Primordial Non-Gaussianity in Spectral Distortions and PBH constraints

Devanshu Sharma[1], Julien Lesgourgues[1], Christian Byrnes[2]

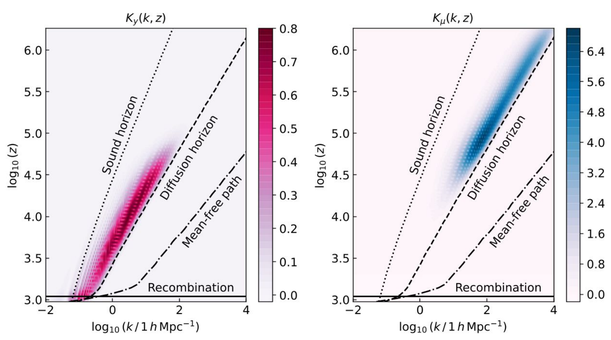
[1]Institute for Theoretical Particle Physics and Cosmology (TTK), RWTH Aachen University, D-52056 Aachen, Germany
[2]Department of Physics and Astronomy, University of Sussex, Brighton BN1 9QH, UK

Inception

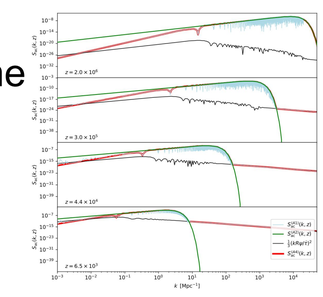
- Distortions may be induced in the frequency spectrum of the Cosmic Microwave Background (CMB) by a number of astrophysical and cosmological processes. In this work, we consider the spectral distortions via acoustic dissipation sourced by the inflationary scalar perturbations.
- Motivated by the fact that the presence of primordial non-Gaussianity (NG) could change the small-scale picture of the baby universe, we quantify the enhancement in the dissipation of acoustic waves in NG scenario and compose a formalism to constrain the primordial power spectrum.
- Furthermore, we provide the modified bounds on the Primordial Black Holes (PBHs) if they were to seed the present Supermassive Black Holes (SMBHs).

Dissipation Source Function

- Continuous energy injection over the history and time-varying efficiency of baryon-photon interaction main culprits.
- This leads to epoch-based classification of the distortions into μ-type and y-type distortions plus some residuals.



- Introduce the most accurate hybrid scheme to compute the distortion source function;in agreement with Cyr et al (2023).



Non-Gaussian model

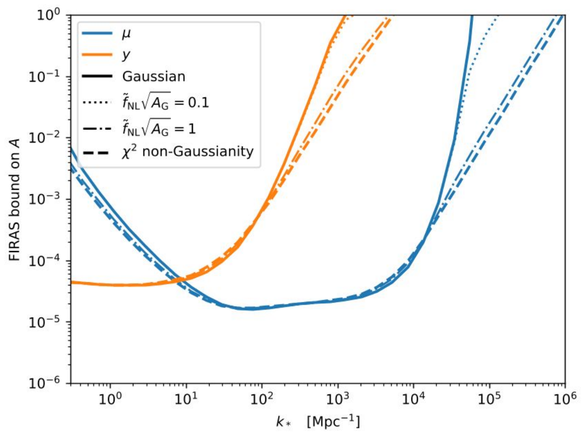
- We model the leading order NG correction with a χ^2- type local term

$$\mathcal{R}(\vec{k}) = \mathcal{R}_{\rm G}(\vec{q}) + \tilde{f}_{\rm NL} \int \frac{d^3\vec{q}}{(2\pi)^{3/2}} \mathcal{R}_{\rm G}(\vec{q})\mathcal{R}_{\rm G}(\vec{k}-\vec{q})$$

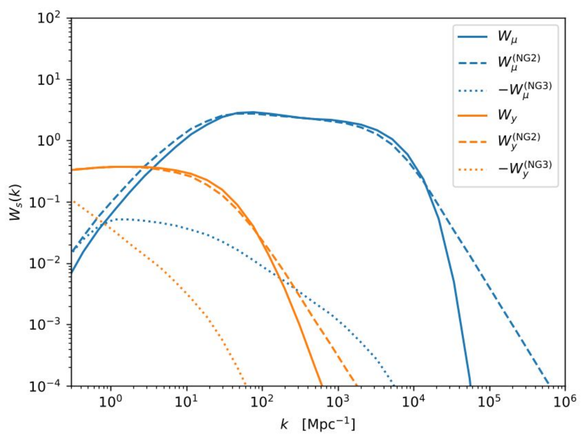
- Perturbative limit : $|\tilde{f}_{\rm NL}|\langle \mathcal{R}_{\rm G}^2\rangle^{1/2} \ll 1$
- Non-perturbative limit : $|\tilde{f}_{\rm NL}|\langle \mathcal{R}_{\rm G}^2\rangle^{1/2} \gg 1$
- NG term completely dominates over the Gaussian term in the non-perturbative limit hence, also called the χ^2 limit.

Spectral Distortions

- Leading order NG correction comes from $\langle\Theta^2\rangle$.
- Perturbative regime sees minuscule deviation from Gaussian case.
- Due to mode-mode coupling dominating in the χ^2 limit, the power spectrum stretches out and tightens at small scales.

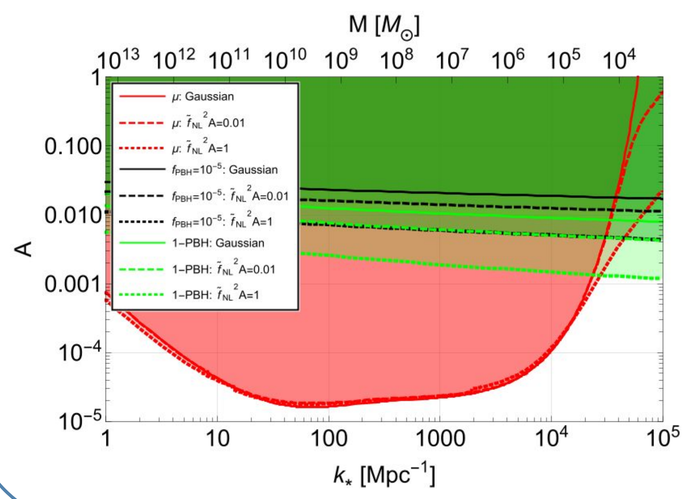


- Next to leading order contribution $\langle\Theta^3\rangle$ suppressed by the zero-centered oscillations of the monopole moment.

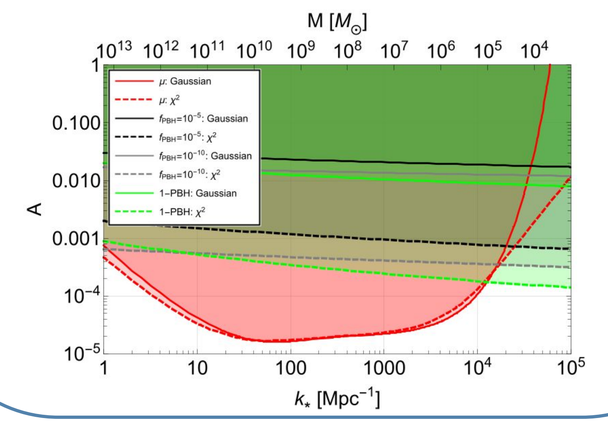


SM-PBH Bounds

- PBH Scales relevant for primordial SMBH (SM-PBH) seeds are tightly constrained from μ-type distortions.
- Not a single SMBH can be of primordial origin in the Gaussian regime for $M_{\rm PBH} \geq 10^4 M_\odot$.
- The picture remained majorly unaffected in the perturbative limit where the PBH bound and maximum PBH mass do not change vastly.
- Things become interesting in the extreme perturbative limit but still weaker than the μ constraint.

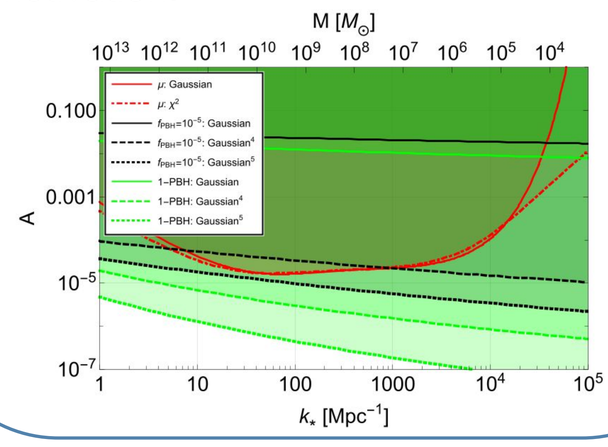


- In the χ^2 limit, the PBH bound comes down by more than one order.
- The μ constraint still does not allow a single SM-PBH.
- The intersection of μ constraint and PBH bound shifts to higher mass by little less than order of one.
- Neglecting the mass change due to accretion and clustering, the heaviest (single) SMBH of primordial origin would be $M^{\rm P}_{\rm SMBH} \lessapprox 10^5 M_\odot$.



Stronger non-Gaussianities

- Even χ^3- type NG incapable to produce at least one SM-PBH without evading μ observations.
- Small abundance of PBHs allowed in more stronger NG for masses as large as $M^{\rm P}_{\rm SMBH} \sim 10^{12} M_\odot$.
- Such NG suffer from lack of physical motivation.



Discussion

- Distortion constraints change at percent level in perturbative NG but flatten substantially at smaller scales in χ^2 limit.
- PBH bounds and maximum mass PBH change mildly in the perturbative limit whereas in χ^2 case, the PBH bound tightens, maximum PBH mass increases.
- Higher powered NG promising with $\chi^n\big|_{n>3}$ escaping μ constraint for tiny PBH fraction.

References

1. **DS**, J. Lesgourgues, C. Byrnes (2024) [arXiv:2404.18474].
2. C Byrnes, J Lesgourgues, **DS** (2024) [arXiv:2404.18475].