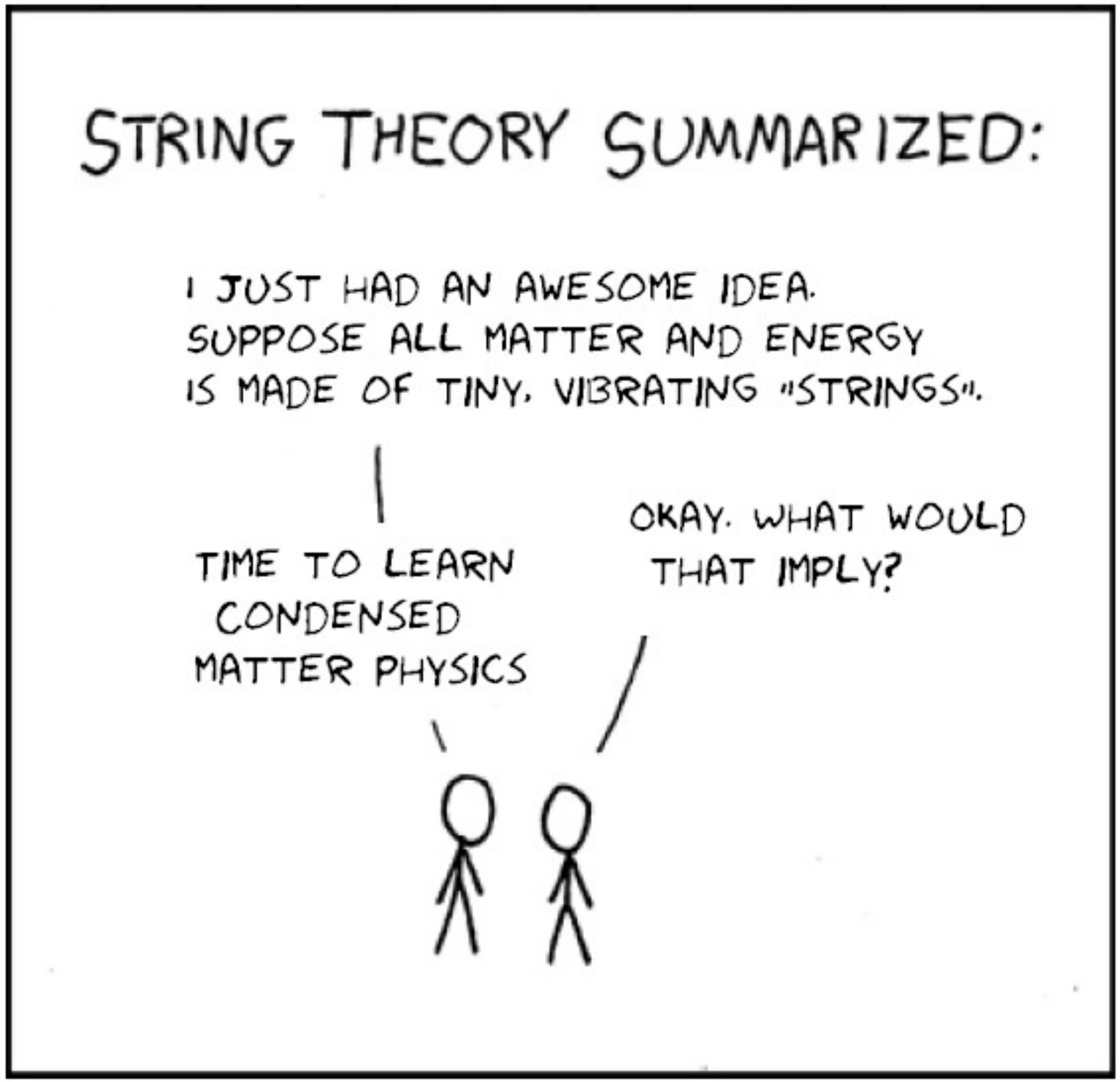


Relationship to quantum Hall bilayers?

Bolognesi and Tong

Many Other Phenomena

- Superconductivity
- Quantum Oscillations (de Haas van Alphen)
- Quantum Hall Transitions
- Band Structure
- Disorder
- …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TIME TO LEARN CONDENSED MATTER PHYSICS
OKAY. WHAT WOULD THAT IMPLY?