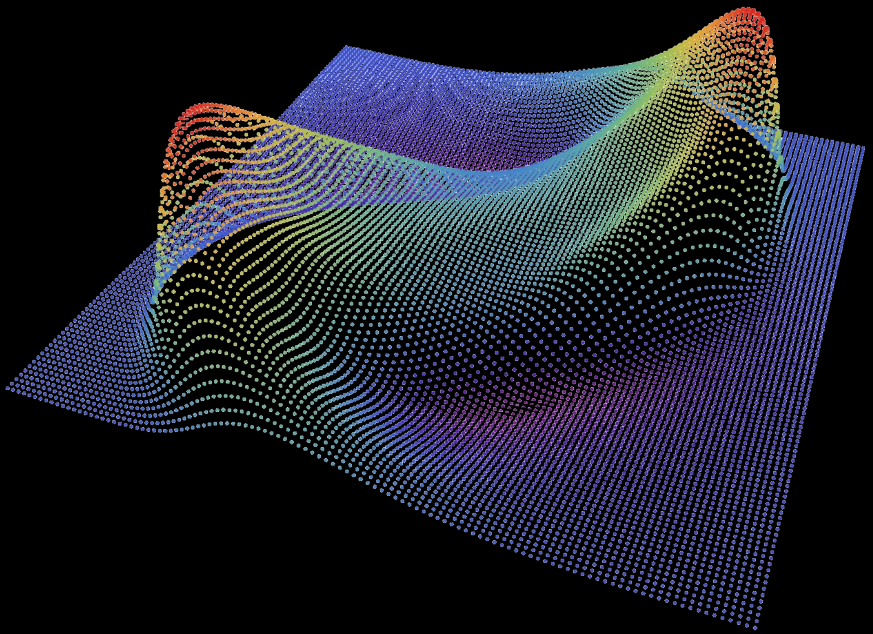
Large D holographic collisions



Mikel Sanchez-Garitaonandia

2212.14440

European Research Council
Established by the European Commission

l'X ÉCOLE POLYTECHNIQUE

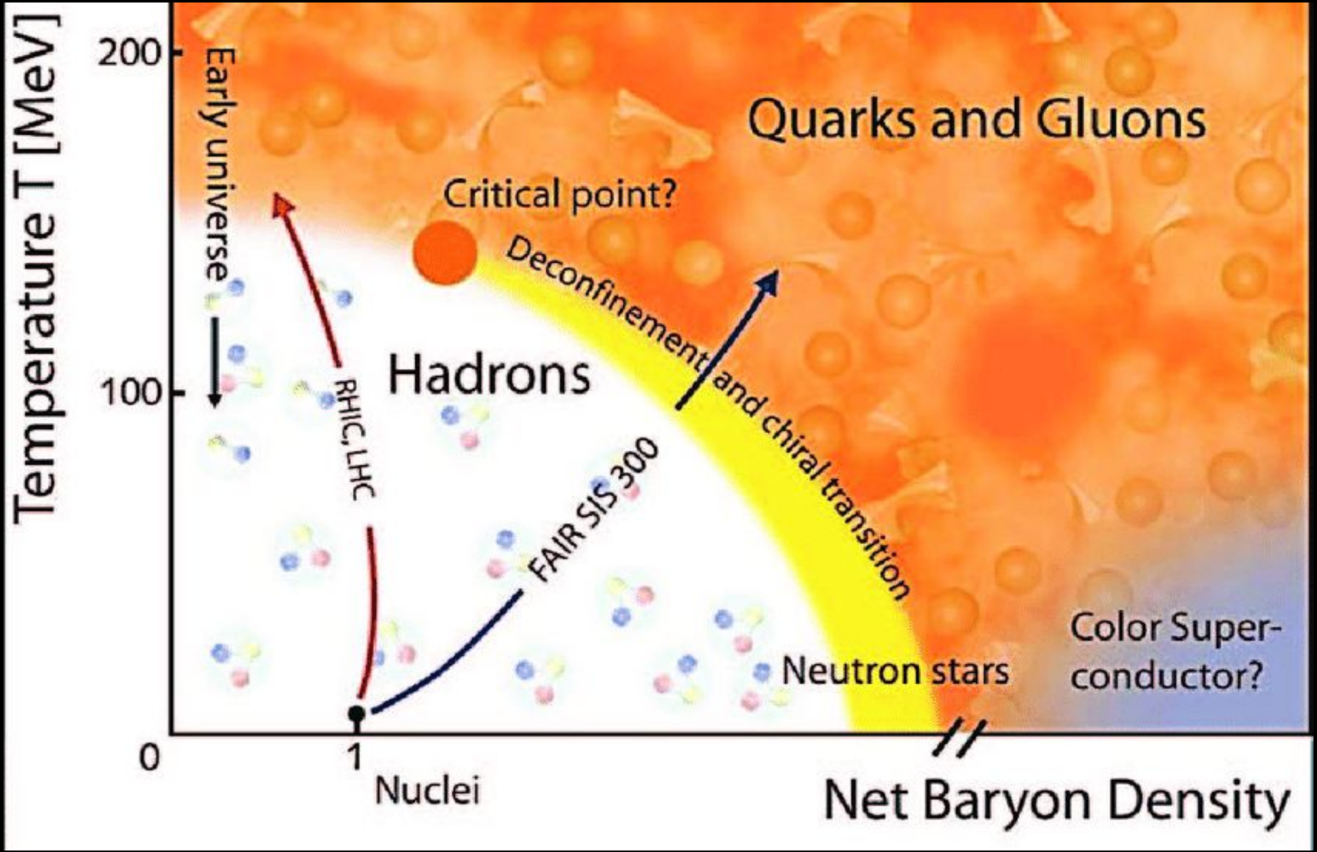
Raimon Luna

Universitat de Valencia

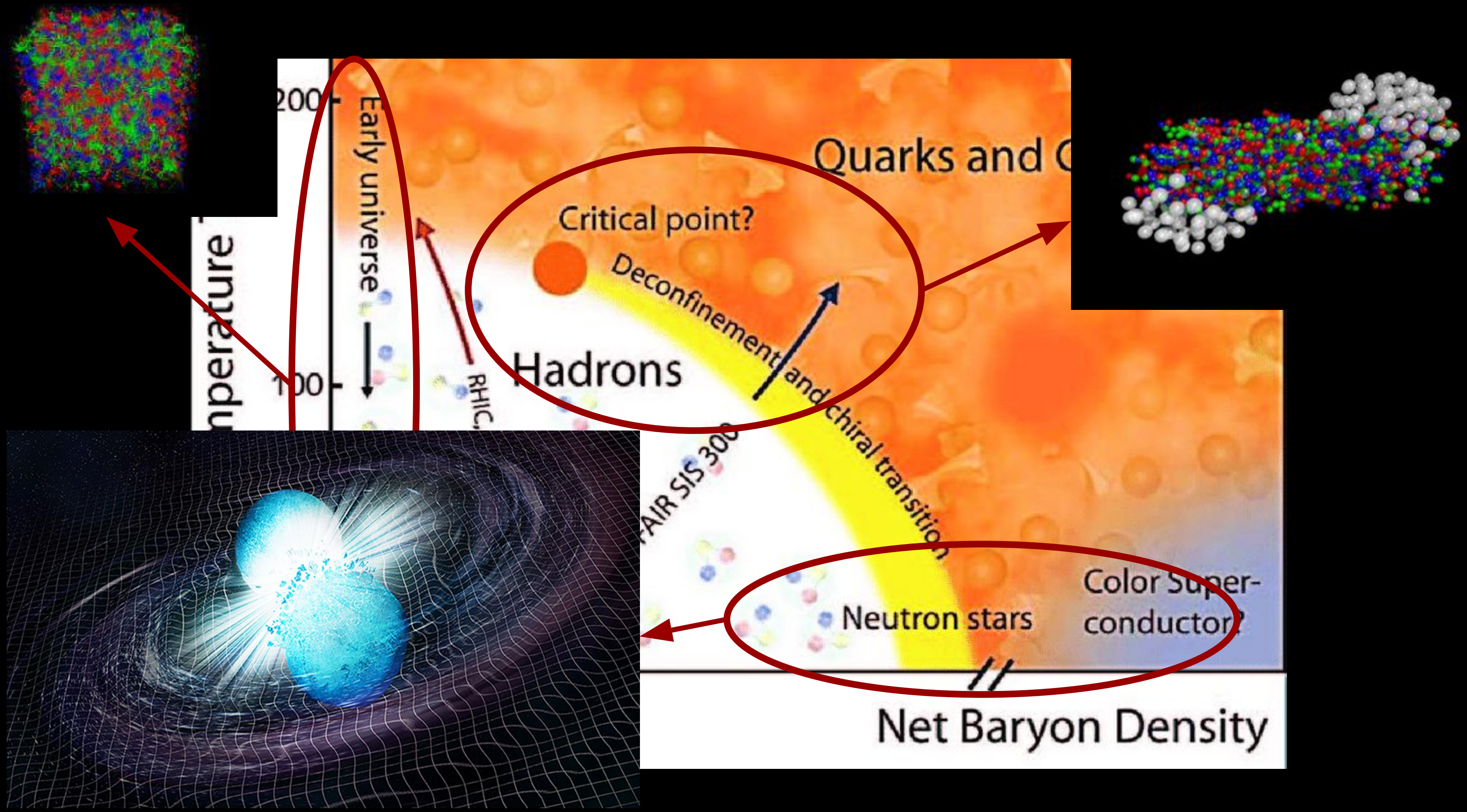
After several years relevant QCD features remain unknown

Strongly coupled nature at $E \sim \Lambda_{QCD}$

Phase diagram?



Temperature T [MeV]
200
100
0
1
Nuclei
Net Baryon Density
Early universe
RHIC, LHC
FAIR SIS 300
Hadrons
Critical point?
Quarks and Gluons
Deconfinement and chiral transition
Neutron stars
Color Super-conductor?



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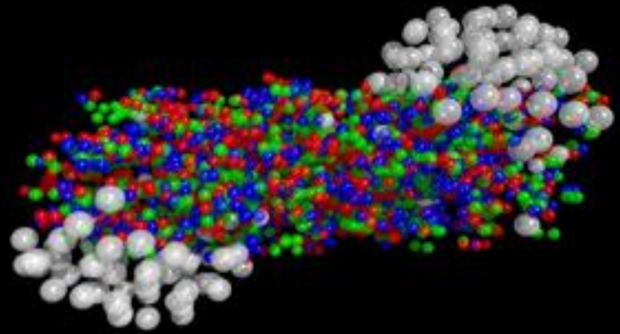
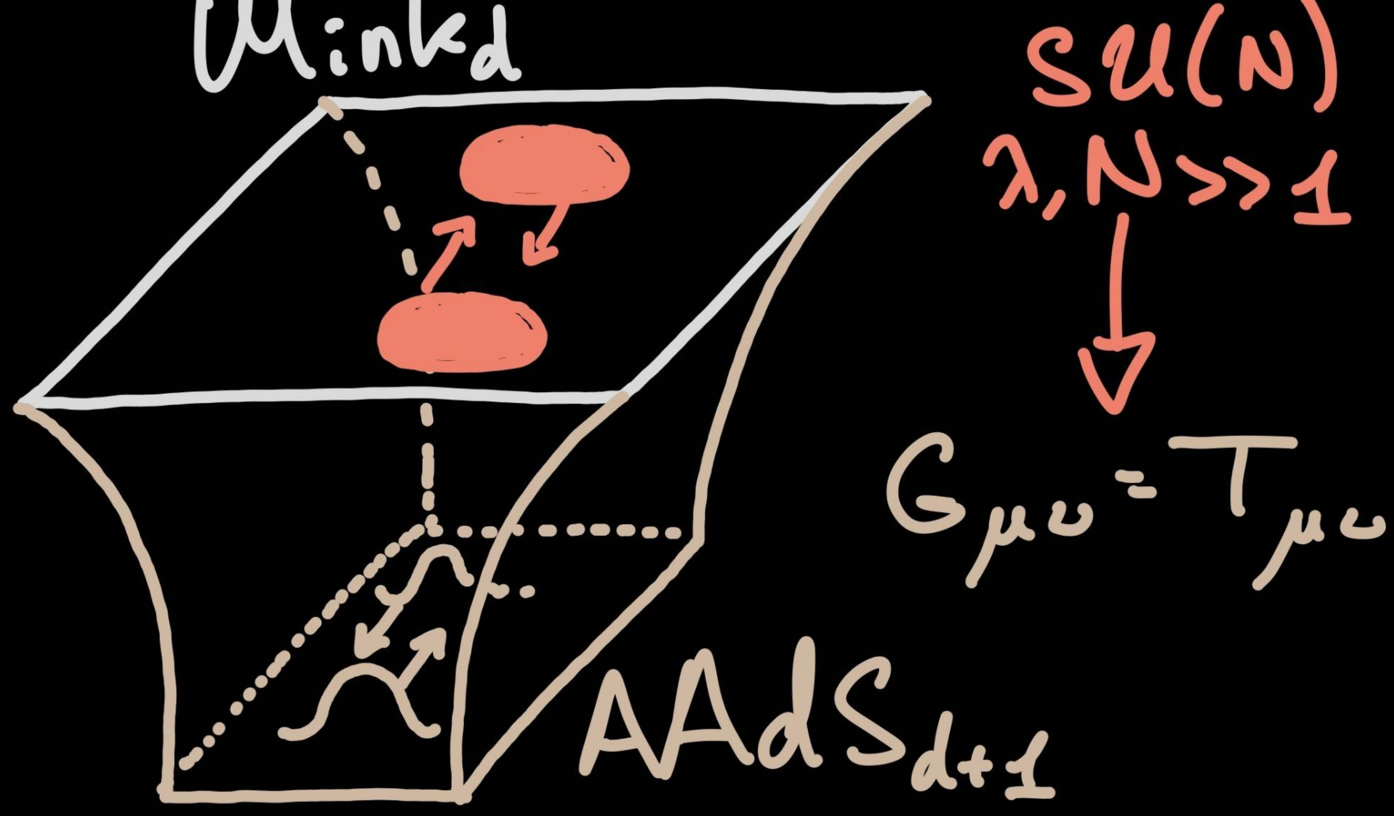


Far from equilibrium

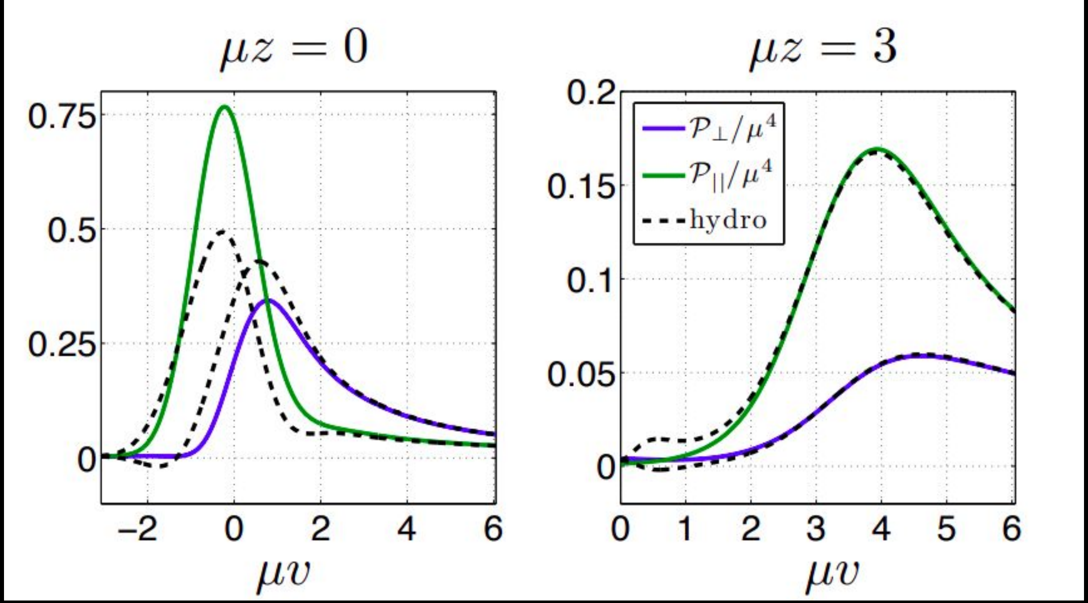
Strongly coupled

Far from the hydrodynamic regime


Mink_d
SU(N)
λ, N >> 1
G_μν = T_μν
AAdS_{d+1}

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

Policastro, Son & Starinets '01



Chesler & Yaffe '10

Very low viscosity

Rapid hydrodinamization/thermalization

General numerical treatment of Einstein's Equations is very expensive

Simplifications to tackle the problem

Planar chocks (2+1), motivated by the high Lorentz contraction in of real ions

Symmetric/Asymmetric shocks, baryonic charge & phase transitions

Full 3-dimensional collision only in pure gravity (no baryonic charge)

Take the large D limit of GR

Outline

- Large D limit
- General results
- Linear entropy growth
- Conclusions and Future

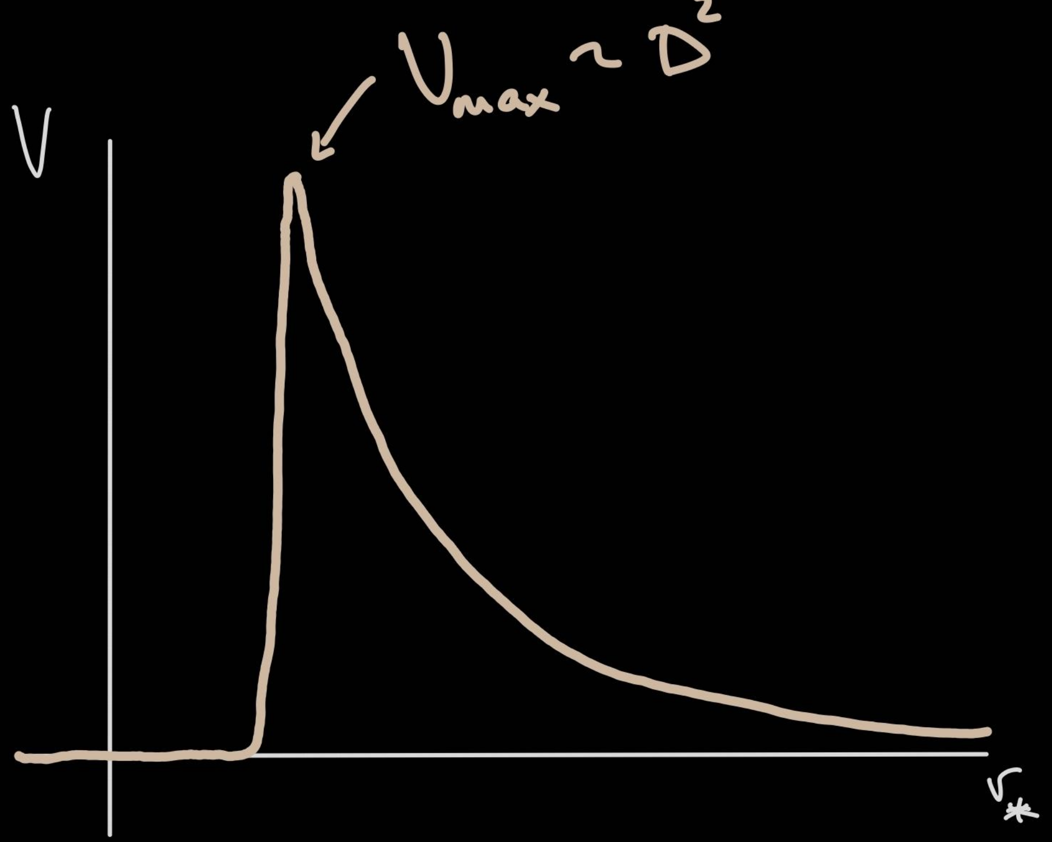
Large D limit

$$D \sim 1$$

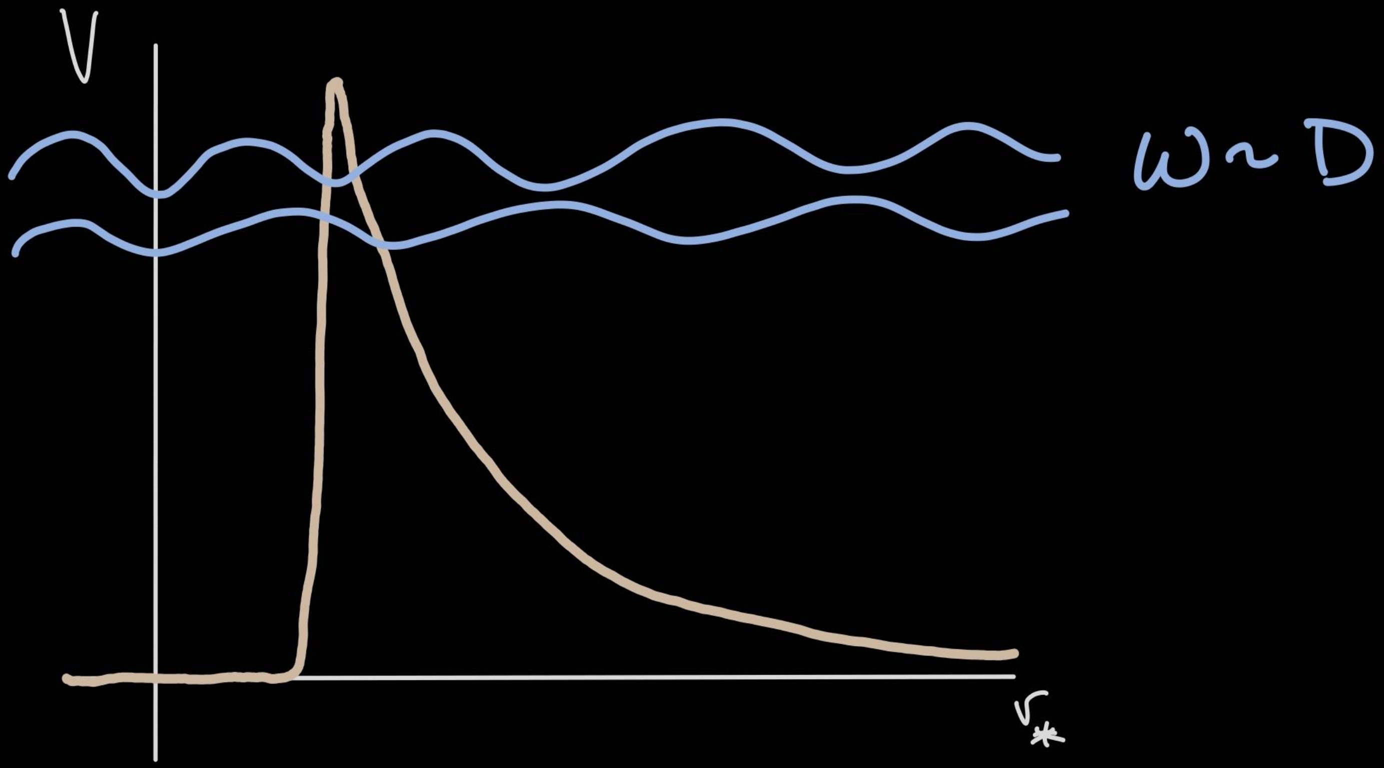
$$r_0, \quad T \sim \frac{D}{r_0} \sim \frac{1}{r_0}$$

$$D \gg 1$$

$$r_0, \quad T \sim \frac{D}{r_0} \gg \frac{1}{r_0}$$



Emparan, Suzuki & Tanabe ‘14



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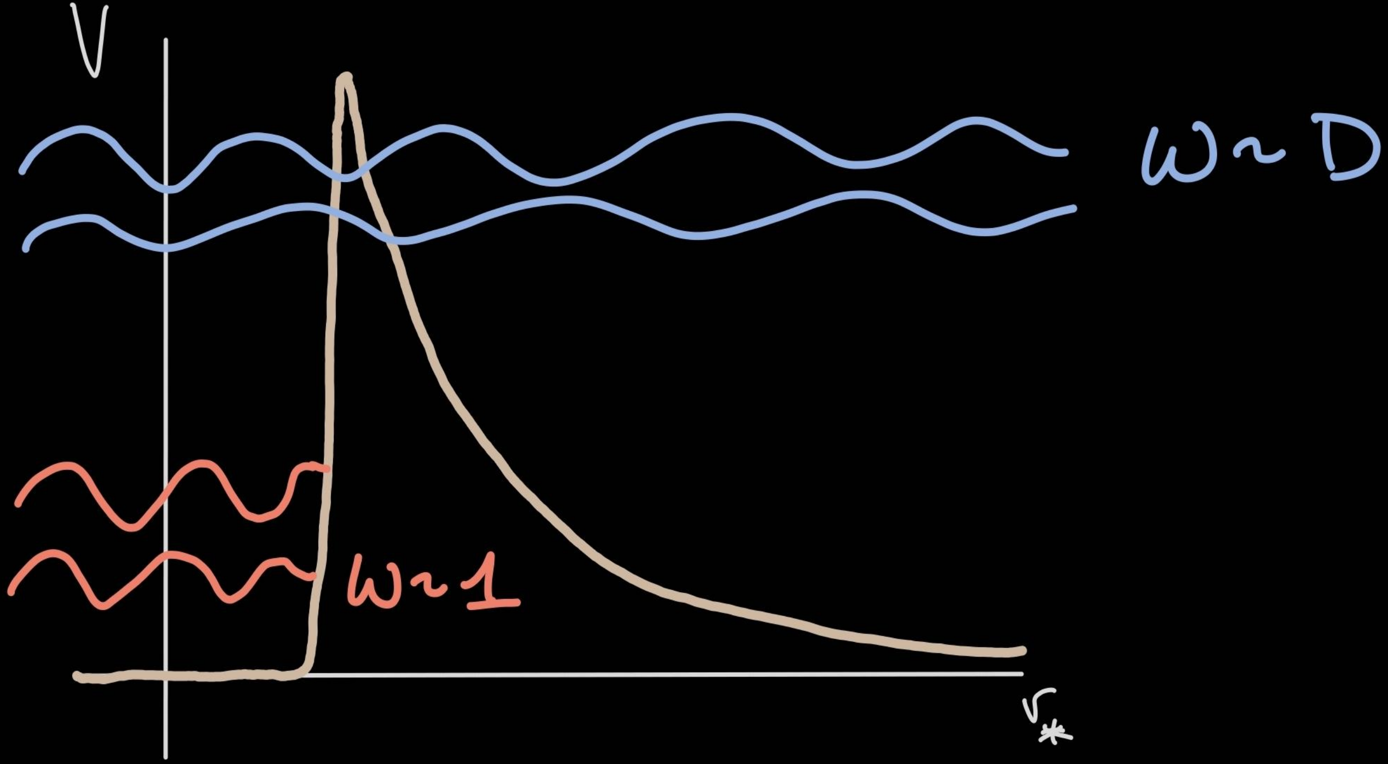


Emparan, Suzuki & Tanabe '14

Effective theory of decoupled modes

=

Effective theory of a horizon decoupled from a fixed background

Emparan, Izumi, Luna, Suzuki & Tanabe '16

$$I = \int d^D x \sqrt{-g} \left(R - \frac{1}{4} F^2 - 2\Lambda \right)$$

$$ds^2 = r^2 \left(-A dt^2 - \frac{2}{D} C_i dt dx^i + \frac{1}{D} G_{ij} dx^i dx^j \right) - 2 dt dr$$

Solve order by order in 1/D

Equations for the (t,x) directions

Emparan, Izumi, Luna, Suzuki & Tanabe '16

$$\partial_t \rho + \partial_i \left(\rho v^i\right) = 0$$

$$\partial_t q + \partial_i j^i = 0$$

$$\partial_t (\rho v^i) + \partial_j \left(\rho v^i v^j + \tau^{ij}\right) = 0$$

$$j_i = q v^i - \rho \partial_i \left(\frac{q}{\rho}\right),$$

$$\tau_{ij} = \rho \delta_{ij} - 2\rho_+ \partial_{(i} v_{j)} - (\rho_+ - \rho_-)\, \partial_i \partial_j \log \rho$$

Not an expansion in gradients

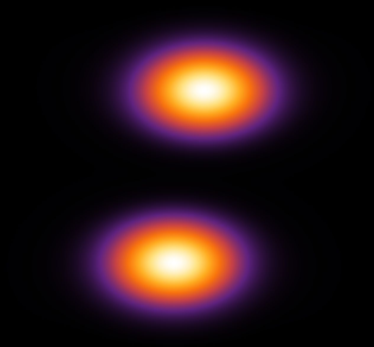
Higher order transport coefficients identically vanish

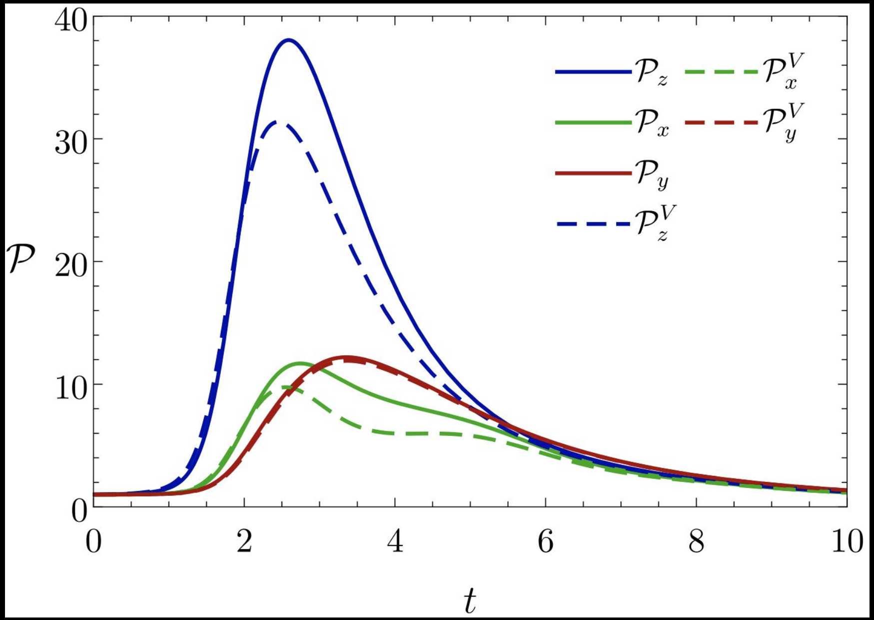
Wider exploratory work

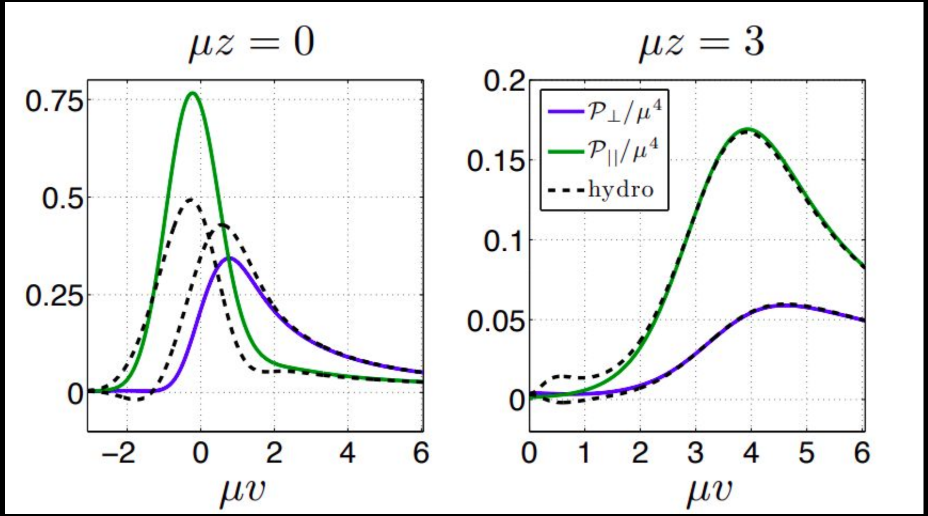
Transport coefficients are not as in 3D

Temp of same order all over horizon. Big dissipation of incoming blobs

General results

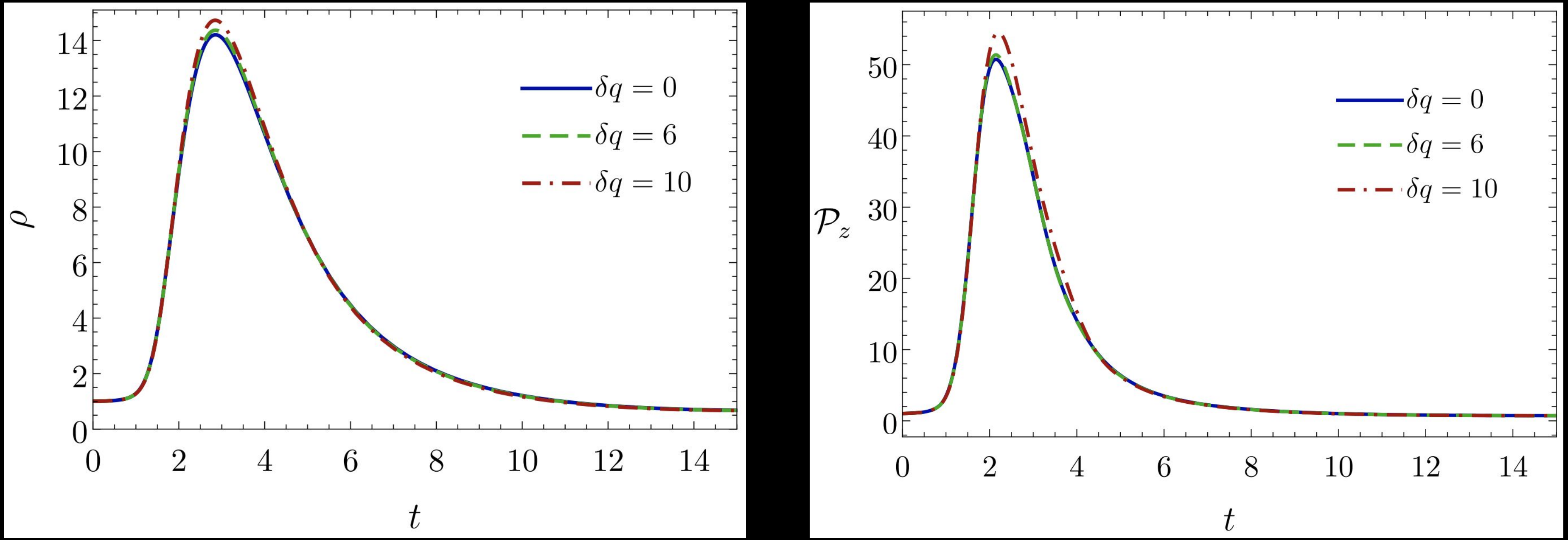






Chesler & Yaffe '10

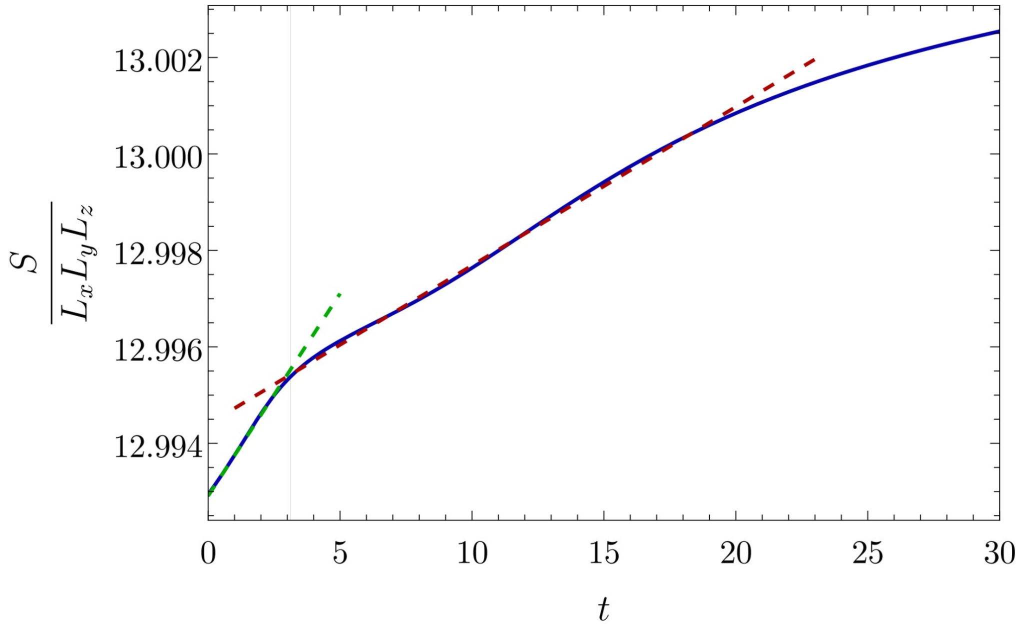
Hydrodinamization time ~ isotropization time



Small quantitative changes in charged collisions

Casalderrey-Solana, Mateos,
van der Schee & Triana '16

Linear entropy growth



Several regimes of linear entropy growth

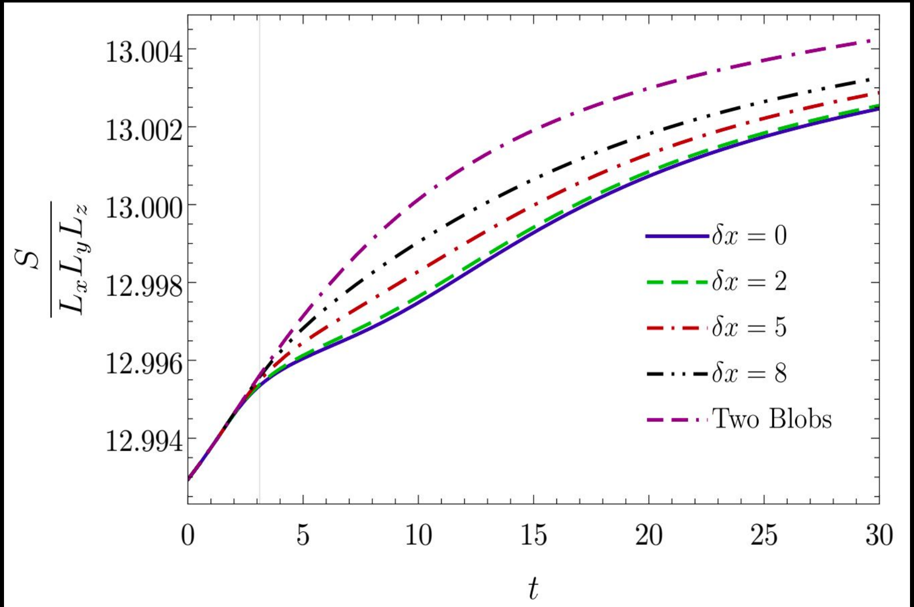
Müller, Rabenstein, Schäfer, Waeber & Yaffe ‘20

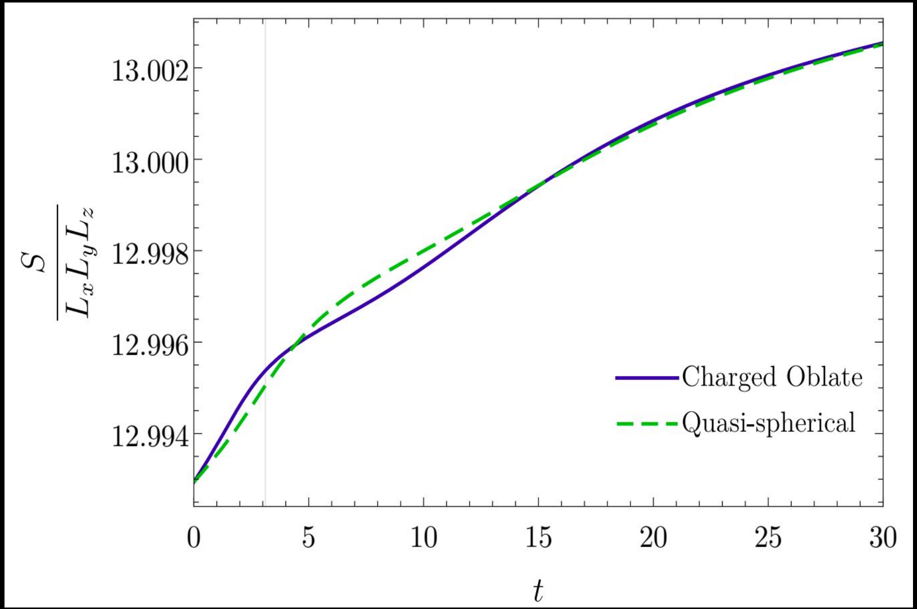
Possible relation to chaos (KS entropy)

Latora & Baranger ‘99

$$\frac{dS}{dt} = S_{KS} = \lambda_L \sim 2\pi T$$

Maldacena, Shenker & Stanford ‘15





Same final T

Variations ~ 8 %

Same impact parameter & final T

Variation ~ 13 %

Sensitive to initial data

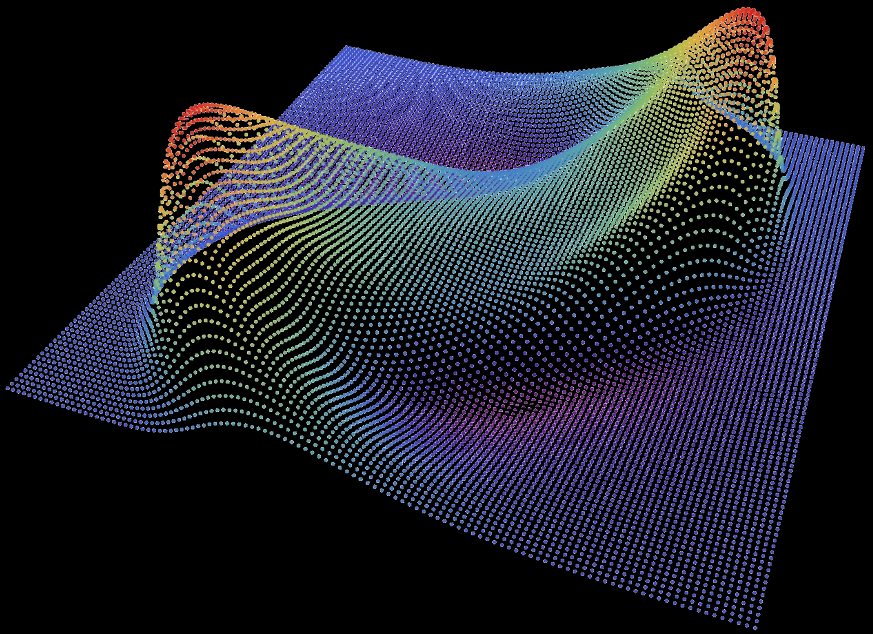
Conclusions

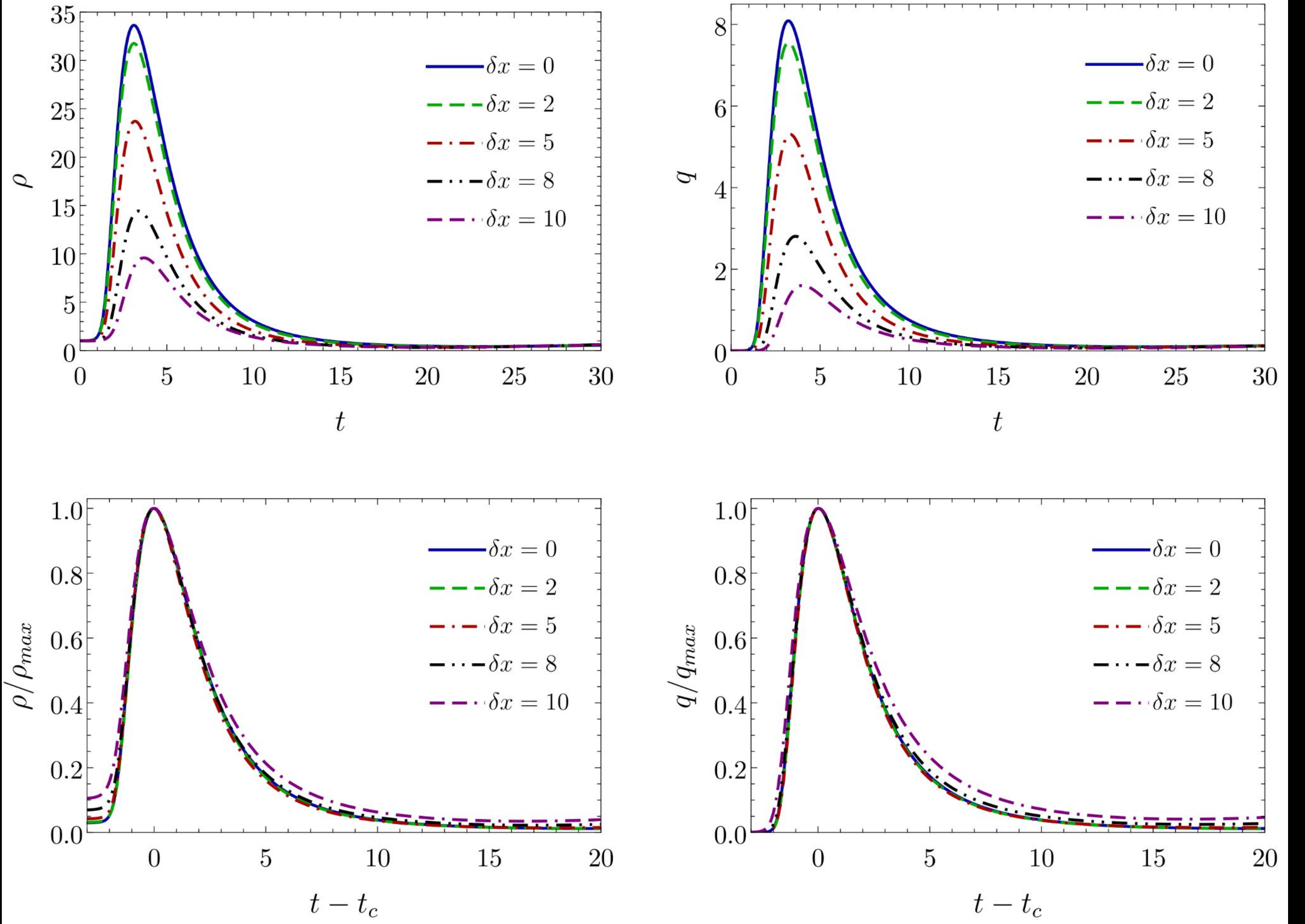
- Large D effective theory as simple model for holographic collisions
- Computationally cheap but dissipation of colliding blobs important
- Similar features at the qualitative level
- Many runs with same end state suggest no relation between entropy linear growth and chaos
- Linear entropy growth stages seems to be a signature of collision dynamics

Future Directions

- 1/D corrections?
- Addition of a scalar field to get theories with phase transitions: superfluids...
- Chaos at large D Cubrovic, Ramirez, MSG & Tomasevic
- Semiclassical gravity at large D: $1/D \sim \hbar$ MSG & Tomasevic ‘23??

Merci!





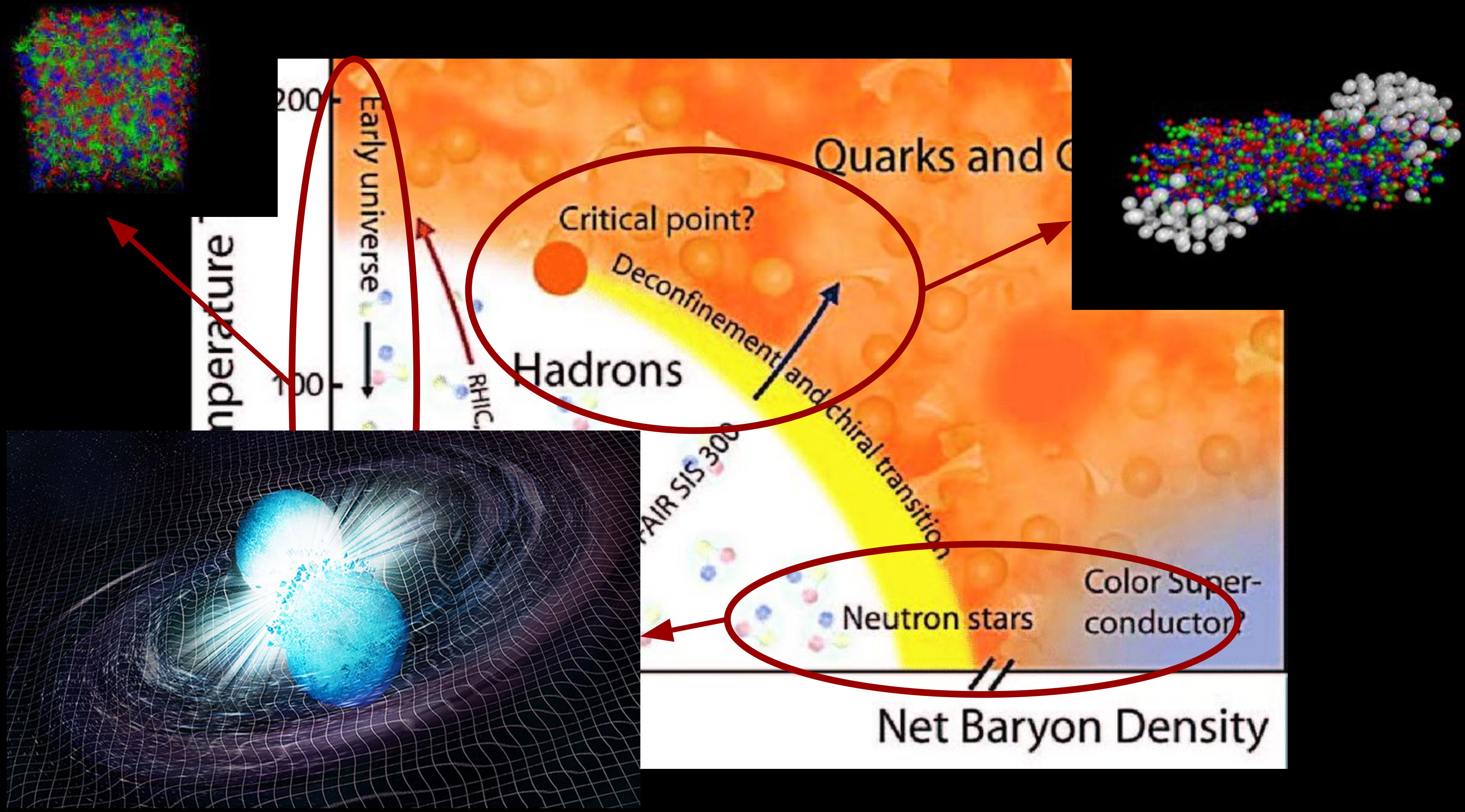
ρ
t
q
t
ρ/ρ_{max}
$t - t_c$
q/q_{max}
$t - t_c$
$\delta x = 0$
$\delta x = 2$
$\delta x = 5$
$\delta x = 8$
$\delta x = 10$

$$I = \int d^D x \sqrt{-g} \left(R - \frac{1}{4} F^2 - 2\Lambda \right)$$

$$t \sim \frac{1}{\omega} \sim 1 \qquad c_s \sim \frac{1}{\sqrt{D}}$$

$$x_i \sim \frac{1}{\sqrt{D}} \qquad g_{ti} \sim \frac{1}{\sqrt{D}}$$

$$ds^2 = r^2 \left(-A dt^2 - \frac{2}{D} C_i dt dx^i + \frac{1}{D} G_{ij} dx^i dx^j \right) - 2 dt dr$$



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