INSTITUTE FOR PARTICLE PHYSICS PHENOMENOLOGY

NEWSLETTER
MARCH 2024

WELCOME TO THE IPPP!

Welcome to the Spring edition of the Institute for Particle Physics Phenomenology's newsletter, another vibrant dispatch from the frontier of particle physics. As the season ushers in renewal and growth, our community too thrives with the continuous pursuit of understanding the fundamental components of our universe.

In this edition, we have the pleasure of introducing you to the nine new postdocs and the outreach fellow who joined the IPPP in the fall of 2023. We are also very excited to share the many upcoming workshops and events sponsored by the Institute, and report on two events in the past half year: the 56th Annual Theory Meeting, and NuPhys2023: Prospect in Neutrino Physics. We finish this newsletter with research highlights on atmospheric neutrinos and microlensing of dark matter objects.

Special thanks to everyone who contributed to this newsletter, and in particular Matteo Marcoli, Ivan Martínez-Soler and Djuna Croon for writing workshop summaries and research highlights. We hope you enjoy reading it!

ANNOUNCEMENTS

1. The IPPP is pleased to announce the following workshops:

- Dark Matter beyond the Weak Scale will be held at the IPPP from 25-28 March:
https://conference.ippp.dur.ac.uk/event/1289/
- NEHOP 2024: New Horizons in Primordial Black Hole physics (NEHOP) will be held in Edinburgh National Gallery from 17-20th June:
https://conference.ippp.dur.ac.uk/event/1283/
- The IPPP will organise the Fermilab Masterclass for ~ 80 high school students. This will be held on the 22nd of March:
https://conference.ippp.dur.ac.uk/event/1287/
- The MC4EIC meeting will take place at the IPPP from 5-7 June and discuss recent theoretical and practical advances and experimental needs in Monte Carlo Event Generators for the Electron-Ion Collider:
https://conference.ippp.dur.ac.uk/event/1292/
- The annual STFC HEP Summer School from 25 July until 6 September:
https://conference.ippp.dur.ac.uk/event/1291/

We look forward to welcoming this year's cohort of experiment particle physics early stage researchers in Durham!

2. The Associateship, Durham IPPP Visiting Award, and Senior Experimental Fellowship programmes are continuing. We encourage applications for all three schemes and invite you to consult the following web pages for application deadlines:
IPPP Associateship: ***https://www.ippp.dur.ac.uk/ippp-associateships***
DIVA: ***https://www.ippp.dur.ac.uk/diva***
Senior Exp. Fellowship:
https://www.ippp.dur.ac.uk/senior-experimental-fellowships
Our next intake will be in September 2024.

3. We encourage organisers of workshops related to HEP theory to reach out for support. The IPPP can help organise workshops in the UK, administratively and financially.

NEW POSTDOCS

MIGUEL CRISPIM ROMAO

Will work on artificial intelligence and machine learning applications to particle phenomenology and theory, including BSM physics, rare events at collider physics, and astroparticle physics. Before joining the IPPP, he was visiting at Southampton, and held a research position at the Laboratory of Instrumentation and Experimental Particle Physics (LIP) in Lisbon, where he retains a visiting role and collaborates with members of ATLAS and QCD phenomenologists. Having followed an unorthodox path, he has also had two distinct industry placements as a data scientist.

JAMES INGOLDBY

Has recently joined the IPPP as a postdoc. His research fcuses on developing tools to analyse strongly coupled quantum field theories, and on beyond standard model phenomenology - in particular new composite dark sectors. He completed his PhD at Yale University and joins us after a postdoc at the International Centre for Theoretical Physics in Trieste, Italy.

MATTHEW KIRK

Recently (re-)joined the IPPP as a postdoc - he completed his PhD here in 2018, then spent 3 years in Rome at La Sapienza, and another 2 in Barcelona at the ICCUB.

His work has mostly focussed on studying anomalies in flavour physics and investigating the phenomenology of BSM models that could explain them. Here in Durham he will be working with Danny van Dyk on ways to distinguish SM non-perturbative effects from new physics in rare B-decays.

MATTEO MARCOLI'S

Research focuses on high-precision theoretical calculations for particle collider experiments, in particular for the LHC. In his work, following his PhD at the University of Zurich, he develops and applies techniques for higher-order computations in perturbative QCD. These are necessary for improving the accuracy of theoretical predictions, in order to consolidate our understanding of the Standard Model, as well as unveil potential signs of New Physics through the comparison with experimental data. His interests include infrared subtraction, multi-loop calculations, Monte Carlo event generators and jet physics.

VISHAL NGAIRANGBAM

Joined the IPPP as a postdoc after completing his PhD at the Physical Research Laboratory, Ahmedabad (India), and worked on exploring deep-learning algorithms for phenomenological studies at the Large Hadron Collider. Hoping to narrow the gap between the black-box nature of these algorithms by drawing on theoretical knowledge from physics and including them in the algorithmic design, he also plans to explore quantum computing and quantum machine learning applications in HEP.

SHAKEEL RAHAMAN

Received his PhD from the Indian Institute of Technology Kanpur in India and joined IPPP as a Postdoc last year. His research has mostly focused on assessing scenarios beyond the Standard Model (BSM) using Effective Field Theory (EFT). In this precision era of particle physics, effective operators are widely used for constructing precision observables. As current LHC data indicate that there may be a considerable gap between the energy scale of new physics and the SM, EFT can serve as a bridge between the known SM and the unknown BSM scenario. Using precision data, he hopes to constrain a wide range of BSM scenarios.

FRANCESCO SERGIO

Is an ESR collaborating with the Science Engagement Office, to improve the IPPP outreach activities. Among other tasks, he is currently co-organizing the International Masterclass for Particle Physics, re-establishing the IPPP participation at "Celebrate Science!" and hosting the Cafe Scientifique, science-based talks in pubs. He also intends to curate the IPPP YouTube channel. After completing his MSc in Physics at University of Trento, he shifted focus to the educational and outreach aspects of Physics.

SERGIO SEVILLANO MUÑOZ

Has just joined the IPPP as a postdoc after finishing his PhD at the University of Nottingham, where he developed a Mathematica package to help test certain modified theories of gravity at colliders. His interests lie in exploring cosmological models from a particle physics standpoint, either by expressing them as BSM-like interactions or through their implications on large scales, such as dark energy or dark matter candidates.

FEDERICO SILVETTI

Got his PhD from Sapienza, University of Rome (2023) and is now a postdoctoral researcher at Durham University's IPPP. His past work focused on high-energy resummation for hadron-collider observables and PDF determination. Currently, his research interests are moving toward parton showers and event generators.

SIMON WILLIAMS'S

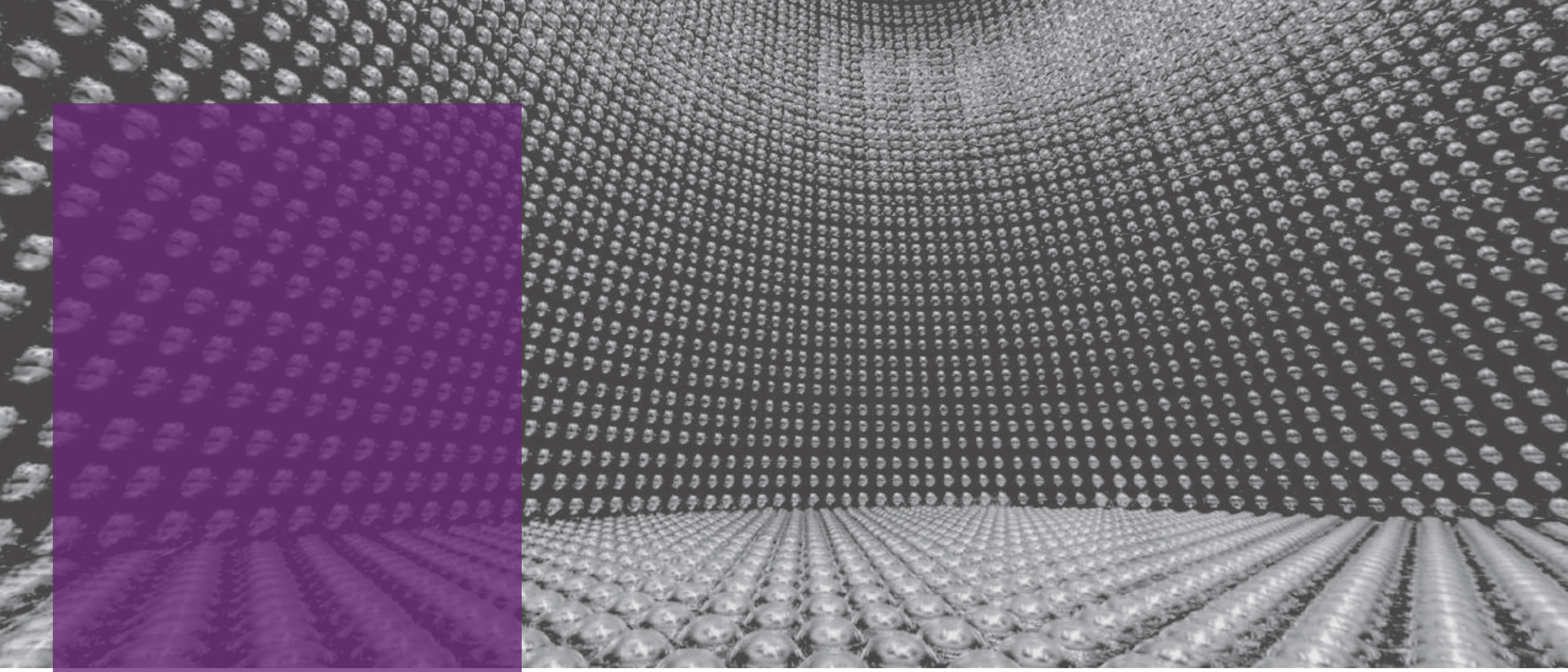
Research focuses on the development of quantum computing algorithms for particle physics applications. He is interested in exploring the potential advantages that quantum computers can provide, specifically for the modelling of high energy collisions and simulating Quantum Field Theories. Before joining the IPPP, Simon completed his Ph.D. at Imperial College London, where he specialised in the simulation of parton showers using quantum computers.

ANNUAL THEORY MEETING 2023

From December 12-14 the IPPP hosted the 56th edition of the Annual Theory Meeting. More than 100 physicists gathered in person, with many others joining remotely, to listen to three days of talks by world-renowned experts. Tarek Anous (Queen Mary University of London) opened the first day, exploring the subtle interplay between quantum mechanics, entanglement and gravity. Clara Murgui (Universitat Autonoma de Barcelona) followed with a talk on the great potential of quantum sensors in the arduous quest towards the discovery of New Physics. In the afternoon session, Peter Skands (Monash University, University of Oxford) and Matthias Neubert (Johannes Gutenberg University Mainz) presented recent developments in collider phenomenology, respectively in the study of non-perturbative hadronisation effects and non-global observables at the LHC.

The second day began with an overview by James P. Edwards (Plymouth University) on the strong-field regime of QED and laser particle experiments. After that, Alessandro Bacchetta (Pavia University) talked about the internal structure of the proton as a multi-dimensional object and the exciting scientific opportunities offered by the Electron Ion Collider soon to be built at Brookhaven National Lab. We then moved on to the study of yet unknown particles with Anne Green (University of Nottingham), who reviewed the forest of possibilities for what Dark Matter could be and the various experiments designed to search for it. In the afternoon, the meeting continued with a session dedicated to cutting-edge computational techniques in lattice gauge theories, with talks by Gurtej Kanwar (University of Bern) and Dorota Grabowska (University of Seattle) on the application of machine learning and quantum computing methods to lattice calculations in strongly-coupled QCD. The day was concluded by Chris Parkes (University of Manchester) with a comprehensive summary of the history, present and future of Flavour Physics experiments, supported by several amusing references to the "Back to the Future" (LHCb) trilogy. After the talks, everyone gathered at Collingwood College for a well-deserved dinner.

The final day began with a review of recent results in random matrix theory and related applications in quantum gravity by Julian Sonner (University of Geneva). Andrea Banfi (University of Sussex) then described the purpose of the Particle Physics Advisory Panel (PPAP), which seeks input from the theoretical community to improve interaction with the Science Board and the STFC. Finally, Grahame Blair, STFC Executive Director Programmes, gave a detailed overview of the STFC's planned strategies, project investments and research funding opportunities. ATM 2023 was certainly a great occasion to catch up with the latest developments in several areas of the field, but also to reunite with friends and colleagues and discuss our research and much more in a friendly and cheerful environment. We are all looking forward to the next edition in 2024.



NUPHYS2023: PROSPECT IN NEUTRINO PHYSICS

From the 18th to the 21st of December 2023, IPPP co-organised the workshop NuPhys2023: Prospects in Neutrino Physics, held at King's College London. NuPhys is a series of workshops that has been organised since 2013 with the goal of discussing open questions in neutrino physics. To this end, the workshop focused on current research efforts and prospects for future experiments, including their performance and scientific potential. The organisers for this edition were Francesca Di Lodovico, Jim Dobson, Teppei Katori, Michele Lucente, Ivan Martinez Soler (IPPP), Silvia Pascoli, and Jeanne Wilson.

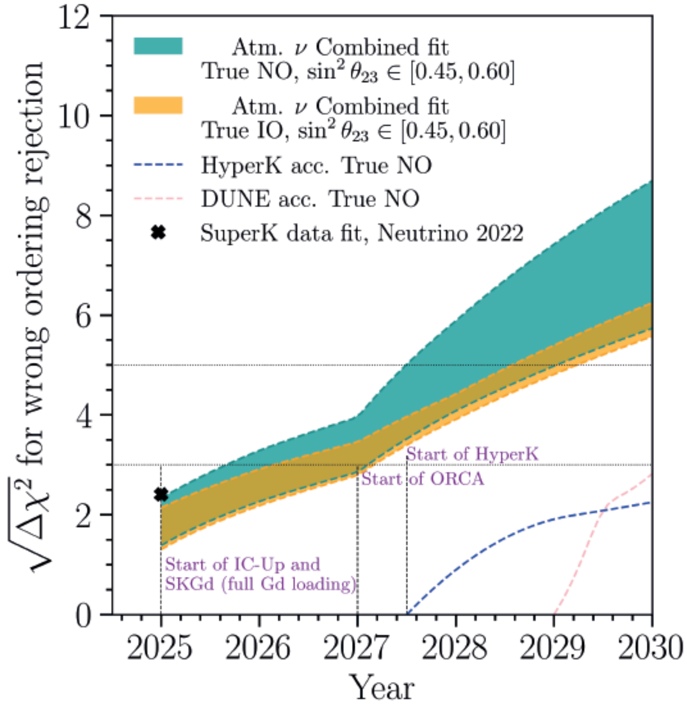
In this edition, a wide variety of topics were covered in the workshops, including theoretical and phenomenological perspectives in neutrino physics, future experiments such as long- and short-baseline oscillation experiments or reactor experiments. A broader range of neutrino sources was discussed, such as solar, atmospheric, and neutrinos from supernovae. The workshop also included discussions about neutrinoless double beta decay. Finally, in light of the recent discovery of gravitational waves (GW), a session was dedicated to present and future searches for GW and coincidence signals with neutrinos.

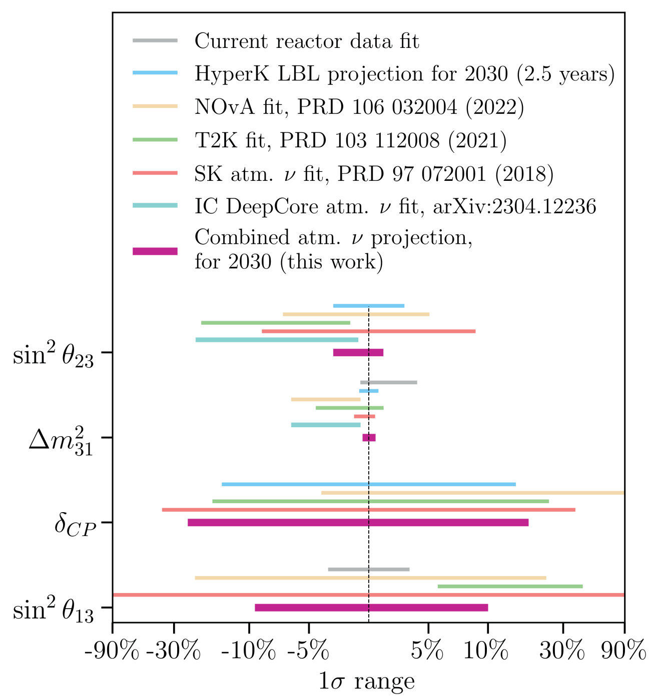
In this workshop edition, there were nearly 40 invited talks and three sessions dedicated to flash talks, allowing young scientists to present their research. Additionally, there were two poster sessions at the end of the first and second days.

The first day focused on describing the various neutrino sources that can be measured, including solar neutrinos, atmospheric neutrinos, high-energy astrophysical sources, and supernovae. The second day began with discussions led by Mariam Tortola and Noemi Rocco on neutrino properties such as mixing, mass ordering, and cross-sections. The remainder of the day was devoted to presenting current results and future predictions from reactor and accelerator experiments, as well as searches for sterile neutrinos. The final day of the workshop was dedicated to Neutrinoless double beta decay experiments and Beyond the Standard Model physics. This edition of the workshop attracted 121 participants.

RESEARCH HIGHLIGHT: ATMOSPHERIC NEUTRINOS

Atmospheric neutrinos have played a crucial role in the discovery and understanding neutrino oscillations, as proved by Super-Kamiokande's observation of a muon neutrino deficit for trajectories crossing the Earth. This deficit is explained by considering neutrinos as massive particles and flavour states as a superposition of massive states. The simplest scenario that can explain neutrino oscillations is the so-called 3ν mixing, where flavour oscillation arises from the interference of three massive states. In this framework, neutrino flavour oscillation depends by the ratio between of the neutrino baseline to energy (L/Eν). Neutrino evolution depends on the differences in mass squared and the lepton mixing matrix, which is parameterised in terms of three mixing angles and the CP-violation phase (δ_CP).





Over the past two decades, the neutrino community has undertaken an extensive program utilising accelerator, reactor, and solar neutrinos to study neutrino evolution. While these efforts have yielded results with precision at the percent level for certain parameters [1], significant uncertainties persist in the neutrino mass spectrum, the relative contribution between ντ and νμ and to the second mass state determined by octant of θ_{23}, and the CP-phase in the lepton sector.

Given the existing unresolved questions, a new inquiry emerges: can atmospheric neutrinos help address these uncertainties? To explore this, IPPP's Ivan Martínez-Soler and collaborators assessed the potential sensitivity of both current and future water(ice)-Cherenkov atmospheric neutrino experiments [2]. Their analysis encompassed Super-Kamiokande, both with and without neutron-tagging, IceCube upgrade, ORCA, and Hyper-Kamiokande. In this initial comprehensive examination, the team accounted for prevailing uncertainties stemming from shared fluxes and neutrino interactions, as well as the systematic uncertainties inherent to each experiment.

Through a comprehensive analysis of these experiments, Ivan and collaborators investigated the synergies of atmospheric measurements in addressing the unresolved questions in neutrino physics. The findings suggest that atmospheric neutrinos can determine the octant of θ_{23} with 99% confidence level within a five-year timeframe, as show in the figure. Similarly, they have determined that the neutrino mass ordering can be established at 5 σ significance using atmospheric measurements. Furthermore, their exploration of sensitivity to the CP-phase reveals that significant portions of the allowed δ_{CP} range can be excluded at over 3σ confidence level.

As atmospheric neutrinos cross the Earth before reaching the detector, matter effects become very important, and at the GeV scale, the impact of these effects is controlled by θ_{13}. In this study, Ivan's team investigated the capability of atmospheric neutrinos to measure this angle independently of other experiments. They found that the sensitivity will be greater than that achieved by accelerator experiments, as illustrated in the figure. These results will provide vital information for next-generation accelerator neutrino oscillation experiments such as DUNE and Hyper-Kamiokande.

Comparison between the present and future projected sensitivities for the oscillation parameters. The figure illustrates the sensitivity in distinguishing between the correct ordering for true normal (cyan) and inverted (orange) ordering. The shaded bands represent the allowed range for sin^2 θ_23 from 0.45 to 0.6. The black dot corresponds to the latest reported Super-K neutrino mass ordering analysis. Additionally, they include the predictions of Hyper-Kamiokande and DUNE for comparison. On the other figure, they compare the 1σ region expected from combining atmospheric neutrino measurements (this study) with the current results.

References:

[1] I. Esteban, M. C. Gonzalez-Garcia, M. Maltoni, I. Martinez-Soler and T. Schwetz,
"Updated fit to three neutrino mixing: exploring the accelerator-reactor complementarity."
JHEP 01 (2017), 087 doi:10.1007/JHEP01(2017)087 [arXiv:1611.01514 [hep-ph]].

[2] C. A. Argüelles, P. Fernández, I. Martínez-Soler and M. Jin,
"Measuring Oscilla- tions with a Million Atmospheric Neutrinos,"
Phys. Rev. X 13 (2023) no.4, 041055 doi:10.1103/PhysRevX.13.041055 [arXiv:2211.02666 [hep-ph]].

DARK MATTER THROUGH A NEW LENS

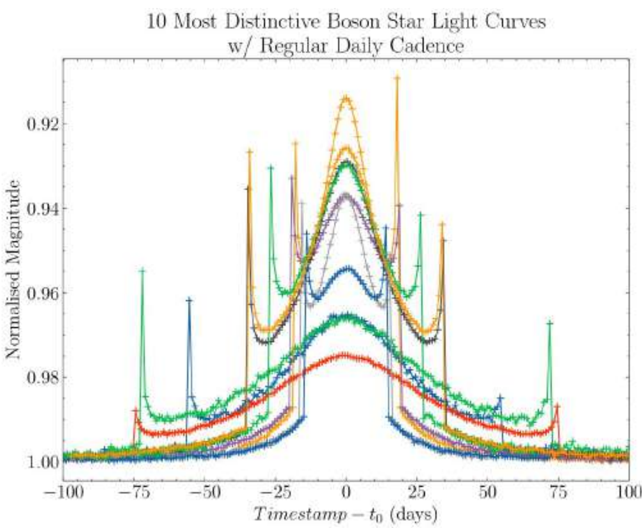
It’s widely accepted that dark matter exists, primarily evidenced through its gravitational effects. Many theories propose that dark matter forms macroscopic structures, including for example primordial black holes, boson stars, axion miniclusters, and other substructures. These objects can have masses similar to asteroids or even multiple times the mass of the Sun. Of course, this leads to a natural question: is it possible to detect these substructures through their gravitational interactions?

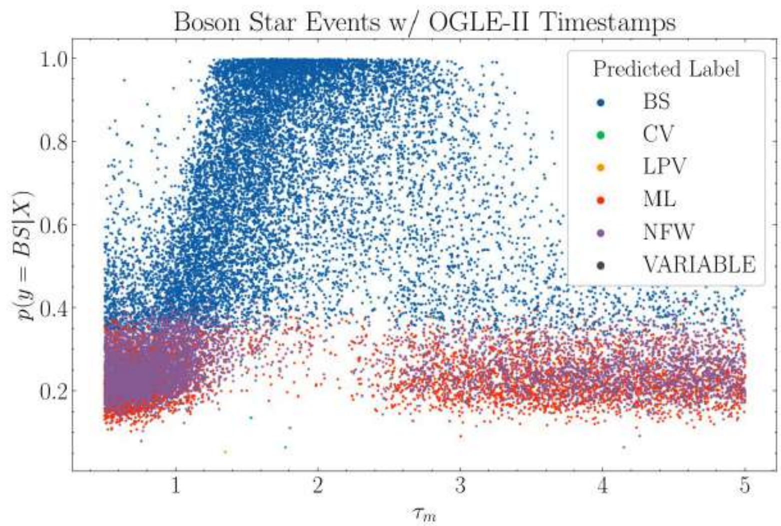
Enter gravitational microlensing, a phenomenon predicted by Einstein’s theory of relativity. When a massive object passes in front of a distant light source, it bends the light in such a way that multiple images of the source are formed as seen by observers on Earth. Even when the images cannot individually be resolved, from the perspective of the observer the light from the source will be temporarily magnified. This effect has been a critical tool in setting constraints on the existence of the compact (point-like) primordial black holes.

But what about non-point-like, or extended, dark matter objects? IPPP staff member Djuna Croon previously explored this question, and discovered that extended objects could alter the expected magnification light curve’s shape, opening a new avenue for investigation. Fast forward to now, Djuna and new IPPP postdoc Miguel C. Romao (introduced earlier in this newsletter) revisited these light curves with a modern twist in the 2024 work “Microlensing Signatures of Extended Dark Objects Using Machine Learning". By adapting MicroLIA, a machine learning package designed for microlensing data, they were able to make strides on distinguishing the magnification signatures of extended objects from point-like sources and other celestial bodies.

The work utilises simulated light curves and realistic observational timestamps to train a histogram-based gradient boosted classifier. The results are promising, particularly for identifying boson stars, which have a relatively flat mass distribution, within certain radii ranges. Investigating the effect of achieving more regular observational cadences, the work reveals that even more peaked structures, like NFW-subhalos, which are closer to primordial black holes, could be positively identified from other sources across a spectrum of radii.

This study sets the stage for dark matter searches using future microlensing observations, such as those anticipated from projects like NASA's Roman Space Telescope. With the public code and data release, Djuna and Miguel hope to make this type of analysis accessible to anyone who shares the same interest of shedding light on dark matter.





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Miguel Crispim Romão, Djuna Croon,
"Microlensing signatures of extended dark objects using machine learning"
e-Print: 2402.00107 [astro-ph.CO]
Code: *https://gitlab.com/miguel.romao/microlensing-extended-objects-machine-learning*
Dataset: *https://zenodo.org/records/10566869*