Towards the one-loop galaxy bispectrum in the weak field aproximation

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Abstract

We perform a calculation which is non-linear and is based in General relativity under the weak field approximation with the purpose to solve the dynamics for dark matter fluid. And connect the dark matter perturbation with the number density of galaxies through a bias expansion. We write the Lagrangian bias expansion in terms of operators built on the curvature of early time hypersurface of comoving observer and evolve it to obtain the Eulerian bias description in the general relativistic framework which is also renormalized properly. These are the first steps towards to determine the gauge invariant galaxy bispectrum.

Dark matter evolution

The starting point is to determine the dark matter evolution in the expanded universe. For this the perturbed Friedmann Lemaître Robertson Walker (FLRW) metric is used

$$ds^2 = -\left(1+2\phi\right)dt^2 + 2\omega_i dt dx^i + a(t)^2\left[\left(1-2\psi\right)\delta_{ij} + \gamma_{ij}\right]dx^i dx^j$$

where a is the scale factor, t is the cosmic time and x^i are the Cartesian comoving coordinates. The off-diagonal part of the metric is split as $\omega_i = \partial_i\omega + w_i$ with $\partial_i w_i = 0$.

The matter content of the universe is considered as a barotropic irrotational fluid with stress-energy momentum tensor given by

$$T_{\mu\nu} = \bar{\rho}(t)\left(1+\delta(t,\boldsymbol{x})\right)u_\mu u_\nu$$

where $\bar{\rho}$ is the background density, δ is the matter density contrast and u_μ is matter fluid 4-velocity, we assume matter-dominated Einstein-de Sitter universe. We take the weak field approximation, that is all the metric perturbations and the fluid velocity are considered small

$$\phi \sim \psi \sim \omega \sim \left(\frac{H^2}{\nabla^2}\right) = \mathcal{O}(\epsilon) \ll 1, \quad w_i \sim \mathcal{O}(\epsilon^{3/2}), \quad \gamma_{ij} \sim \mathcal{O}(\epsilon^2)\,.$$

Stress energy tensor and metric perturbations satisfy the continuity and Einstein equations respectively. The Fluid Equations are

Continuity equation

$$\dot{\delta} + \theta = -\partial_i\left(\delta u^i\right) + S_\delta\left[\psi, \delta, u^i\right]$$

Mass conservation

Euler equation

$$\dot{\theta} + 2H\theta + \frac{3}{2}H^2\delta = \partial_j\left(u^i\partial_j u^i\right) + S_\theta\left[\psi, \delta, u^i\right]$$

Momentum conservation

Einstein equations

$$\nabla^2\psi = \frac{5}{2}H^2\delta + S_\psi[\psi,\delta,\theta] \qquad \nabla^2 w_i = S_w[\psi,\delta,\theta]$$

Where $\partial_i u^i$. The sources contain relativistic corrections up to order ϵ. In order to solve the system of equations we do the separation $\delta = \delta_N + \delta_R$ and $u_i = u_N^i + u_R^i$ where u_R^i is decomposed its longitudinal and transverse part. Additionally, we consider $\delta \ll 1$ and the solution up to fourth order perturbations in Fourier space is given by (For more details see [2])

$$\delta(t,\boldsymbol{k}) = \sum_{n=1}^{\infty} a^n(t)\int_{\boldsymbol{k}_1\cdots\boldsymbol{k}_n}(2\pi)^3\delta_D(\boldsymbol{k}-\boldsymbol{k}_{1\cdots n})\left[F_n\left(\boldsymbol{k},\cdots,\boldsymbol{k}\right) + a^2(t)H^2(t)F_n^R(\boldsymbol{k}_1,\cdots,\boldsymbol{k}_n)\right]\delta_l\left(\boldsymbol{k}_1\right)\cdots\delta_l\left(\boldsymbol{k}_n\right)$$

Relativistic galaxy bias

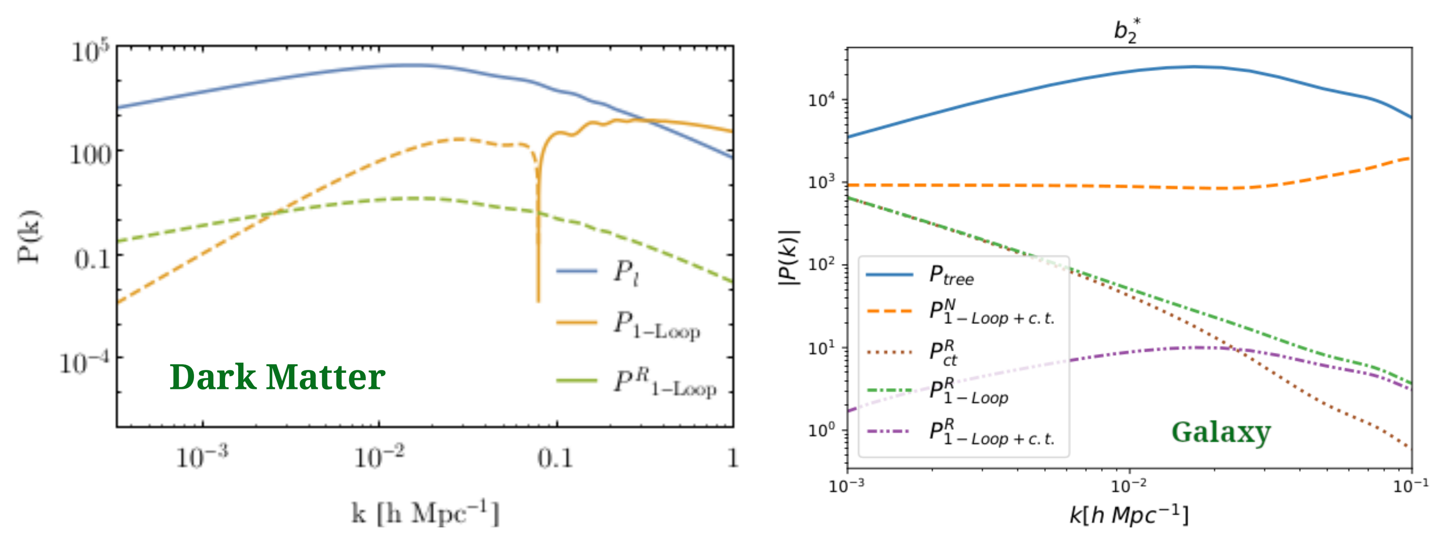
In [1] we consider biased tracers such as galaxy clusters. Due to galaxy formation is a complex process its description and connection with dark matter at large scales is made through the bias expansion, where the unknown physics is parameterized in the bias coefficients $b_{\mathcal{O}}$. The expansion is made by taking into account the following considerations:

- The bias expansion should only depend on the quantities that an observer would measure such as the local curvature.
- We assume the four velocity of galaxies is the same as the one for dark matter fluid, then we neglect bias velocity.
- We write down the bias expansion in terms of geometrical quantities describing the hypersurfaces of constant comoving time of observers at a very early time.
- Our first building blocks are the extrinsic curvature $K_{\mu\nu}$ of the constant-time hypersurfaces, and the matter density contrast δ.
- We take the Lagrangian expansion up to four order and evolve it with the Fluid Equations taking $\delta \to \delta_g$.
- Operators are renormalized such that expectation value of δ_g vanish and long wavelength correlation functions behave well.

Correlation functions

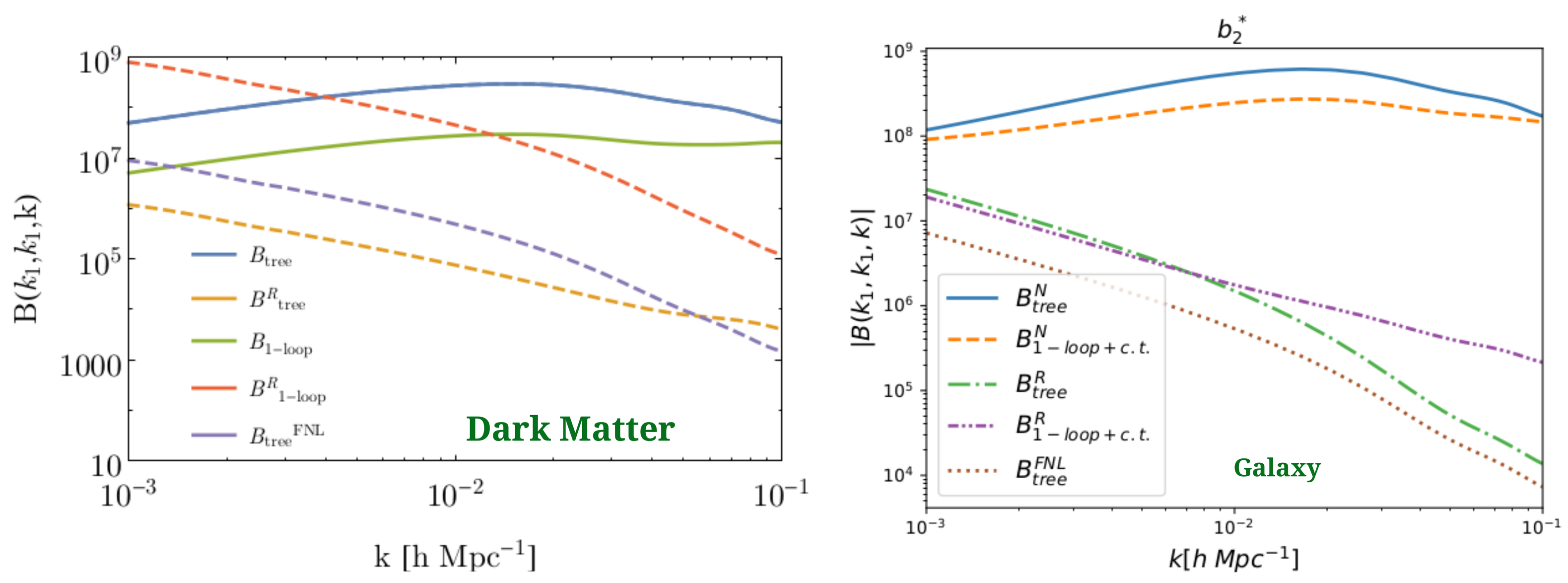
Power spectrum up to one loop

$$\langle\delta(\boldsymbol{k}_1)\delta(\boldsymbol{k}_2)\rangle = (2\pi)^3\delta_D(\boldsymbol{k}_{12})P(k_1) \qquad P(k) = P_{11}(k) + P_{22}(k) + P_{13}(k)$$



Bispectrum up to one loop

$$\langle\delta(\boldsymbol{k}_1)\delta(\boldsymbol{k}_2)\delta(\boldsymbol{k}_3)\rangle = (2\pi)^3\delta_D(\boldsymbol{k}_{123})B(\boldsymbol{k}_1,\boldsymbol{k}_2,\boldsymbol{k}_3)$$



Conclusions

Relativistic correction to the bispectrum is as large as the Newtonian result in the squeeze limit. Also in this limit it is degenerated with the primordial non-Gaussianity signal of the local type $F_{NL} \sim \mathcal{O}(1)$. Thus when comparing to observations relativistic corrections must be taking into account due to they could contaminate the primordial non-Gaussianity signal. $1/k^2$ behavior in the galaxy power spectrum and galaxy bispectrum is cancel for the counter-terms from renormalization.

References

[1] J. Calles, L. Castiblanco, J. Noreña, and C. Stahl. From matter to galaxies: General relativistic bias for the one-loop bispectrum. *JCAP*, 07:033, 2020.

[2] L. Castiblanco, R. Gannouji, J. Noreña, and C. Stahl. Relativistic cosmological large scale structures at one-loop. *JCAP*, 07:030, 2019.

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