Constraining early time dynamics in ultrarelativistic Heavy Ion Collisions

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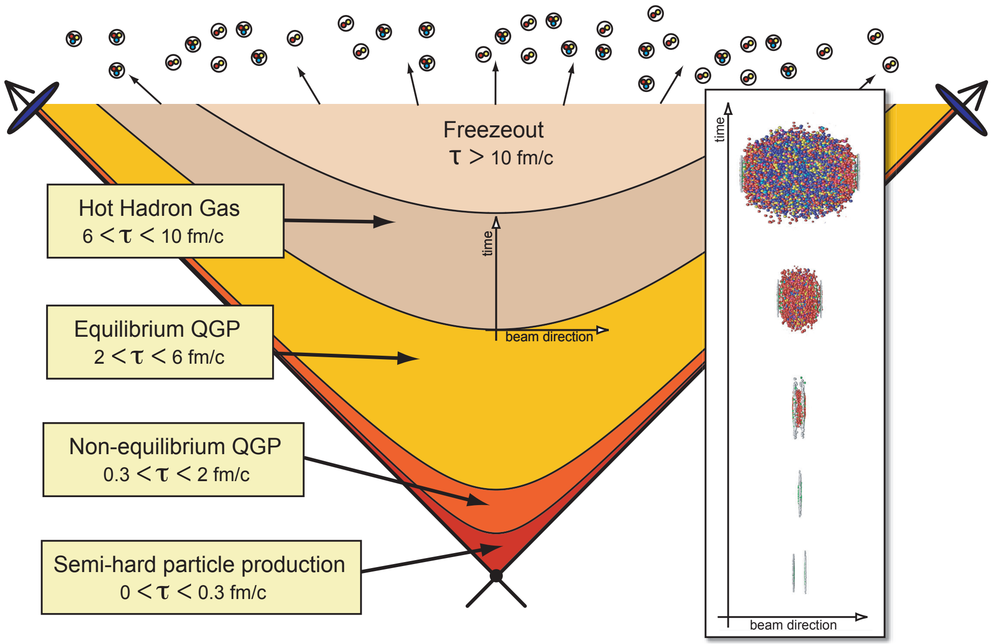
Universal dynamics at early times

A **far-from-equilibrium** attractor is a property of the system where the memory of initial conditions is rapidly swept away and a universal behaviour sets in $\tau \sim 0.5\ \mathrm{fm/c}$

$$\nabla_\mu T^{\mu\nu} = 0 \iff \tau \partial_\tau \log \epsilon = -\frac{4}{3} + \frac{2}{9} \mathcal{A}(w)$$

energy density

Pressure anisotropy



universal time variable → $w = \tau T(\tau)$

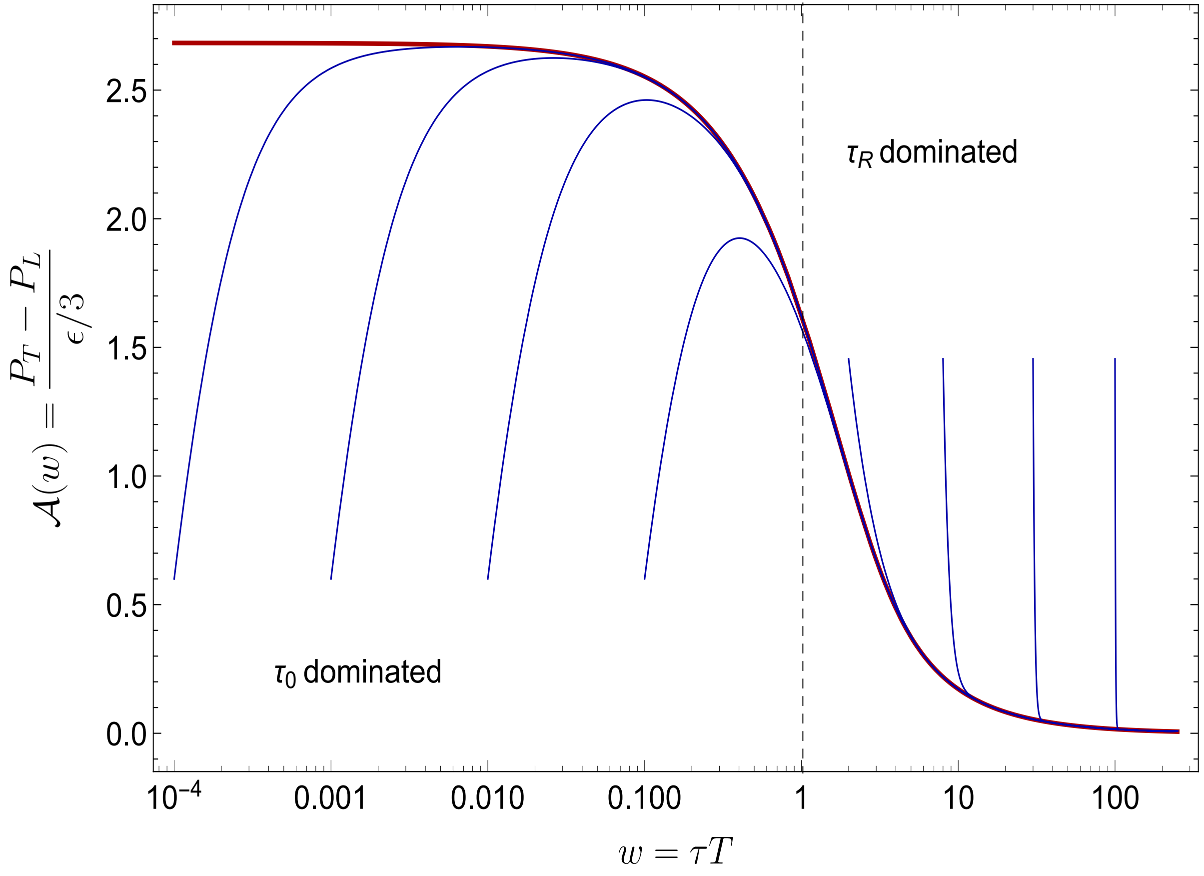
$$ds^2 = -d\tau^2 + \tau^2 dy^2 + dx_\perp^2$$

Soloviev, A. 2109.15081
Spaliński, M. and J. J. to appear

What attracts to attractors?

- **Early time**: system's expansion rate dominates the dynamics leading to a universal, power-law behaviour determined by the Bjorken symmetry

- **Late time**: decay of the non-hydro mode resulting in a transseries structure with exponentially decaying modes symmetry independent



J. P. Blaizot, L. Yan,Phys. Lett. B **780**, 283-286 (2018)

A. Kurkela, *et al.* ,Phys. Rev. Lett. **124**, no.10, 102301 (2020)

Connecting early and late times

- The system follows universal dynamics apart from the initial transient
- Almost all memory of initial conditions is lost, only temperature remains
- If an attractor exists then we approximate the time evolution as

early times μ

free streaming

entropy~particle number

late times Λ

$$\beta_{\rm fs} = 1$$

$$\tau s \sim \Lambda^2$$

ATTRACTOR

$$\epsilon(\tau) \sim \frac{\mu^4}{(\mu\tau)^{\beta}} \iff \mathcal{A}_*(w) \sim 6\left(1 - \frac{3}{4}\beta\right) \longrightarrow \epsilon(\tau) \sim \frac{\Lambda^4}{(\Lambda\tau)^{\frac{4}{3}}}$$

$$\nabla_\mu T^{\mu\nu} = 0$$

$$T(w) \sim T(w_0) \exp\left(\int_{w_0}^{w} \frac{dx}{x} \frac{\mathcal{A}_*(x) - 6}{\mathcal{A}_*(x) + 12}\right)$$

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Giacalone, *et al.* Phys. Rev. Lett. 123 (2019) 26, 262301

Experimental constraints

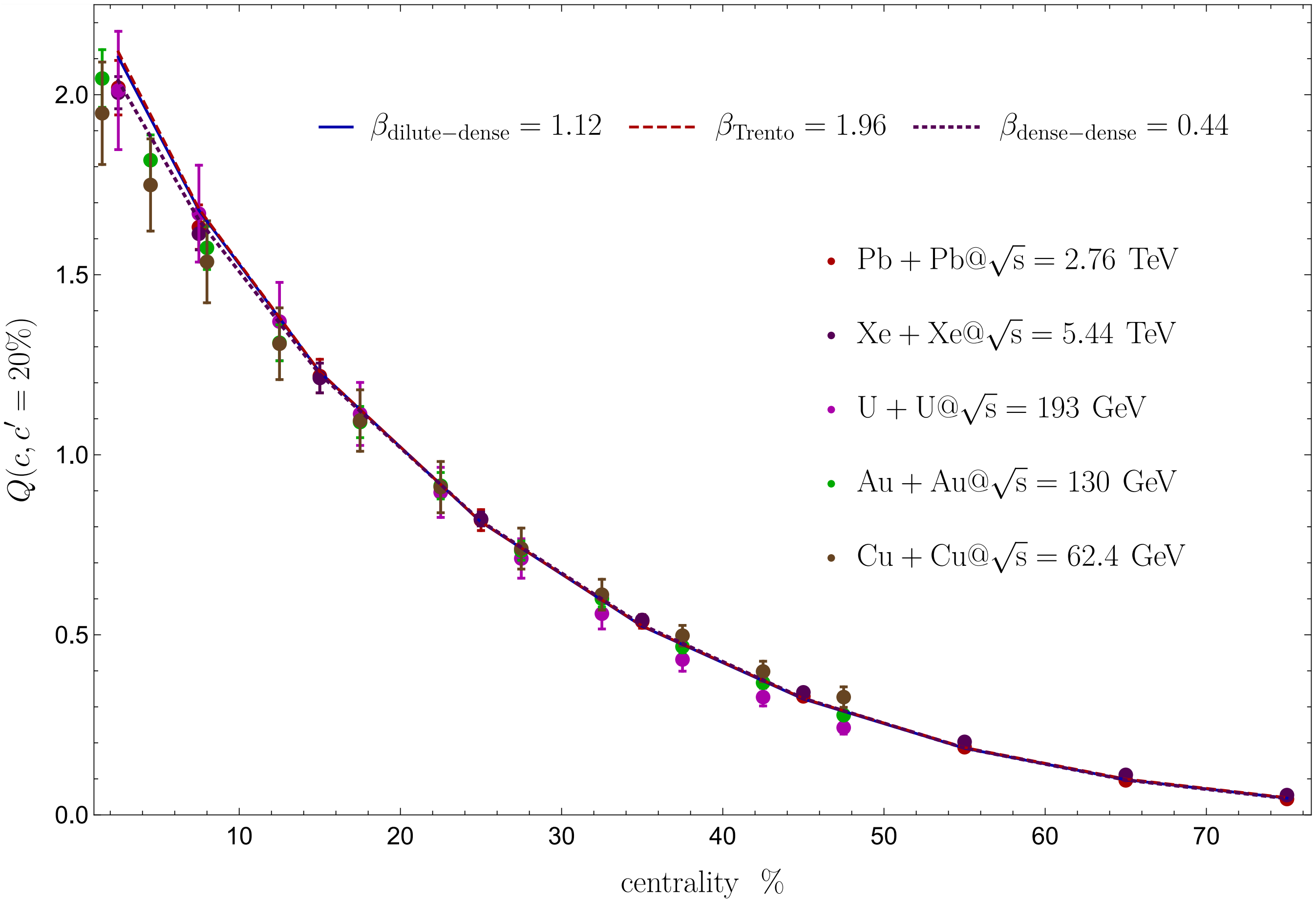
particle production

$$\frac{dN}{dy} = h(\beta) \int d^2x_\perp \epsilon(\tau_0, x_\perp)^{\frac{2}{4-\beta}}$$

initial energy

$$Q(c, c') = \frac{\langle dN/dy \rangle_c}{\langle dN/dy \rangle_{c'}}$$

c, c' centralities



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Summary

- Pre-hydrodynamic flow is tightly connected to the initial state model, and determines initial pressure anisotropy

$$\beta^{\mathrm{dilute-dense}} = 1.12 \quad \beta^{\mathrm{Trento}} = 1.96 \quad \beta^{\mathrm{dense-dense}} = 0.44$$

$$\mathcal{A}_{\mathrm{dilute-dense}} = 0.96 \quad \mathcal{A}_{\mathrm{Trento}} = -2.82 \quad \mathcal{A}_{\mathrm{dense-dense}} = 4.02$$

- In contrast free-streaming, popular in kinetic theory approaches, is not necessarily consistent with a generic initial energy deposition model

$$\beta_{\mathrm{fs}} = 1 \qquad \mathcal{A}_{\mathrm{fs}} = \frac{3}{2}$$

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