Probing the nature of dark matter with modified Poisson's equations

Most of the public opinion believes that "science" is "certainty". Thus, it would surely sound shocking to know that, at the present stage, scientists have no idea about what is the Universe made of. If we exclude ourselves and the small atomic particles which build up the world around us, astronomical observations are telling us that about 95% of the matter and the energy in the Universe come in unknown "dark" forms.

These puzzling components have a name: they are called Dark Matter and Dark Energy. The only thing we know about them is that they are out there, because we can measure them, indirectly. We can measure the velocity of the stars in the galaxies, and this velocity depends on the matter which is inside the galaxy. But if we take into account only the matter which we see, then, we conclude that stars are moving much faster than they should. This can be explained assuming that there is a lot of mass which we cannot see but which has some gravitational attraction; this is what we call Dark Matter, and we have evidence of it everywhere in the Universe. Dark Energy, instead, looks even weirder. Imagine to throw a stone in the sky and to see that, instead of stopping and falling, it starts to accelerate. The more it goes up in the sky, the more and the faster it will escape from you. That is what Dark Energy is doing: it is a sort of "anti-gravitational" force which is pushing forward, accelerating the expansion of the Universe.

One further thrilling ingredient in this history is that Dark Matter and Dark Energy emerge as "problems" only when we assume that the laws of Physics which we use to describe gravity here on the Earth or in the Solar System (we call this theory General Relativity, introduced by Albert Einstein about 100 years ago), are the same everywhere in the Universe. Thus, scientists are reflecting on two possibilities. The first one, is the more conservative, and is based on assuming that actually gravity does work everywhere in the infinite Universe as it does on our planet, but eventually at the expense of having two dark elements which we have not been able to understand and to find out in our laboratories. The second one is more exoteric and exotic, because pushes our minds to the borders of the known Physics: what if gravity is not simply described by General Relativity, but maybe by a more general theory, which might behave differently here or in a far galaxy, and for which Dark Matter and Dark Energy are not "real" but just manifestations of what we don't know yet about gravity?

In this project we will follow this second option. Such general theories are becoming more common in the scientific community, because they are helping us to understand many things about our Universe; they are called in many ways: "modified", "alternative", or "extended" theories of gravity. Unfortunately, it is not so easy to build up such alternatives: when we solve one problem, we create others; when we are able to explain some observations, we lose others. A lot of hard work is before us. One of the main problems is that you can create a theory which does all the craziest things you want in the outer space; but then, when you consider how it should behave on Earth, you must obtain General Relativity, because we know that this theory is working perfectly well here and now.

Here it comes the main motivation of our project. These extended theories of gravity are generally introduced to explain Dark Energy but not Dark Matter. In this project we will investigate a bit more about the nature of Dark Matter, working on one of the cornerstones of General Relativity, the Poisson's equation. This equation gives us a connection between the way matter distributes in the space and the way the gravitational force works. What would happen if we modified it from the standard version of General Relativity? Would Dark Matter effects and phenomenology change? Or more: would it be possible to get rid of Dark Matter at all? This would mean that Dark Matter is not a real physical entity, but a manifestation of a breakdown of General Relativity at large scales, and our modified Poisson' equation would be clue about what should be the real effective and more general theory of gravity we should seek for.

We will use as much data as we can from all that have been collected so far, ranging from galaxies to clusters of galaxies to even the largest scales of the cosmological background. We will look for new and unusual phenomena which could confirm or not our ideas. In any case, we are going to learn something more about how our crazy Universe behave.