STUDYING INHOMOGENEOUS UNIVERSES AND MODIFIED GRAVITY WITH STANDARD SIRENS

Marios Kalomenopoulos[1,a], Sadegh Khochfar[1], Jonathan Gair[2], Shun Arai[3]

[1]Institute for Astronomy, University of Edinburgh, Royal Observatory, Edinburgh EH9 3HJ, UK.
[2]Max Planck Institute for Gravitational Physics, Potsdam Science Park, Am Muhlenberg 1, D-14476 Potsdam, Germany.
[3]Center for Gravitational Physics, Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan.
[a]`mariok@roe.ac.uk`

Introduction

During this project [3], we want to investigate the large-scale structure of the universe with gravitational wave (GW) observations that have an electromagnetic (E/M) counterpart, and its effect on the GW signals. This allows an independent confirmation of the concordance model which is based on the Friedmann-Lemaître-Robertson-Walker (FLRW) metric and the investigation of possible degeneracies with modified gravity theories. On this poster, we present results on:

- Constraints on inhomogeneous parameters exploiting future GWs measurements and their E/M counterparts.
- The level of the degeneracy between GW signals expected in modified gravity theories and cosmological models based on standard gravity, but including matter density inhomogeneities.

Model & Simulations

A GW detection with an E/M counterpart leads to two independent observables: the **luminosity distance** to the source d_{GW} and its **redshift** z.

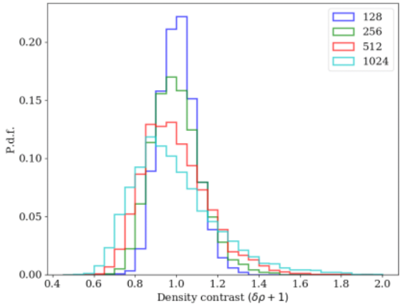

Fig. 1: Distribution of densities along 1D trajectories ($\langle\delta\rangle_{1D} + 1$) on simulations of different resolution, at $z = 0$.

Assuming an inhomogeneous cosmological model, we can convert the observed redshift to a luminosity distance $d_L^{\rm inh}$. Comparing this distance with d_{GW}, we are able to constrain the parameters that enter the inhomogeneous models.

In our case, we exploit two inhomogeneous distance models [2], the Dyer-Roeder (DR) and the modified Dyer-Roeder (mDR), that include an extra parameter α, which describes the clustering of the matter in the universe ($\alpha = 1$ corresponds to the standard ΛCDM cosmology, while $\alpha = 0$ to the extreme "empty beam" case, where all matter in the universe is highly clustered).

This effective description has been parameterised as: $\alpha(z) = a_0 + a_1 z$ or $\alpha(z) = 1 + f(z)\langle\delta\rangle_{1D}$, where a_0, a_1 are arbitrary constants, the function $f(z)$ is chosen to be consistent with weak lensing studies [1] and $\langle\delta\rangle_{1D}$ denotes the average present-time density contrast along a ray, with $\delta = \delta\rho/\rho$.

We create mock GW observations based on a population synthesis model and use the LEGACY suite of cosmological N-body simulations to obtain realistic anisotropies along rays (Fig 1). The highest resolution (1024^3 grid cells) is used in the following.

Homogeneity Probe

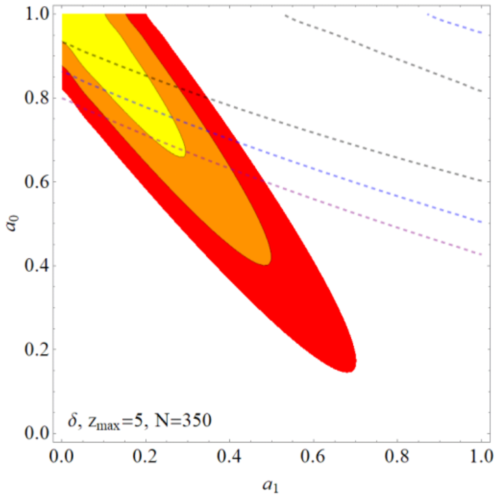

Fig. 2: Constraints on the inhomogeneity parameters (a_0, a_1) based on a realistic density distribution from numerical simulations. For both cases (DR - filled contours, mDR - dashed contours) there is consistency with a FLRW background, where $(a_0, a_1) = (1, 0)$. More detections or smaller observational errors would be needed to significantly improve constraining power.

Degeneracy with Modified Gravity

Modifications to General Relativity (GR) can also induce changes in the distances calculated from GWs. More specifically, there are models that include an extra "friction term" ν, leading to larger inferred distances: $d_L^{\rm GW}(z) = d_L^{\rm E/M}(z)\ (1+z)^{\nu/2}$.

Inhomogeneous models also result in higher distances. Hence a deviation from ΛCDM, can occur both ways and an investigation of possible systematics due to inhomogeneities need to be done before constraining modified gravity parameters.

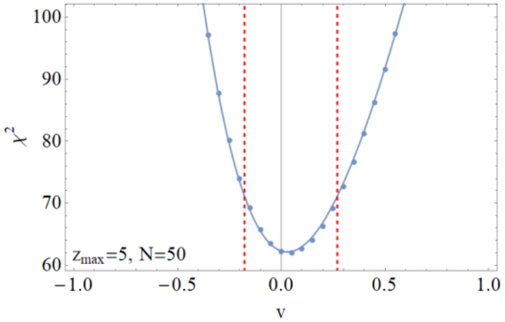

Fig. 3: χ^2 fit of a modified gravity model for realistic inhomogeneous distances from a cosmological simulation. The vertical lines denote the 99% confidence limits. Even a large number of observations ($N = 50$) requires deviations from $\nu = 0$ of the order of $\mathcal{O}(0.1)$ to disentangle modified gravity effects.

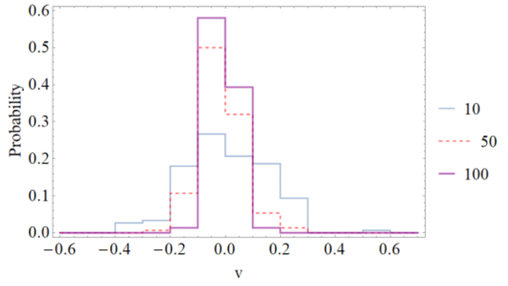

Fig. 4: Probability distribution for the ν parameter based on different number of observations. The presence of inhomogeneities can mimic a deviation from GR, leading to higher uncertainties when constraining ν. $N \geq 100$ would be required to increase accuracy on ν at the order of $\mathcal{O}(0.1)$.

References

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