Propagation of gauge fields in hot and dense plasmas at higher orders

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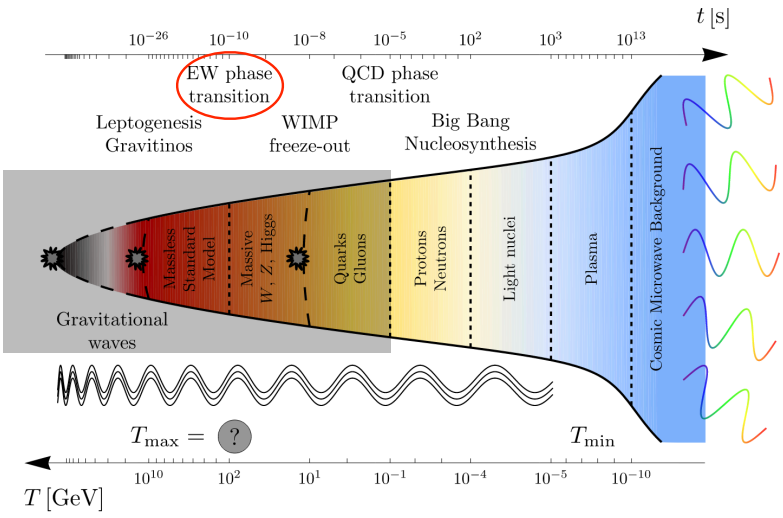
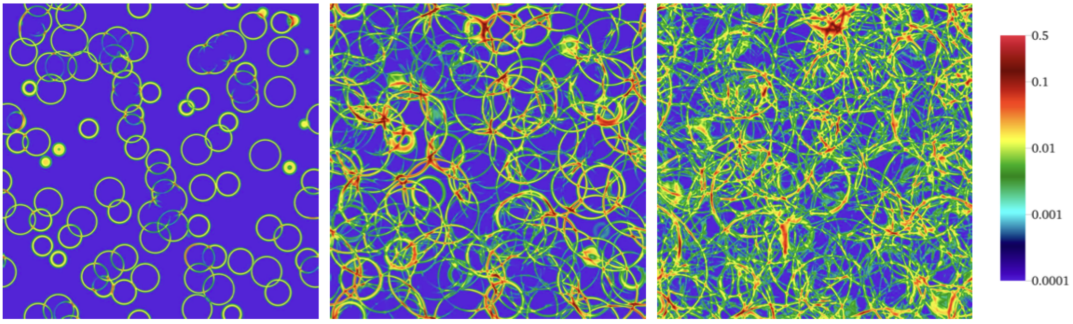
The Cosmological History



Adapted from 1307.3887

Hydrodynamics: Scalar field undergoing a phase transition

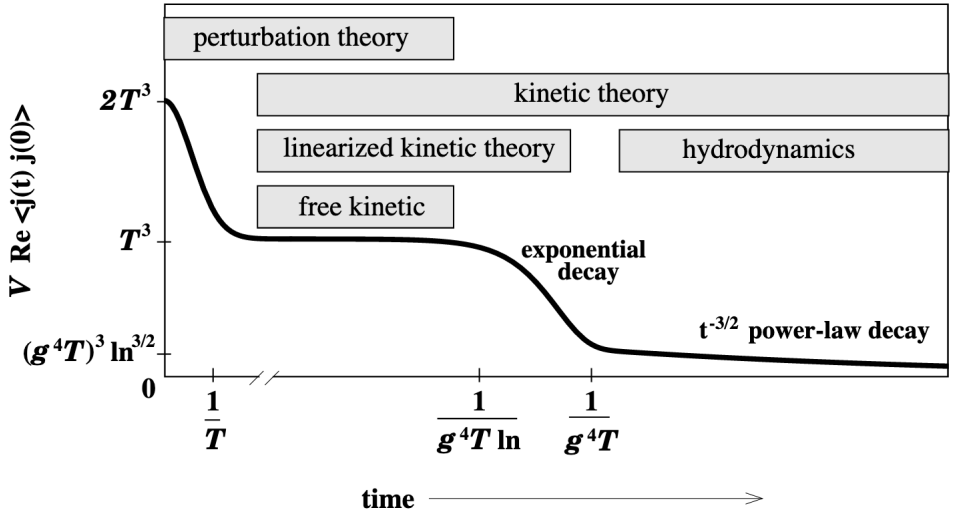


Hindmarsh, Huber, Rummukainen, Weir 2015

Open questions:

- Can we capture turbulence?
- What is the viscosity?
- How do we find the scalar damping $\sim \partial_t \phi$?

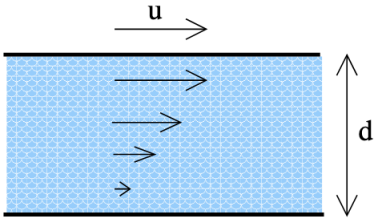
High-temperature field theories in a nutshell



Arnold, Yaffe 1998

Collisions push the system back to equilibrium

$\rho \frac{D\vec{u}}{Dt} = -\vec{\nabla} p + \mu \nabla^2 \vec{u} \quad \rightarrow \quad$ The mean-free path controls the viscosity: $\mu \sim \lambda_m$



http://www.damtp.cam.ac.uk/user/tong/kinetic.html

In a relativistic plasma the typical cross-section is set by the screening length:
$T^2 \sigma \sim g_s^4 \log T\lambda_s \quad \rightarrow \quad \lambda_m \sim (\sigma n)^{-1} \sim \left(g_s^4 T \log T\lambda_s\right)^{-1}$ Arnold, Moore, Yaffe 2000

Screening at high temperatures Braaten, Pisarski 1989

Fast $\vec{p} \sim T$ electrons behave as quasiparticles Blaizot, Iancu 1993

$$\partial_\mu F^{\nu\mu} = j^\nu = 2e \int_p v^\nu \left[n^+(p) - n^-(p) \right] \sim e^2 T^2 \vec{E}$$

An accelerated electron can travel for $\delta t \sim \left[\left(p^0 + k^0 \right) - \left| \vec{p} + \vec{k} \right| \right]^{-1}$

$\rightarrow$Its change in velocity is $T \delta v \sim t(e\vec{E})$

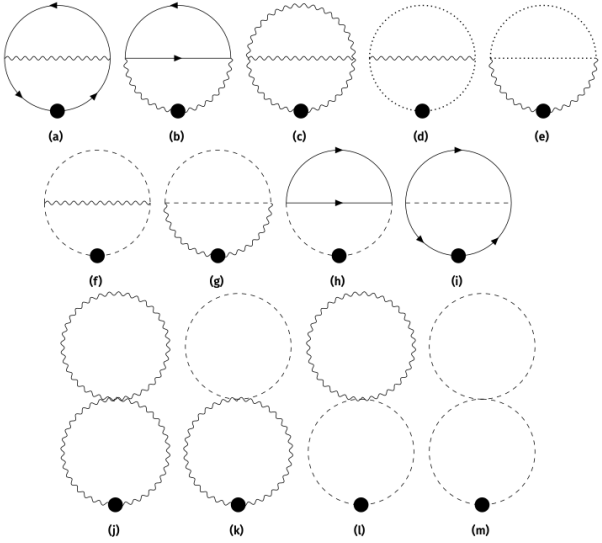
$\rightarrow$The **generated** current is $\vec{j} \sim en\delta v \sim t\left(T^2 e^2 \vec{E} \right)$

$\rightarrow$The screening length is **parametrically** $\lambda_s \sim (eT)^{-1}$

Thermal masses are responsible for the next order: $(p^0)^2 \rightarrow \vec{p}^2 + \underbrace{m_\infty^2}_{\sim e^2 T^2}$

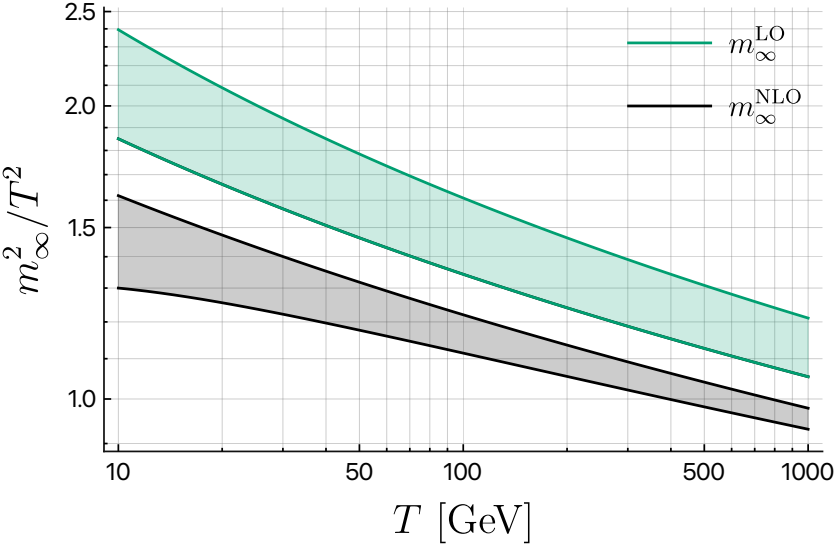
$\rightarrow$Charges can only travel for $\delta t \sim T m_\infty^{-2}$

What goes into the two-loop calculation?



How large are higher-order corrections?

Roughly 30% correction for thermal gluons Ekstedt 2023 & Gorda et.al 2023



Where do we stand and where are we going?

Some recent applications:

- Shear viscosity (in QCD) at almost next-to-leading order Ghiglieri et.al 2018
- Dense equations of state to N^3LO in QED (soon QCD) Gorda et.al 2023
- Systematic bubble nucleation at higher orders Gould, Hirvonen 2021

Some open problems:

- What is the value of the shear/bulk viscosity around the electroweak scale?
- How are long-wavelength fermions screened at higher orders?
- How do we calculate the scalar friction?
- Can we actually see turbulence in numerical simulations?