Nonextensive entropies impact onto black holes and holography.

Two greatest discoveries of the last decade are the discovery of a black hole at the center of our galaxy and the discovery of gravitational waves being emitted in the collision of black holes in the distant universe. Both these discoveries confirmed that the black holes are real objects despite the fact they possess very peculiar property which is the event horizon – a spherical surface surrounding a black hole of which even the light cannot run away once being trapped by. This and other theoretical properties of black holes have been studied many years before their discovery also leading to the Nobel prize in physics awarded to Sir Roger Penrose in 2020. Formally, a black hole possesses a singularity at its center which characterizes by the infinite density and what is more curious is that no matter what falls into it and with what physical properties at the final stage of evolution the black hole is characterized only by its mass, rotation and electric charge. In that sense one looses the whole information about falling objects.

However, some physicists noticed that the black holes allow for the properties which are analogous to the systems which exchange heat. Such systems in standard physics are subject to thermodynamics in which the notions of heat and temperature appear. It emerged that one is able to formulate the thermodynamical laws for black holes in full analogy to common life systems like car engines. A very important characteristics of such systems is the entropy which measures the degree of unorder of a system. The larger the entropy the less the order of the system (less information of the system in analogy to our unordered files on the desk) and according to the second law of thermodynamics the order always is lost in the natural processes (for example a broken glass never spontaneously glues together) without doing any extra work. It was a great discovery by Jakob Bekenstein that the entropy of a black hole can be related to the area of its horizon which has a property that it never diminishes spontaneously exactly as it does not for natural systems. In thermodynamics there is a notion of thermal equilibrium which defines the temperature. As it was proven by Stephen Hawking, who took into account some quantum effects, black holes can have a nonzero temperature which is inversely proportional to their masses and so they can radiate heat to their environments – this is called Hawking temperature.

According to Bekenstein and Hawking, the black holes interact with the environment which results in their evaporation due to the emission of the Hawking radiation. In fact, the Bekenstein entropy tends to zero and the Hawking temperature blows up to infinity when the mass approaches zero during the Hawking evaporation process which means that the black hole completely evaporates due to the emission of the Hawking radiation. This poses a problem of the information loss paradox.

On the other side, one can treat the whole universe as kind of a black hole with the horizon having some area and attach the entropy to such an area. It comes from the fact that the light from distant objects cannot travel faster that light and so an observer on Earth cannot see more that from the surface of the sphere of some radius known as the Hubble radius. This cosmological horizon can have some influence onto the overall evolution of the universe which has another mysterious property known as the dark energy – something which makes the evolution to speed up and is yet unknown.

The main objective of the project will be the studies of some new proposals for the generalization of the Bekenstein entropy which have specific thermodynamical property known as nonadditivity which means that the two contributions to the entropy of two different systems do not sum up in a simple way. These new entropies are the Renyi, Tsallis and Barrow entropies. All of them change the thermodynamical properties of a black hole or the universe. In particular, they may change the evolution of the Hawking radiation of the black hole leaving a remnant in which still there is some remaining information. On the cosmological side, they may have properties which are in better agreement with astronomical data than currently recognized model of the evolution of the universe known as ΛCDM (Lambda Cold Dark Matter) model. Among other issues it wi worth mentioning that the nonadditive entropies will also be investigated in relation to some quantum gravity effects which are related to phenomenological generalizations of the uncertainty principle in quantum mechanics: the Generalized Uncertainty Principle (GUP) and the Extended Uncertainty Principle (EUP).