Gravitational dual of a lead-lead collision

Or the difference between a point and a sphere

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Motivation

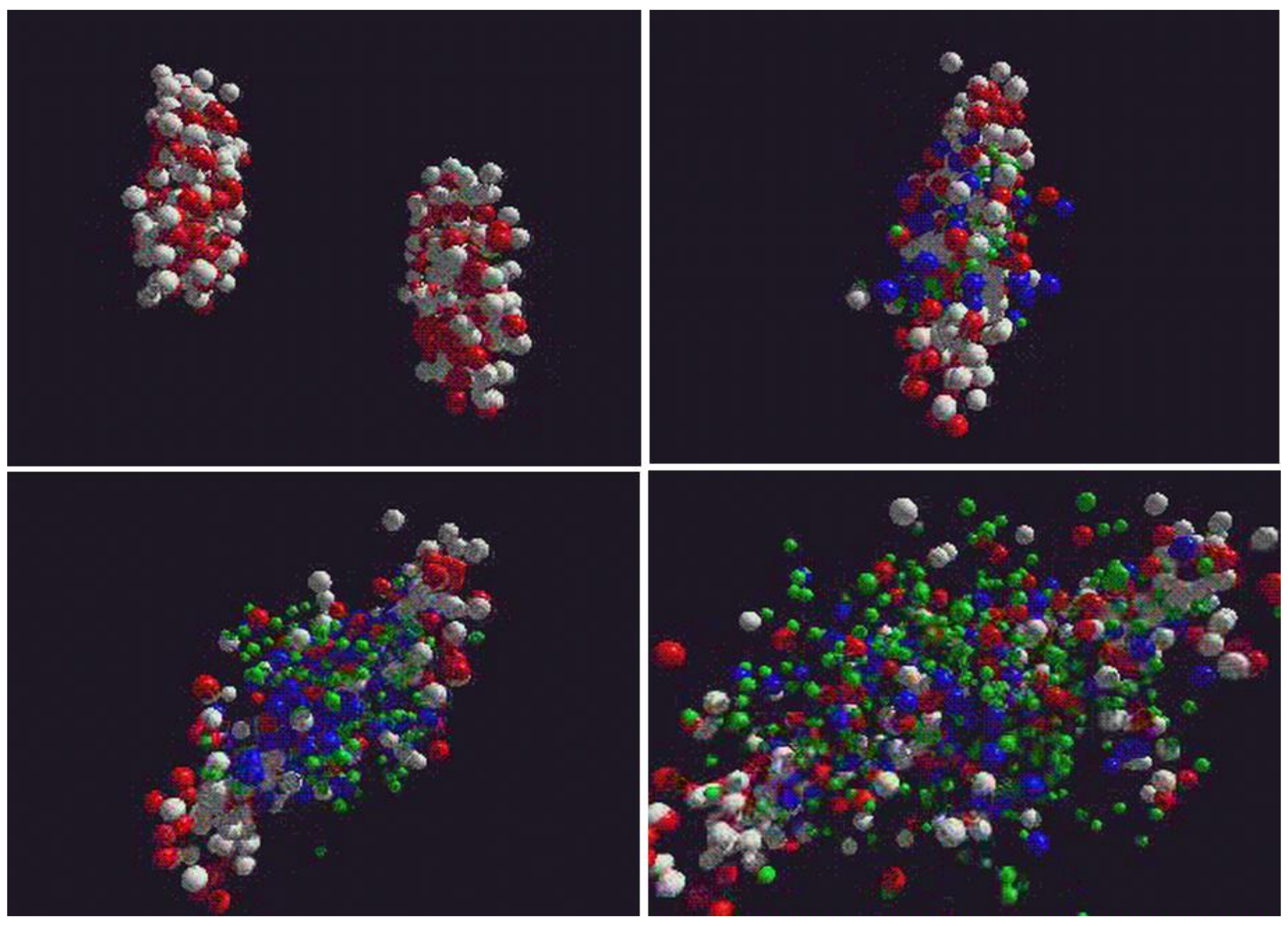

Figure 1. Schematic impression of a slightly off-center Pb-Pb collision, after the second picture the quark-gluon plasma (QGP) is expected to be thermalised. The motivation of this research is to use the gauge/gravity duality to study this thermalisation process, since in this strongly coupled field theory there are hardly any other tools available. Figure from http://www-subatech.in2p3.fr/

Gauge/gravity

Many motivations:
- Almost only tool for non-static strongly coupled gauge theory
- Very encouraging results (viscosity QGP, thermalisation time)

Main problems:
- Only very few well understood gauge theories (especially not QCD!)
- Duality maps into (very) complicated *5D* gravity problems

The *dictionary*: incomplete

Operators in the gauge theory are boundary conditions for **fields** in the gravitational theory (which is classical).

For lead – lead collision focus on energy:

Stress-energy $\longleftrightarrow$ spacetime metric (@boundary)

$$< T_{\mu\nu} > \longleftrightarrow \frac{N_c^2}{2\pi^2} g^{(4)}_{\mu\nu}$$

In coordinates s.t. $g_{\mu\nu}(x^\rho, z) = \eta_{\mu\nu} + z^4 g^{(4)}_{\mu\nu}$ (@z=0)

Dual of nucleus

Simplest choice: point source (Schwarzschild-AdS metric):

$$ds^2 = -f d\tau^2 + \frac{d\rho^2}{f} + \rho^2 d\Omega_3^2 \qquad f \equiv 1 + \frac{\rho^2}{L^2} - \frac{\rho_0^2}{\rho^2}$$

With ρ_0^2 proportional to black hole mass and L the AdS-radius

Boost this solution to obtain model for dual nucleus,

but note that the dictionary is incomplete (for instance microscopic degrees of freedom); there is just a hope that this metric is more or less dual to a nucleus, mainly because the energy density is quite similar.

Energy density

Gauss's law: field outside homogeneous sphere is same as field of point charge.

↓

Energy density on boundary for sphere/point charge will be equal!

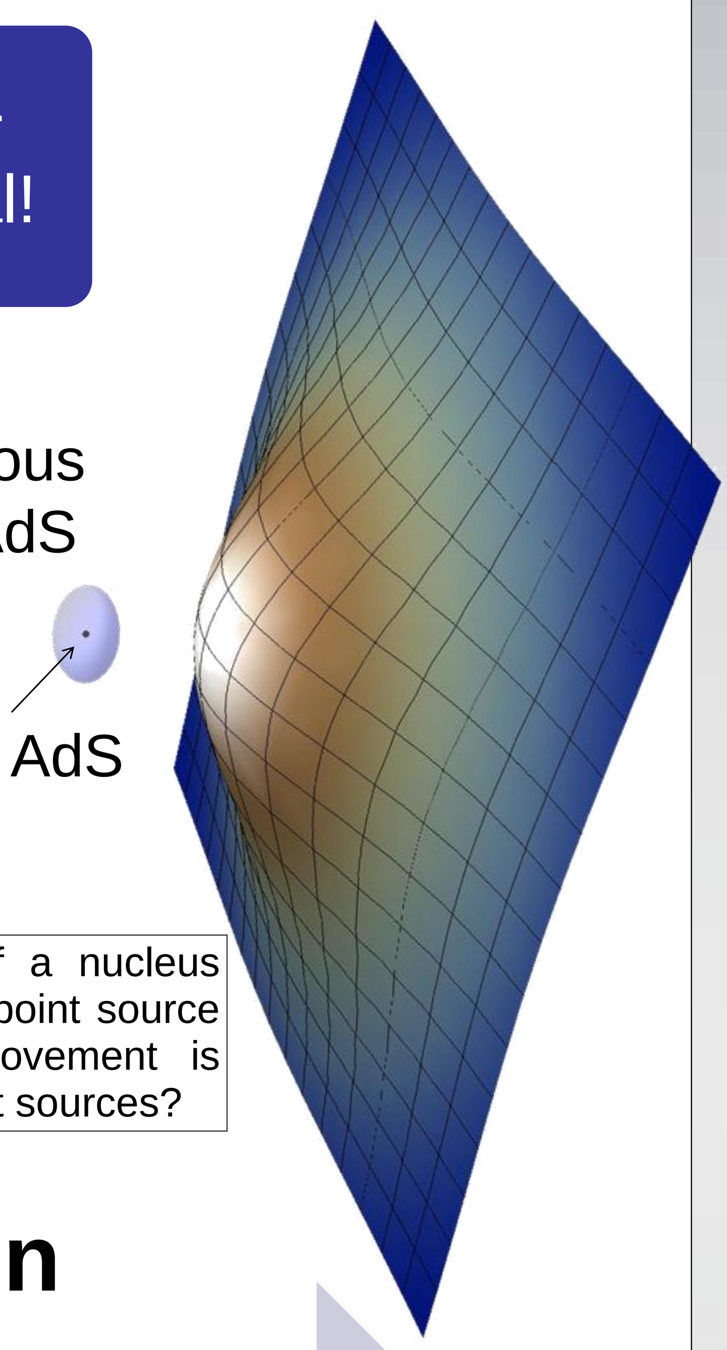

Figure 2. Energy density plot (on the boundary) of a nucleus moving with the speed of light, either represented by point source or a sphere (in AdS-space). The direction of movement is suppressed. Maybe spheres are a better dual than point sources?

The collision

Collide two sources → Black hole will form(?) → Use hydrodynamics

Note: most of energy in AdS will end up in black hole, unlike in realistic lead-lead collisions! Many quarks may not interact and just fly on (spectators). Maybe point source not realistic (enough)?

Conclusion and discussion

- Energy density gives no unique gravitational dual
- Angular momentum in real QGP much lower than point sources suggest (due to spectators)
- *Sphere may be a better dual of a nucleus*

- In principle one should compute things like 2-point functions to determine best dual
- In practice one can try different duals and see which fits experimental data best
- Probably collision should be described at much higher energy scale

- Still a long way from realistic QCD dual … !

S. S. Gubser, S. S. Pufu, A. Yarom, Off-center collisions in AdS_5 with applications to multiplicity estimates in heavy-ion collisions, *JHEP* **11** (2009), 050