Abstract

We are at the dawn of a data-driven era in astrophysics and cosmology. A large number of ongoing and forthcoming experiments combined with an increasingly open approach to data availability offer great potential in unlocking some of the deepest mysteries of the Universe. Among these is understanding the nature of dark matter (DM) – one of the major unsolved problems in particle physics. Characterizing DM through its astrophysical signatures will require the use of novel statistical methods and a robust understanding of its distribution in the sky.

The first part of this thesis describes the implementation of a novel statistical technique which leverages the "clumpiness" of photons originating from point sources (PSs) to derive the properties of PS populations hidden in astrophysical datasets. This is applied to the gamma-ray sky at higher latitudes as seen by the *Fermi* satellite to characterize the contribution of PSs of extragalactic origin, finding that the majority of the extragalactic gamma-rays can be ascribed to unresolved PSs having properties consistent with known sources such as active galactic nuclei, leaving considerably less room for a dark matter contribution.

The second part of this thesis asks the question: "what is the best way to look for annihilating dark matter in extragalactic sources?" and attempts to answer it by constructing a pipeline to robustly map out the distribution of dark matter in the local neighborhood using galaxy group catalogs. This framework is applied to *Fermi* data and existing group catalogs to search for annihilating dark matter in local galaxies and clusters, and stringent bounds are obtained in the absence of a signal.