EXPLORE 2021 Workshop: Astrophysical Laboratories of Dark Matter

Report of Contributions

https://indico.global/e/6712

Contribution ID: **1** Type: **not specified**

Welcome

Wednesday 25 August 2021 16:00 (15 minutes)

Presenters: SAGUNSKI, Laura (Goethe University Frankfurt); TULIN, Sean (York University)

Contribution ID: **2** Type: **not specified**

Plenary talk: ”Detecting Dark Matter in Celestial Bodies”

Wednesday 25 August 2021 17:30 (45 minutes)

- Chair: Laura Sagunski
- Co-Chair: Nassim Bozorgnia

Stars and planets can be ideal playgrounds to discover dark matter. In this talk, I will review a range of dark matter searches using celestial objects, including neutron stars, exoplanets, solar-system planets, and our Sun. I will discuss different search strategies, their opportunities and limitations, and the interplay of regimes where different celestial objects are optimal detectors.

Presenter: LEANE, Rebecca (Massachusetts Institute of Technology)

Contribution ID: **3** Type: **not specified**

Project 1: Dark stars

Contribution ID: **4** Type: **not specified**

Get together

Wednesday 25 August 2021 18:15 (30 minutes)

Contribution ID: **5** Type: **not specified**

Plenary talk 2

Contribution ID: **6** Type: **not specified**

EXPLORE project: ”Probing Dark Matter with Gravitational Waves ” (Dark Matter Team)

Thursday 26 August 2021 16:00 (55 minutes)

- Chair: Y. Fabian Bautista
- Co-Chair: Nassim Bozorgnia

Mentors: Laura Sagunski, Saeed Rastgoo
Junior mentors: Niklas Becker, Julia Lienert

Supermassive black holes at the centers of galaxies are surrounded by gigantic dark matter halos. Near these black holes, the dark matter density is extremely high and forms a so-called dark matter density spike. Due to its extremely high density, the dark matter density spike creates a violent environment around the black hole. If the black hole then merges with a smaller companion object, the presence of the dark matter density spike will drastically affect the binary merger dynamics. In particular, it will leave an imprint on the emitted gravitational wave signal. If we detect such a signal, we can thus probe the nature of dark matter with gravitational waves!
Main tasks: 1. Model the profile of the dark matter density spike around the black hole for different dark matter models (cold dark matter, self-interacting dark matter) in Newtonian gravity and then include relativistic effects.
2. Model the merger dynamics and the gravitational wave signal including post-Newtonian and further relativistic effects and then in a fully general relativistic formulation.
3. Compute the gravitational wave signal for different dark matter models, check its detectability with current and future gravitational wave detectors (LIGO, LISA) and constrain the particle nature of dark matter with gravitational waves.

Author: Prof. SAGUNSKI, Laura (Goethe University)

Co-author: LIENERT, Julia (Goethe University & Frankfurt Institute for Advanced Studies)

Presenters: JAMALY, Keiwan (Goethe University); HÖLKER, Lukas (Goethe University); KÜBLER, Natey (Goethe University); AFIFY, Tarnem (York University)

Contribution ID: **7** Type: **not specified**

EXPLORE project: ”Probing Dark Matter with Gravitational Waves” (Gravity Group)

Thursday 26 August 2021 17:10 (45 minutes)

- Chair: Alejandro Cruz-Osorio
- Co-Chair: Jürgen Schaffner-Bielich

Mentors: Laura Sagunski, Saeed Rastgoo
Junior mentors: Niklas Becker, Julia Lienert

Supermassive black holes at the centers of galaxies are surrounded by gigantic dark matter halos. Near these black holes, the dark matter density is extremely high and forms a so-called dark matter density spike. Due to its extremely high density, the dark matter density spike creates a violent environment around the black hole. If the black hole then merges with a smaller companion object, the presence of the dark matter density spike will drastically affect the binary merger dynamics. In particular, it will leave an imprint on the emitted gravitational wave signal. If we detect such a signal, we can thus probe the nature of dark matter with gravitational waves!
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Author: Prof. RASTGOO, Saeed (York University)

Co-author: BECKER, Niklas (Goethe University)

Presenters: MONTALVO, Diego (York University); SCHMIDT, Ida (Goethe University); KHALIL, Nour (York University)

Contribution ID: **8** Type: **not specified**

Break-out session

Contribution ID: **9** Type: **not specified**

EXPLORE project: ”The Galactic Distribution from Dark Matter Simulations”

Friday 27 August 2021 16:05 (45 minutes)

- Chair: Reuben Blaff
- Co-Chair: Sean Tulin

Mentor: Nassim Bozorgnia
Junior Mentor: Yilber Fabian Bautista

In this project, we will use cosmological simulations of self-interacting dark matter (including baryons) to study the dark matter distribution in Milky Way–like galaxies. The complicated interplay between astrophysical processes and dark matter self-interactions can result in dark matter distributions which are quite different from those extracted from collisionless dark matter simulations. The results will be important for the interpretation of data from dark matter direct and indirect detection experiments. We can access the data for simulated Milky Way size galaxies in EAGLE cosmological simulations including dark matter self-interactions.
Main tasks: 1. Access the simulation data of dark matter particle positions and velocities in the halo.
2. Compute rotation curves of simulated galaxies and fit them to observed rotation curve data. —> Specify the simulated galaxies which fit the observed data better.
3. Define the “solar neighborhood”in the simulated galaxy and extract the DM velocity distribution and DM density.
4. Compare the velocity distribution to the usual Maxwellian distribution assumed in the Standard Halo Model.
5. Fit the velocity distribution with some known functional forms.
6. Compute the “halo integral”which is the quantity that enters in the event rate of dark matter direct detection experiments.

Author: Prof. BOZORGNIA, Nassim (York University)

Co-author: BAUTISTA, Fabian (York University & Perimeter Institute)

Presenters: RAHIMI, Elham (York University); HARTMANN, Jasmin (Goethe University); ARDA, Lukas (Goethe University)

Contribution ID: **10** Type: **not specified**

EXPLORE project: ”Dark Stars”

Friday 27 August 2021 17:05 (45 minutes)

- Chair: Julia Lienert
- Co-chair: Laura Sagunski

Mentor: Jürgen Schaffner-Bielich
Junior mentor: Alejandro Cruz-Osorio

In this project, we explore the properties of astronomical objects which can be formed by dark matter and the properties of neutron stars in the presence of a dark matter component. First, we will get ourselves acquainted with the properties of interacting bosons and interacting fermions and the properties of compact objects consisting of these dark matter particles. For this purpose, a specialized introductory lecture will be given based on the textbook 'Schaffner-Bielich: Compact Star Physics'. Then, we will specifically address the following three topics: i) We will study the properties of dark matter particles with a dark charge corresponding to a dark photon. Also, interactions will be taken into account where we use input from the study of self-interacting dark matter from the other projects. The equation of state will be calculated and used as input to solve the Tolman-Oppenheimer-Volkoff equations. The mass-radius relation of dark compact objects with a dark charge will then be computed numerically. Possible constraints from astrophysical observations on the possible existence of those dark charge compact objects will be investigated also in connection with gravitational wave signals. ii) We will look at the modification of the properties of neutron stars, if there is some amount of dark matter present in the core. Here, we will use a model of self-interacting dark matter, which we assume to be dark bosons. The equation of state of neutron stars will be added to the one for dark bosons. The TOV equations will be solved numerically and the change of the mass-radius relation of neutron stars with a dark boson component derived. Constraints on the properties and the amount of dark bosons present in neutron stars will be delineated also in connection with gravitational wave signals. iii) We will derive analytic or semi-analytic expressions for the solution of the TOV equations by assuming a core of an incompressible fluid (of dark matter) surrounded by ordinary matter. The case for a compact object consisting of an incompressible fluid alone is known by the Schwarzschild solution. The limit on its compactness is known as the Buchdahl limit which can be calculated analytically. The solution for the case of an incompressible fluid surrounded by some additional matter is not known yet. For the equation of state of ordinary matter surrounding the incompressible core we adopt a relativistic polytrope and look for possible scaling solutions.

Author: Prof. SCHAFFNER-BIELICH, Jürgen (Goethe University)

Co-author: Dr CRUZ-OSORIO, Alejandro (Goethe University)

Presenters: BRISEBOIS, Alex (University of Toronto); CASSING, Marie (Goethe University); AZEEM, Muhammad (York University)

Contribution ID: **11** Type: **not specified**

Social event

Friday 27 August 2021 17:50 (50 minutes)

Contribution ID: **12** Type: **not specified**

Feedback event

Contribution ID: **13** Type: **not specified**

Discussion session for EXPLORE students

Thursday 26 August 2021 18:15 (45 minutes)

Presenters: SCHAFFNER-BIELICH, Jürgen (Frankfurt University); SAGUNSKI, Laura (Goethe University Frankfurt); BOZORGNIA, Nassim; RASTGOO, Saeed (York University); TULIN, Sean (York University)

Contribution ID: **14** Type: **not specified**

Plenary talk: ”Constraining Dark Matter Self-interactions with Galaxy Clusters”

Friday 27 August 2021 15:00 (45 minutes)

- Chair: Nassim Bozorgnia
- Co-Chair: Sean Tulin

As the objects with the largest dark matter densities and velocity dispersions, galaxy clusters are an ideal laboratory in which to search for evidence of dark matter self-interactions. I will discuss how self-interacting dark matter (SIDM) is implemented within cosmological simulations, and then how comparing these simulations with observations we can place constraints on the nature of dark matter.

Presenter: ROBERTSON, Andrew

Contribution ID: **15** Type: **not specified**

EXPLORE project: ”The Life and Death of Dark Matter Halos”

Wednesday 25 August 2021 16:15 (55 minutes)

- Chair: Niklas Becker
- Co-Chair: Saeed Rastgoo

Mentor: Sean Tulin
Junior mentor: Reuben Blaff

Dark matter halos are a fundamental unit of structure in the Universe: from the very first stars born in small mini-halos, all the way up to the supermassive halos that hold together clusters of thousands of galaxies. This research will study how dark matter's particle dynamics –its interactions and forces beyond gravity –can affect the time evolution of halos, potentially inducing a gravothermal catastrophe that causes runaway collapse. Performing a series of simplified numerical simulations, we will investigate the impact of several dark matter properties on halo dynamics: whether dark matter is one or more than one species of particle, whether different species can scatter elastically or inelastically into one another, and whether species have dissipative interactions that cause energy loss. Finally, we will consider these simulations in the context of the first stars to investigate whether collapsed mini-halos lead to the formation of supermassive early stars that ultimately seed supermassive black holes that form in the centers of galaxies. Our treatment for dark matter halo dynamics will be based on the so-called "fluid approximation"in which dark matter is treated as an ideal gas described by Euler's equations for a compressible fluid. We will review some basics of fluid dynamics and learn how dark matter's particle interactions are described (e.g. heat conduction and heat loss). Our approach for solving Euler's equations will be based on an elegant framework known as Smoothed Particle Hydrodynamics (SPH). SPH is the basis for any state-of-the-art numerical simulations for astrophysics (and beyond) that are run on supercomputers. Here, we will follow a much-simplified approach for SPH where spherical symmetry is assumed. Lastly, our numerical treatment of dark matter halo evolution has many interesting applications across the range of smallest to largest halos in the Universe. One such application is the formation of the first stars.

Author: Prof. TULIN, Sean (York University)

Co-author: BLAFF, Reuben (York University)

Presenters: SINGH, Darren (York University); VORMANN, Hannah (Goethe University); GRAN, Megan (York University); RAUM, Tobias (Goethe University)