Preferred Foliation in Modified Gravity Theories

Our understanding of gravity has hugely improved in the last century with the development of Einstein's theory of general relativity. It enables us to describe the evolution from our Universe from the Big Bang up to today with the formation of stars and galaxies up to a very high accuracy. However, it requires the postulation of unknown new energy ingredients: dark matter, which is responsible for the formation and stability of galaxies, and dark energy, which causes the accelerated expansion of our Universe. A fundamental understanding of this dark sector, in particular from dark energy, is still missing. Therefore, alternative models have been proposed including modified theories of gravity, which change the laws of gravity in order to explain the current experimental observations.

Usually, in this modified gravity theories there is an additional scalar field, similar to the Higgs field in particle physics, leading to an additional force which pushes the space apart and causes the accelerated expansion. In this case, we also say that there is an additional scalar degree of freedom.

In general relativity and also in many modified gravity models the time and space directions in our four-dimensional spacetime are not fixed but instead we can freely choose which direction we choose as time without changing any physics. The choice of the time direction is also called the foliation of spacetime. Recently, there has been a growing attention to modified gravity theories with a preferred foliation, namely where the choice of the foliation of spacetime impacts if the scalar degree of freedom is present or not. This discrepancy remains an open issue.

On the other side, this kind of models can provide interesting new phenomenological properties. Even if there is no additional scalar degree of freedom in this preferred foliation, this kind of models can have a significantly different behavior from standard general relativity. As one example, it has been shown that in this kind of models it might be possible to reduce some of the current observational discrepancies which are present in the current standard model of Cosmology like the Hubble tension.

In our research we want to focus on this kind of models. First, we want to investigate the origin and the physical consequences of the preferred foliation. As a second aspect, we are interested in phenomenological consequences and we want to investigate how we can test this theories with current or future experimental observations.

The result of this research project will help to clarify if this new class of modified gravity models can provide a viable description of the dark sector of our Universe both from the theoretical as on the experimental/observational side.