THE AMAZING WORLD OF Effective Field Theory of Large Scale Structures & Redshift Space Distortions

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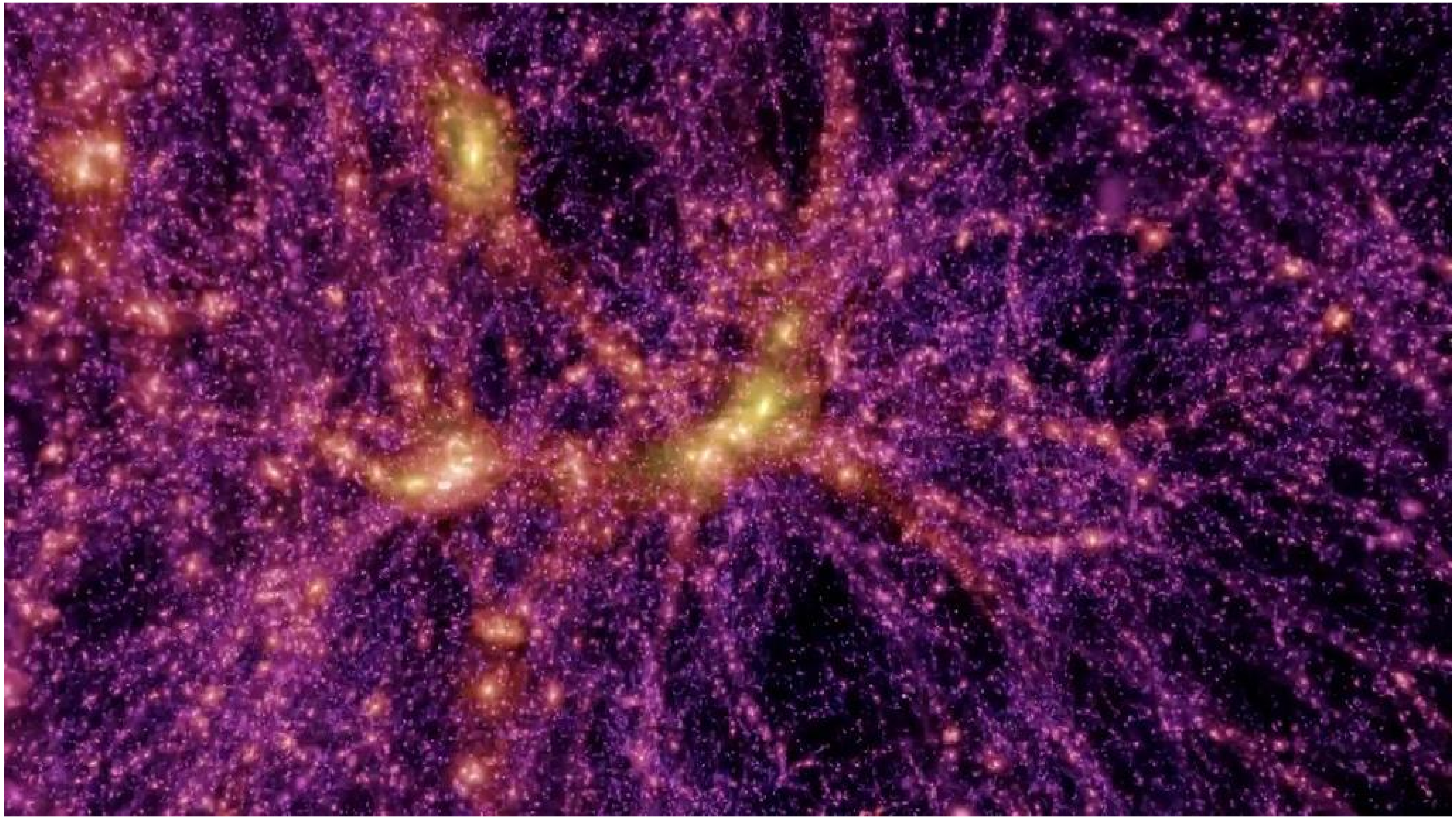
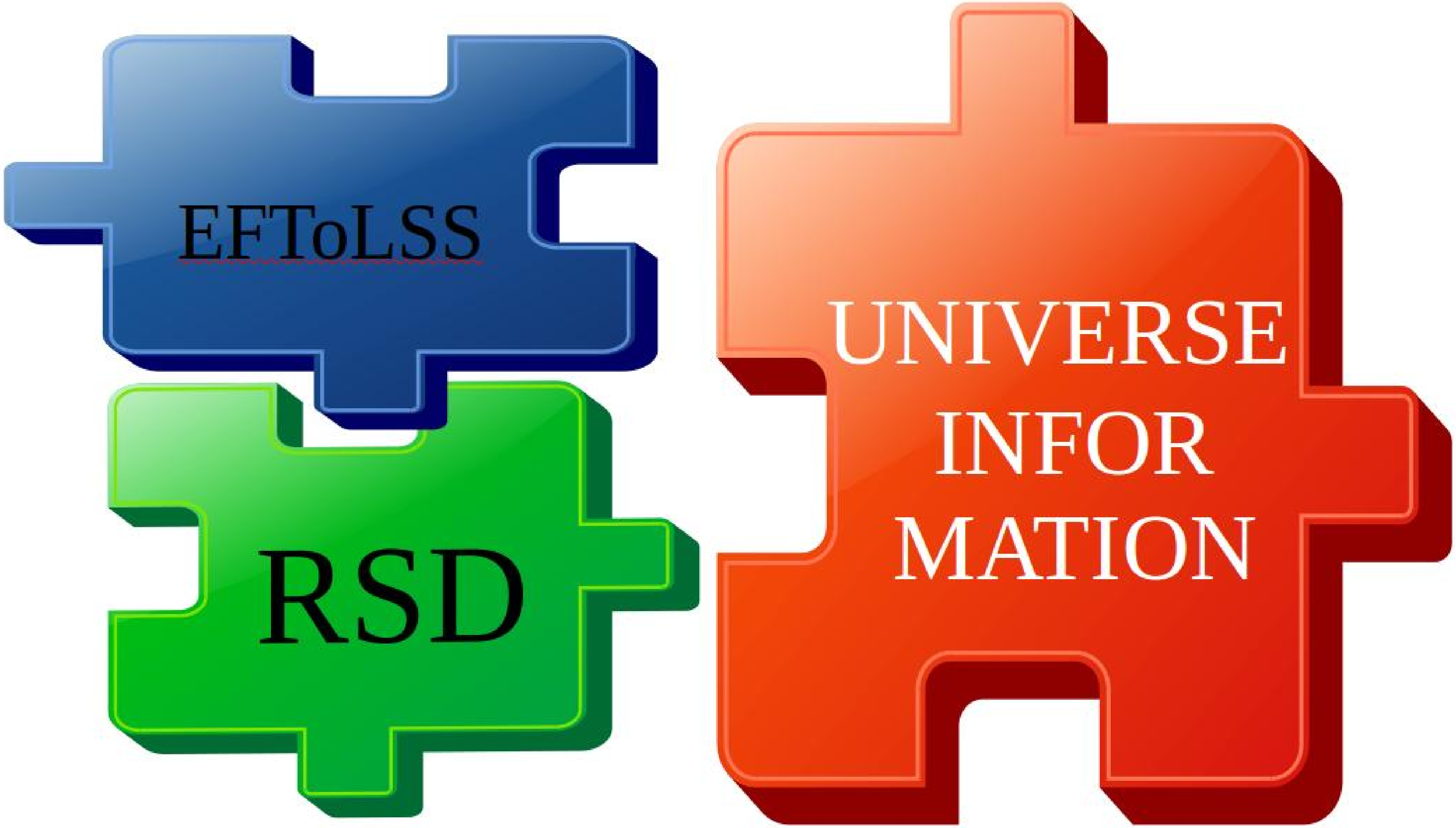
"...to boldly go where no one has gone before..."

...why is this important?

Millenium simulation. Springer et al 2005

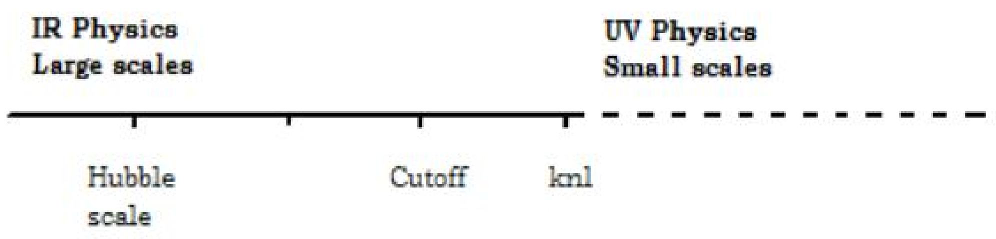


...we'll talk about



EFToLSS- Effective Field Theory of Large Scale Structures

Carrasco, Hertzberg, Senatore 2012



- Large Scale Structures
  - Most relevant information.
  - described by the density contrast of dark matter $\delta = \frac{\Delta\rho}{\rho_0}$ and the matter power spectrum, P.
  - Evolve almost linearly ⟶ PERTURBATION THEORY

Standard Perturbation ✗

- No good agreement with new generation of high precision observational data
- Perfect fluid
- UV divergences → Unphysical predictions

EFToLSS ✓

- Much better fit with observations.
- Viscosity, dissipation...
- UV divergences absorbed by counterterms!

- Fluid equations in k space

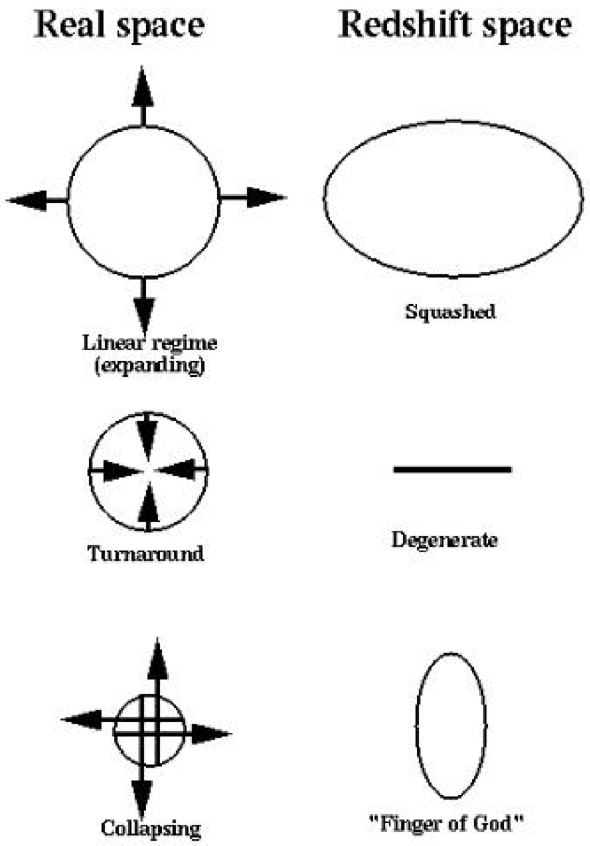
$$\dot{\delta}_k + \Theta_k = -\int \frac{\mathrm{d}^3\vec{q}\,\mathrm{d}^3\vec{r}}{(2\pi)^6}(2\pi)^3\delta(\vec{k}-\vec{q}-\vec{r})\alpha(\vec{q},\vec{r})\Theta(\vec{q})\delta(\vec{r})$$

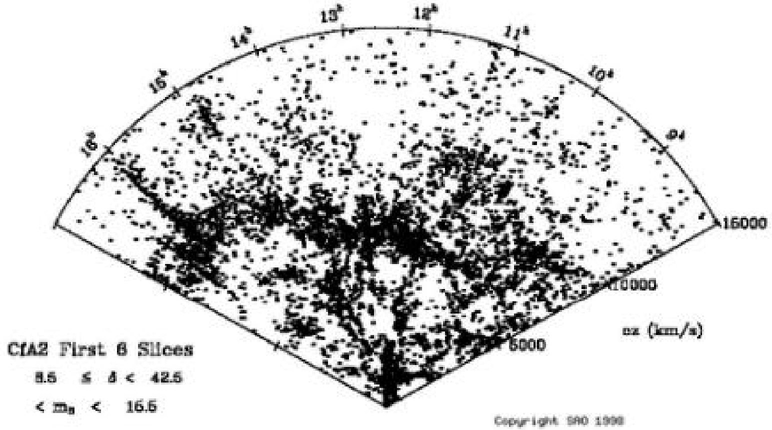
$$\dot{\Theta}_k + 2H\Theta_k + \frac{3}{2}H^2\Omega_M(z)\delta_k = \boxed{-\frac{k^2}{a^2}[Z_\delta\delta_k + Z_\Theta\Theta_k]} - \int \frac{\mathrm{d}^3\vec{q}\,\mathrm{d}^3\vec{r}}{(2\pi)^6}(2\pi)^3\delta(\vec{k}-\vec{q}-\vec{r})\beta(\vec{q},\vec{r})\Theta(\vec{q})\Theta(\vec{r})$$

Theta is the divergence of the velocity field, alpha and beta are kernels.

RSD- Redshift Space Distortions

Kaiser 1987



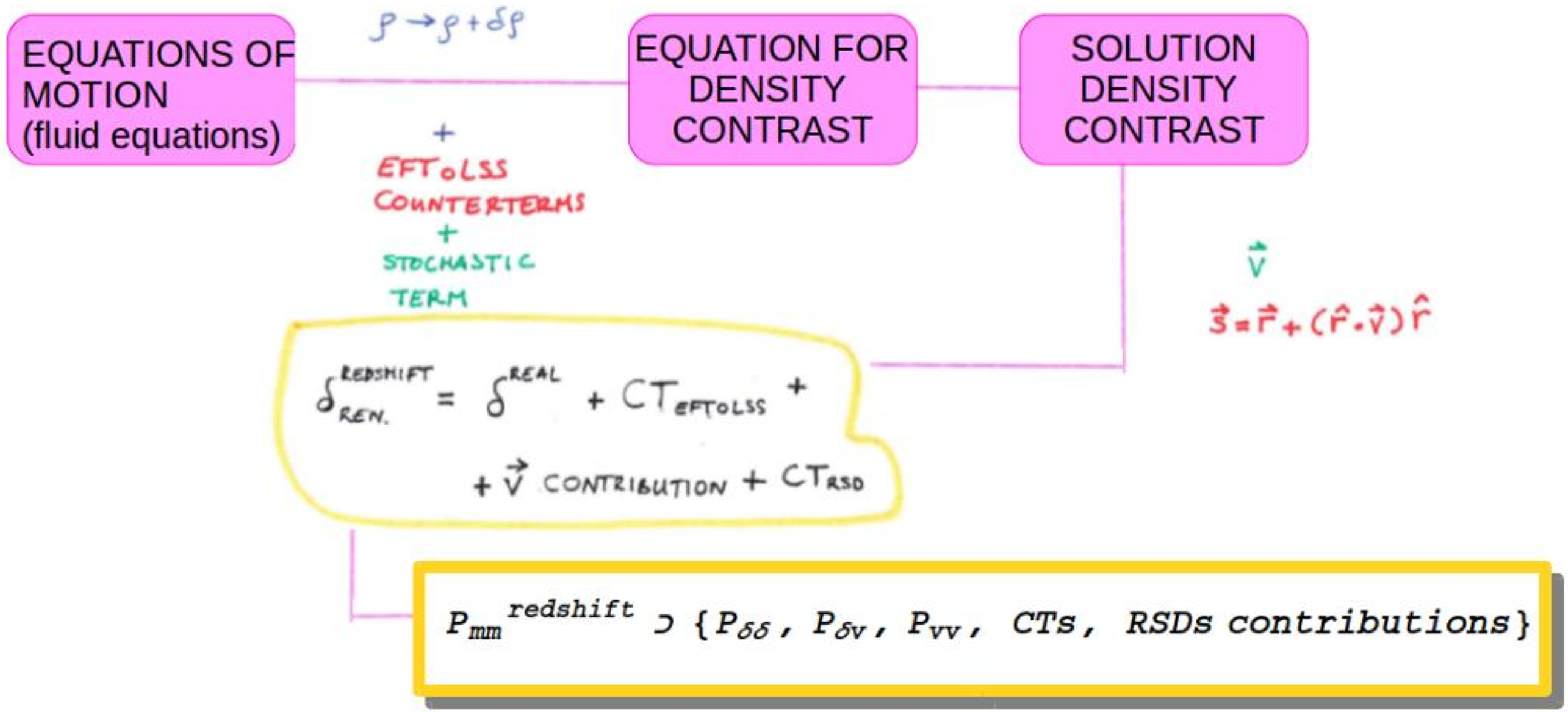


- Learn about velocities.
- Additional countertem (CT) contributions to the matter power spectrum involving velocity fields.

EFToLSS & RSD

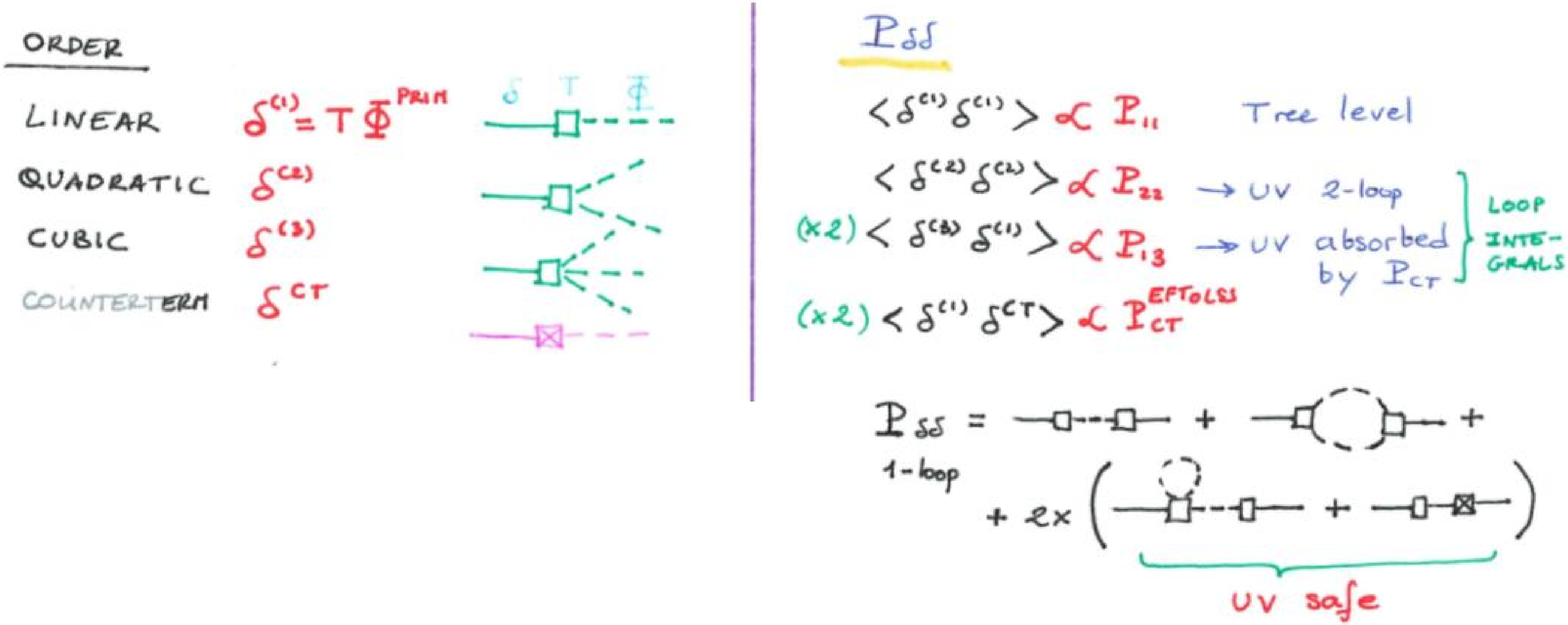
Senatore, Zaldarriaga 2014

- Power spectrum $< \delta^*(k,z)\delta(k',z) >= (2\pi)^3 \delta_D(\vec{k}+\vec{k}')P(k,z)$



…1-loop corrections

- Solving equation for density contrast



- Analogously, for $P_{\delta v}$ and P_{vv}

…1-loop matter power spectrum in Redshift Space

$$
\begin{aligned}
P_{r,\delta,\delta,||\text{1-loop}}(k,\mu,t) =\ & P_{\delta,\delta,||\text{1-loop}}(k,t) + 2\mu^2 P_{\delta,\frac{\dot\delta}{H},||\text{1-loop}}(k,t) \\
& + \mu^4 P_{\frac{\dot\delta}{H},\frac{\dot\delta}{H},||\text{1-loop}}(k,t) - \left(\frac{k\,\mu}{aH}\right)^2 P_{\delta,[v_z^2],\text{tree}}(k,t) \\
& - \mu^2 \left(\frac{k\,\mu}{aH}\right)^2 P_{\frac{\dot\delta}{H},[v_z^2],\text{tree}}(k,t) + \frac{1}{4}\left(\frac{k\,\mu}{aH}\right)^4 P_{[v_z^2],[v_z^2],\text{tree}}(k,t) \\
& + (1+f\mu^2)\left(\frac{k\,\mu}{aH}\right)^2 P_{\delta,[\delta\, v_z^2],\text{tree}}(k,t) + \frac{i}{3}(1+f\mu^2)\left(\frac{k\,\mu}{aH}\right)^2 P_{\delta,[v_z^3],\text{tree}}(k,t) \\
& - (1+f\mu^2)\left[(c_1+c_2)\,\mu^2 + (c_1+c_3)\,\mu^4\right]\left(\frac{k}{k_{\text{NL}}}\right)^2 P_{\delta,\delta,11}(k,t)\ ,
\end{aligned}
$$

UV DIVERGENCES AND RENORMALISATION

	LOCAL	NON-LOCAL	EFFECTS
MANIFEST BY	ANALYTIC	NON-ANALYTIC	TERMS
STRUCTURE	=	≠	COUNTERTERMS
CUTOFF	DEPENDENT	INDEPENDENT	
PHYSICAL	X	V	
PREDICTED BY EFFECTIVE THEORY	X	V	

- Local in wave number, k.
- Analytic means polynomial in $\mathbf{k}^2$.
- Non-analytic, log or fractional powers of $\mathbf{k}^2$.

- Example of loop integrals in momentum space found in P_{13}

$$I_{\alpha\alpha}(\Lambda) = \int^{\Lambda} \frac{d^3\vec{q}}{(2\pi)^3}\mathcal{P}_R(\vec{q})\alpha(\vec{k},-\vec{q})\alpha(\vec{k}-\vec{q},\vec{q})$$

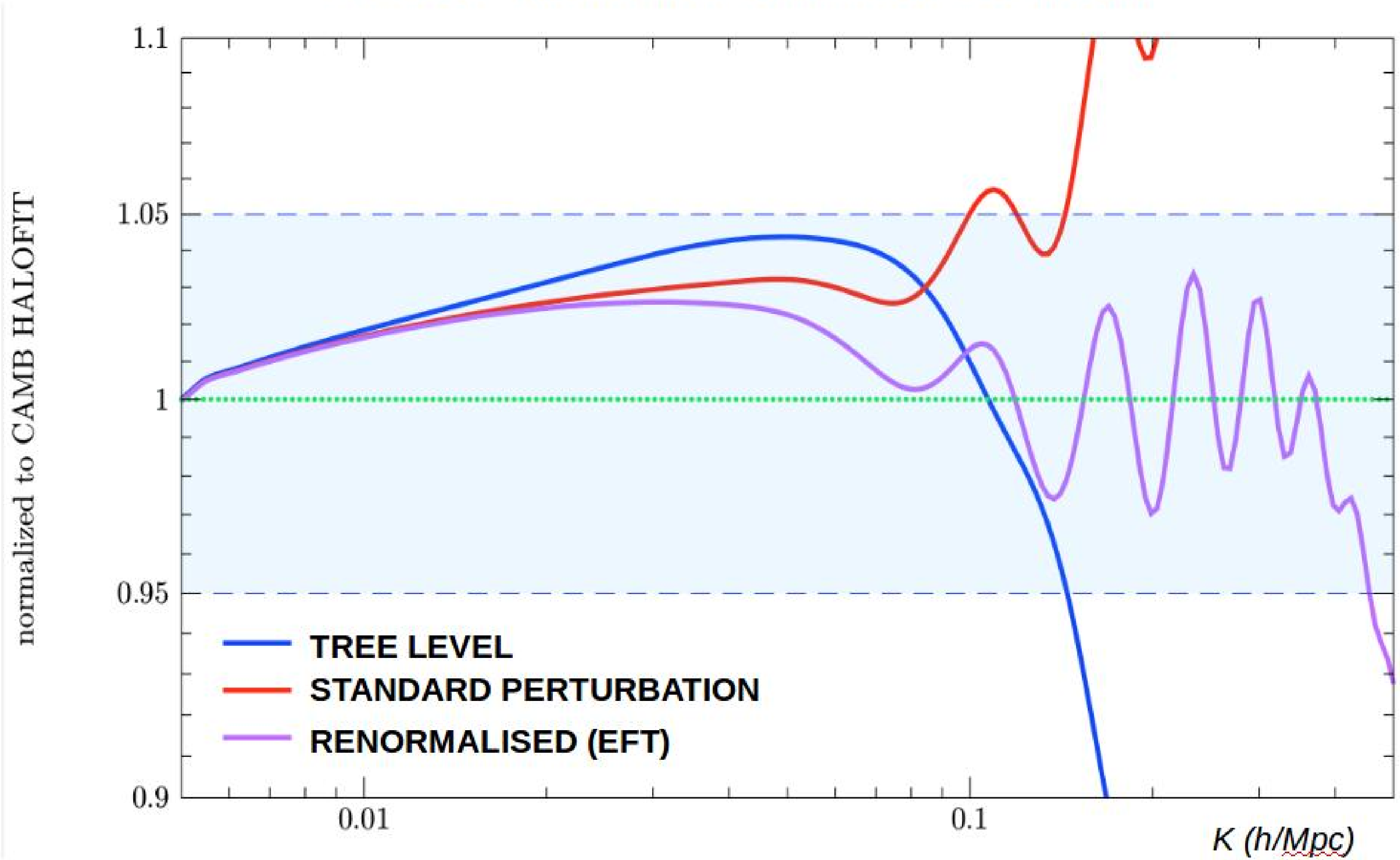
$$= \underbrace{\int_0^{k_*} \frac{d^3\vec{q}}{(2\pi)^3}\mathcal{P}_R(\vec{q})\alpha(\vec{k},-\vec{q})\alpha(\vec{k}-\vec{q},\vec{q})}_{k_* << k \text{ regime, } \Lambda\text{-independent}} + \underbrace{\int_{k_*}^{\Lambda} \frac{d^3\vec{q}}{(2\pi)^3}\mathcal{P}_R(\vec{q})\alpha(\vec{k},-\vec{q})\alpha(\vec{k}-\vec{q},\vec{q})}_{k/k_* << 1 \text{ Taylor expansion, } \Lambda\text{-dependent}}$$

$$= \underbrace{\underbrace{a_1(\Lambda)}_{\text{fixed by renormalisation}} \cdot k^2}_{\text{analytic behaviour, UV sensitive}} + \underbrace{\underbrace{b_1}_{\text{low-energy}} \cdot k^3}_{Non-analytic} + O(k^4).$$

COUNTERTERMS

Fit cubic polynomial

1 LOOP MATTER POWER SPECTRUM



Repeat analysis for $P_{\delta,\frac{\dot{\delta}}{H},||_{\text{1-loop}}}(k,t)$, $P_{\frac{\dot{\delta}}{H},\frac{\dot{\delta}}{H},||_{\text{1-loop}}}(k,t)$ and rest of counterterms

CONCLUSIONS

- The Universe is treated as a fluid. Most of the relevant information in Cosmology is found at large scales.
- At large scales, galaxies are point-like objects. There exist voids, filaments, clusters of galaxies...
- We want to study the backreaction from small scales and the so-called Redshift Space Distortion effect on large scale structures.
- Simulations are very expensive. We would need to run several simulations with different initial conditions.
- Effective Field Theory of Large Scale Structures is a powerful tool
  - This framework solves those theoretical issues present in Standard perturbation theory.
  - Some parameters need to be included in the analytical prediction and need to be measured by matching to numerical data → Renormalisation.
  - It agrees much better with new high precision observational datasets.

& PROSPECTS

- To obtain the renormalisation for the 1 loop matter power spectrum in Redshift Space.
- Compare with observations and N-body simulations.
- To apply this tool to the analysis of the screening mechanism in theories of Modified Gravity.

...1-loop $P_{\delta\delta}$ renormalisation

- $P_{\delta\delta\,|\,1\text{-loop}} = P_{11} + P_{13} + P_{CT}$

  Tree level UV-div

- Low-k behaviour (analytic terms) ↣ Taylor expansion loop integrals

$$P_{13}(k,z) \approx P_{11}(k,z)\, k^2\, h(z) \underbrace{\int_0^{\Lambda} \frac{dq}{2\pi^2}\, \mathcal{P}_{\mathcal{R}}(q)}_{\mathcal{A}(\Lambda)}$$

Cutoff dependence eliminated by CT in the UV limit (same k & z dependence up to a constant)

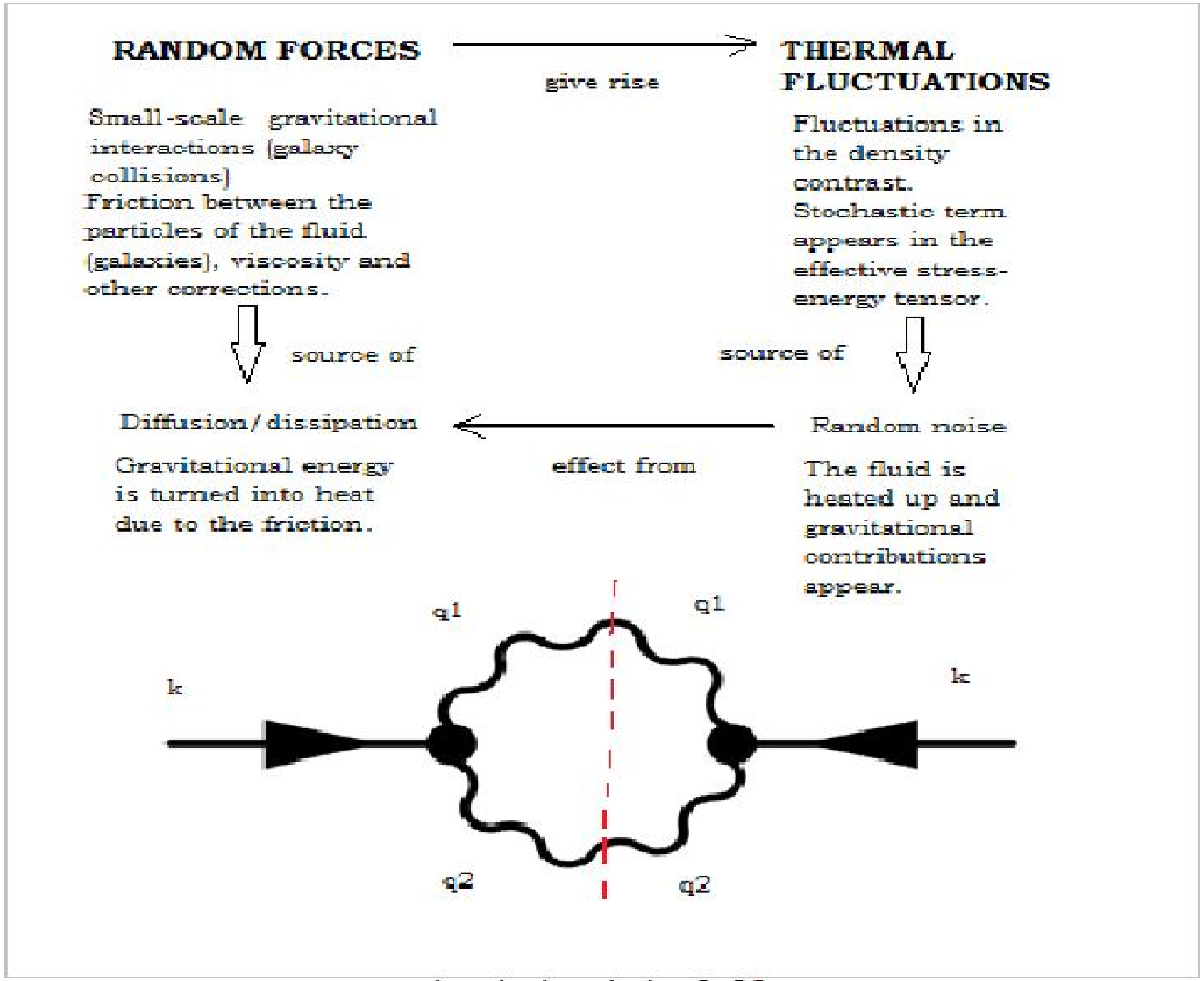
Therefore,

$$P_{\delta\delta\,|\,1\text{-loop}} = P_{11}\left(1 + {c_s}^2\, h(z)\, k^2\right)$$

Renormalisation parameter

Fixed observationally or by simulations

Stochastic term



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