Research Statement

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Why dark matter? The modern hypothesis of dark matter originates from the huge unseen mass in Zwicky's study on the dynamics of the Coma cluster of galaxies using Virial theorem during 1930s [1]. It tooks about 40 years until the community began to treat this radical insight seriously. Two triggering findings were the severe contradiction between the simulated unstable spiral galaxies and the observed stable ones [2], and new evidences from their non-declining galactic rotation curves [3].

Why self-interacting dark matter (SIDM)? After 1980, a popular dark matter framework, i.e. standard lambda cold dark matter (ΛCDM) paradigm, was gradually built up due to its successful application on the problem of structure formation in a nearly homogeneous Universe under the constrain from the observed cosmic microwave background radiation [4,5]. In this paradigm, the dark matter consists of subatomic particles that interacts only weakly with baryons and photons. However, a series of challenges began to emerge during the detailed study of galaxy property and formation on small nonlinear scales, for example, the core-cusp problem, missing satellites problem, diversity problem, baryon-dark matter coupling and so on [6]. SIDM was proposed with the purpose to solve these small scale issues and it departs from the original CDM model only in the inner region of galaxies due to the introduction of self-interactions between dark matter particles with a light mediator. Recent years, SIDM demonstrated its great potential to relieve the tension on small scales [7,8] and offered alternative detection mechanisms [9, 10]. Once the self-interactions are detected, it would rule out many popular dark matter candidates like axions or neutralinos. However with these exciting progresses but without direct signals, we still can't answer **what is dark matter? what are dark matter particles? what are their properties? if they are SIDM type, how might we study and detect them independently of their gravitational influence?** These are the central questions my research wants to address.

How to study and search for SIDM? In the center of a galaxy with high mass density, dark matter particles with self-interactions experience sufficient collisions and become thermalized during the galaxy life time. This will result in different dark matter density distribution comparing to CDM and construct a more direct connection between dark matter and baryons [11]. Therefore further study of macroscopic astrophysical systems may offer key information of microscopic dark matter. For spiral galaxies, I have analyzed more than 130 rotation curve data in the framework of SIDM, which exhibit a great diversity, a big challenge for the prevailing CDM model. My analysis shows that SIDM can explain the observed diversity and provides an excellent fit to the rotation curve data. As a bonus, the modeling result that reproduces the radial acceleration relation [12], may offer a SIDM picture for understanding modified Newtonian dynamics theory. I also work on stellar kinematics of elliptical galaxies. Since baryons dominate the central regions in these systems, they are ideal for testing unique correlation between the baryon and dark matter distributions predicted in the SIDM model. I expect to submit two papers on spiral and elliptical galaxies in early 2018.

SIDM particles not only interact with one another, but also very weakly interact with the nuclei of atoms in principle. Since the disk of the Milky Way is presumably rotating through a massive non-rotating dark matter halo—a sea of dark matter particles, the Earth is in fact moving through a wind of dark matter particles. Now and then, one of them will interact with and scatter nuclei so that generate detectable signals. Although the sensitivity of direct detection experiments has been improved by three to four orders of magnitude, solid evidence is still missing [13]. While experiments still can be improved, alternative theoretical models, after all, are another ways for progress. Dark matter models with a light mediator could lead to interesting signatures in detections. If the mediator is much lighter than the dark matter particle, the event spectra is peaked towards low recoil energies. I am exploring the possibility of resolving this feature in current and future experiments.

If the self-interaction is strong enough, two dark matter particles (if produced) can form a bound state in high energy colliders under certain conditions [14], which provides another access to the self-interaction. The collider signatures of forming a dark matter bound state is very different from the traditional dark matter search at colliders. Instead of looking for the missing energy, one can look for the resonance of the bound state. This greatly reduces the standard model (SM) background and helps to extract information about dark matter particles, such as mass. The two dark matter particles in the bound state can also annihilate into light mediators and further into SM particles, which provides new channels to search in existing colliders. Currently, I have learned the necessary tool, MadGraph, for simulation of the high-energy phenomenology in colliders and began to use published relevant LHC data for calculating parameter constrains. I am also exploring the detailed description from generating dark matter particle to bound state formation theoretically and looking for new signatures as guides for experimental collaborators.

Who will care? It is truly an interdisciplinary enterprise to hunt for the dark matter, which involves laboratory, ground and underground experiments, astrophysical and cosmological observations combined with simulations, searches at accelerators, and particle physics theory. My undergoing research connects to most of these fields and interests people with a new dark matter framework born from traditional CDM and embracing the anomalies on small scales. It is this kind of sufficient communications between theory, experiment, observation and computation that make this field a vital and active one, which I like a lot. I believe this is the way to push one area in science forward that can be borrowed to benefit other fields.

What social impacts? Searching for dark matter belongs to completely fundamental physics. It may take decades to get some actual breakthroughs and even longer time to transfer these discoveries to daily applications in life and industry. On a timescale of years, the student groups, from kindergarten to graduate school, will get benefits most. It arouses the curiosity of young children and encourages them to start an adventure in science. On a timescale of centuries, the understanding of dark matter may help us uncover other mysteries in the universe and further make the imaginations in current scientific fictions like interstellar communication, traveling and immigration possible. These are for the whole human beings.

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