Gravitational Instability Theory

While it is hard, or perhaps even unfeasible, to encrypt a fully self-consistent analytical description of the formation of structure in the Universe from the pristine initial conditions of the random stochastic density field, we may identify various crucial evolutionary stages and seek to formulate appropriate approximations illuminating the essential aspects of these stages. Thus, we will follow the following action plan:

PLAN OF ACTION

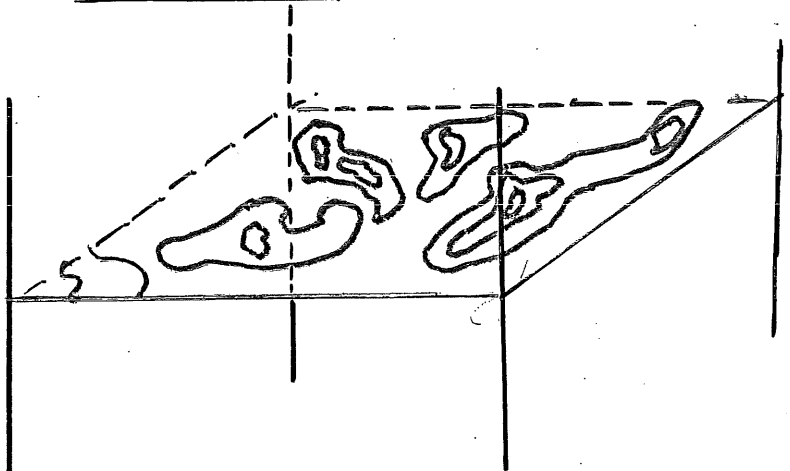
⇒ • **STARTING CONDITIONS**

* a (stochastic) Gaussian Primordial Density Field.

↑

fully characterized by:

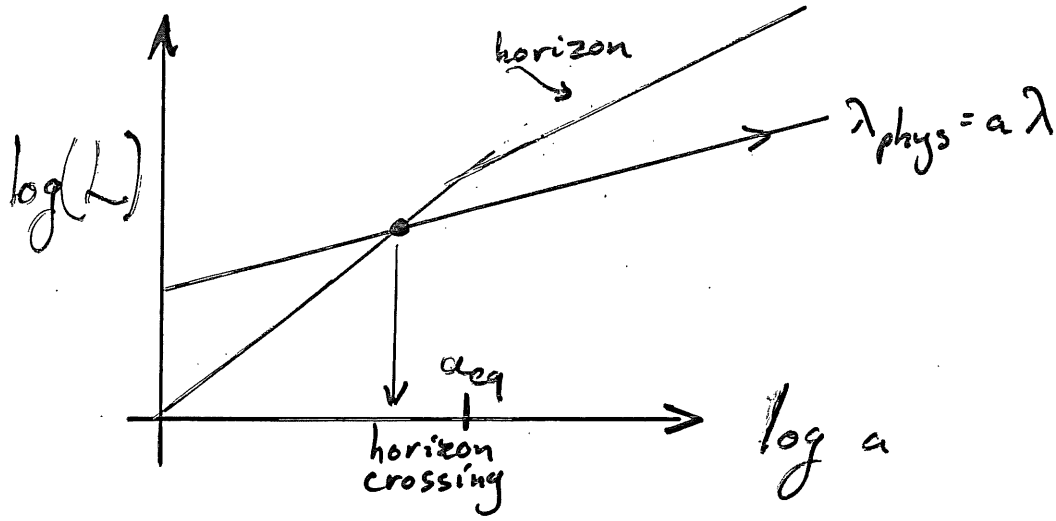
Power Spectrum P(k)



included:
- statistical description Gaussian density field
- mass perturbations
- protostructures & filtering

Stage 0

* From Superhorizon ⟶ Subhorizon



Stage 1

LINEAR PHASE:

Density fluctuations still small: $\delta \ll 1$.

① Pressureless "Dark Matter"

- Basic Linear Theory of Perturbation Growth

– Basic description of perturbation evolution in early stages of Cold Dark Matter scenarios (current "paradigm").

CDM supposedly only interacts via gravity and weak force/interaction.

- CDM is the dominant factor (gravitationally) in the total mass budget.

WMAP: $\Omega_{CDM} \approx 0.27$, $\Omega_{baryon} \approx 0.04$ $\Big\}$ $\frac{\Omega_{CDM}}{\Omega_b} \gtrsim 7$

- $\Rightarrow$ Basic understanding of influence of Ω on evolution cosmic structure.

(2) Jeans Instability Theory

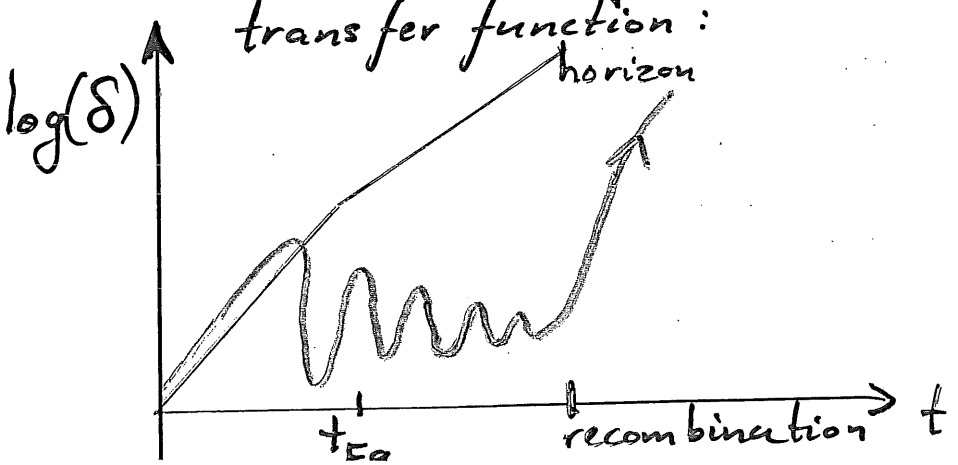
↓

Linear fluctuation theory for a generic medium with pressure

- as when baryons dominate matter budget
- before recombination, when photon pressure plays an extremely important role:

$\Longrightarrow$ Essential for Analyzing CMB fluctuations.

- important to understand spectrum of density fluctuations:
  modification primordial power spectrum ↓ transfer function:



included: Physical Mass Scales:
- Jeans Mass
- Photon Diffusion: Silk Mass
- Meszáros Effect. (CDM)

Stage 2

QUASI - LINEAR PHASE

- fluctuations start to decouple from Hubble expansion
- fluctuations change physical shape.
- imprint foamlike matter distribution.

⇓

Displacement particles (not yet crossing paths):

Linear Lagrangian formalism:

Zel'dovich approximation

- important tool to understand the generic properties of spatial pattern mass distribution.
- crucial for setting initial conditions N-body simulations

Stage 3

FULLY NONLINEAR EVOLUTION

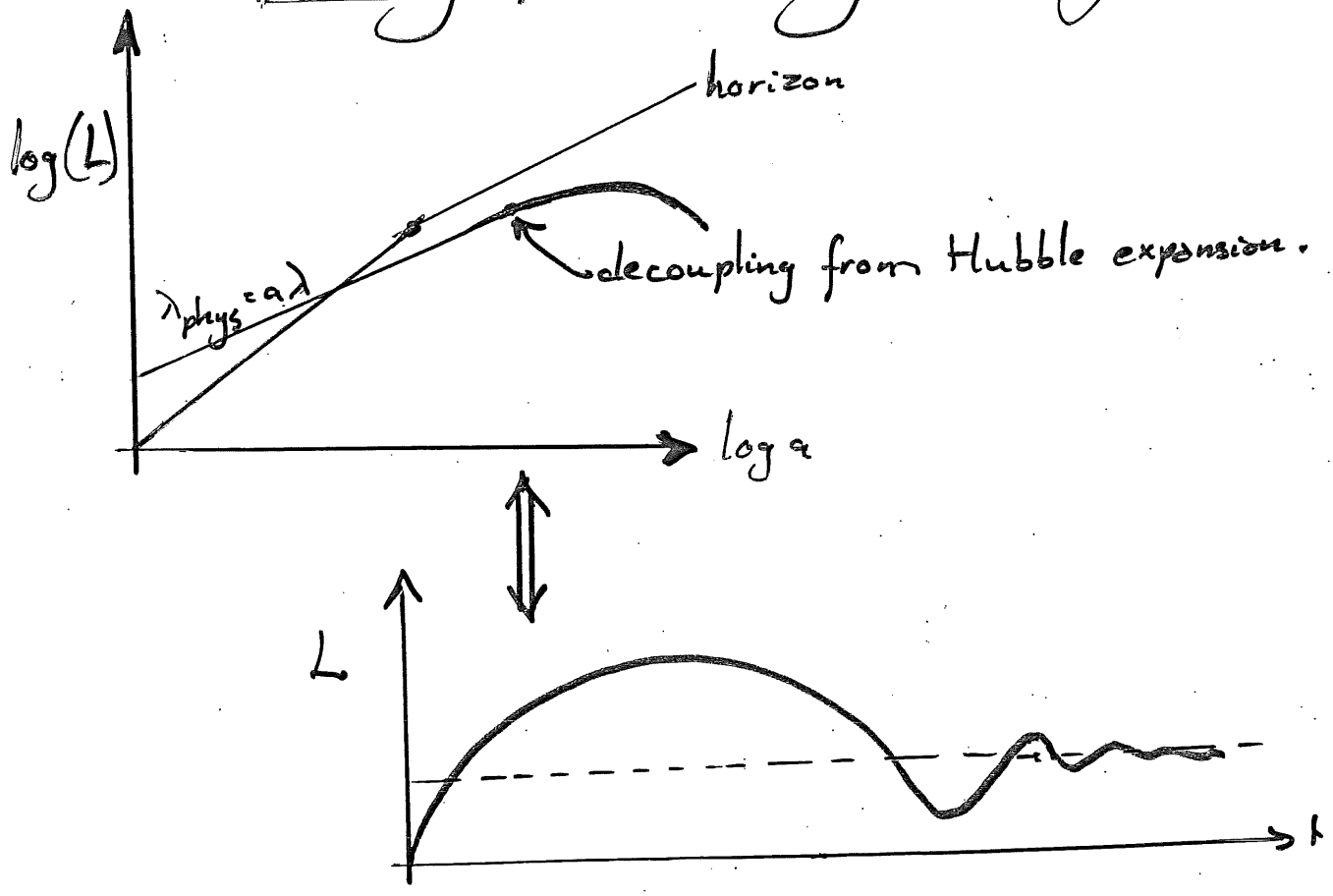
fully selfconsistent analytical treatment not possible.

- **Nonlinear Models** (approximation)

Models for highly symmetric configurations, used to understand generic behaviour and interpret more genetic complex situations!

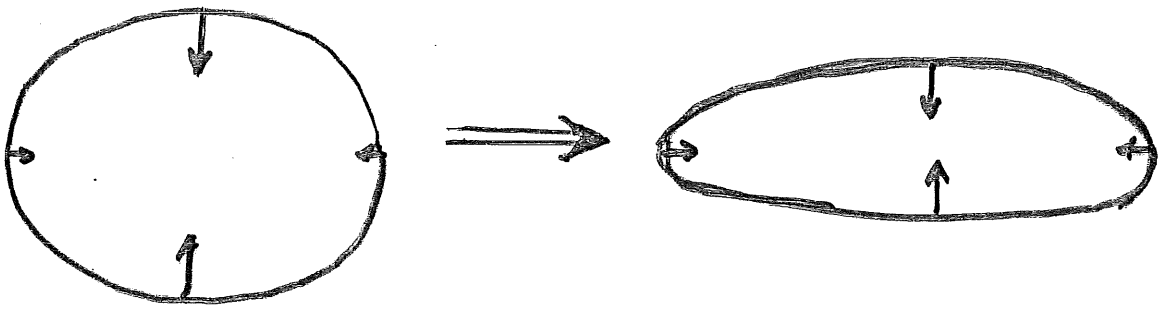
① Spherical Model

Template for generic collapse history of overdensity into "object":



② Ellipsoidal Model

Template for modified
collapse history
shape evolution
of generic nonspherical density perturbation



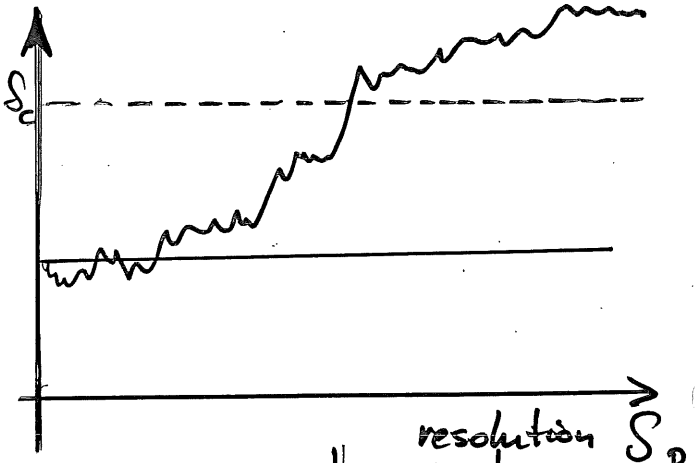
Fully Self-consistent and Complete Evolution N-body Simulations

Hierarchical Structure Buildup:

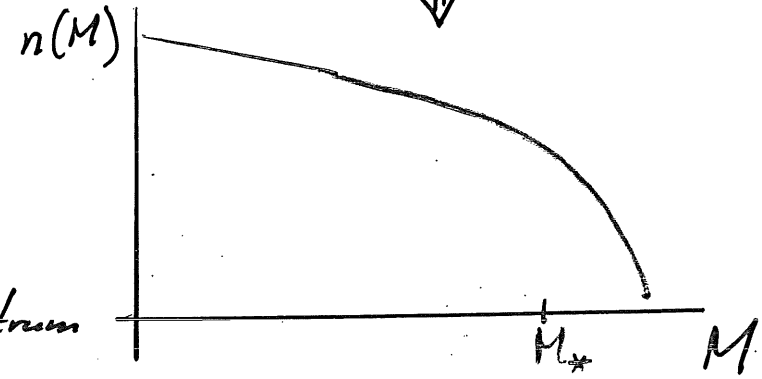
③ Press-Schechter / Excursion Set formalism

- Approximate Description for Hierarchical Structure Formation Scenarios
- simplest form based on spherical model.

(in principle suited to invoke further complexities).



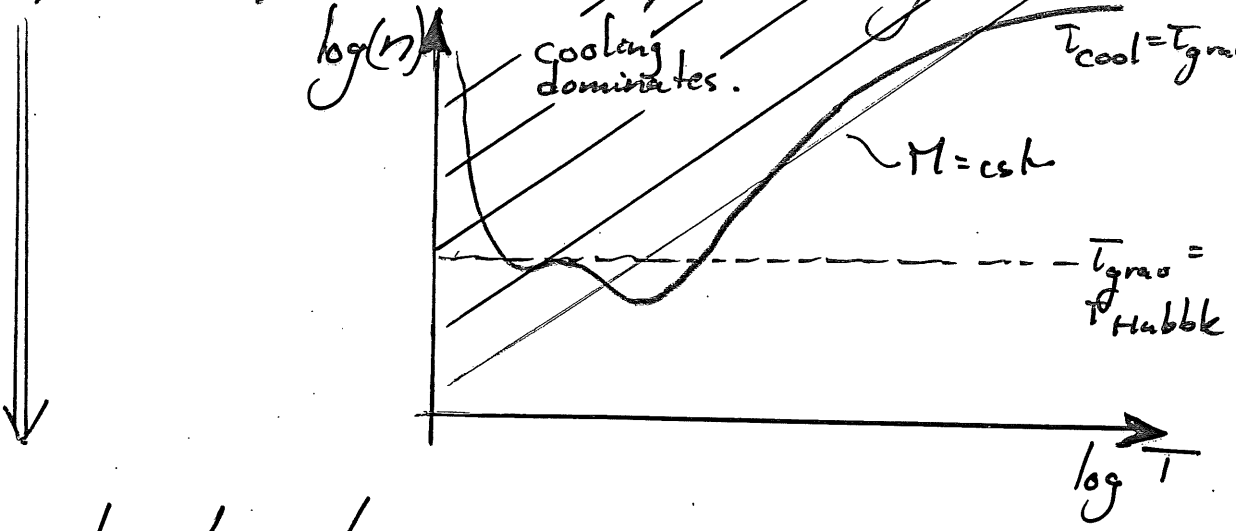
predictions influence cosmology on condensations nonlinear objects. e.g. cluster mass spectrum



Stage 4 DISSIPATIONAL phase

Dissipational :

- as gas follows into nonlinear potential wells, dissipative effects kick in prominently.



energy loss by cooling processes ⟹
reduction of pressure ⟹
infall and further compression baryons.

⇓

Crucial for formation of galaxies & stars

⇓

highly complex interplay of various physical processes:
- radiative processes
- thermodynamic processes
- star formation
- stellar feedback processes
- etc.

Still largely un-understood