Mauro **Bernardini**

Postdoc at UZH in Data Science and Astrophysics

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Education

Postdoc in Data Science and Astrophysics — *University of Zurich*

Topics: Structure and Galaxy Formation, Machine and Deep Learning — *Dec. 2023 - present*

Supervisor: Robert Feldmann

- Focus on Deep Learning, galaxy formation simulations, Active Galactic Nuclei physics and feedback
- My current projects involve running galaxy formation simulations and train neural networks on their output

Ph.D. in Data Science and Astrophysics — *University of Zurich*

Thesis: Emulating Cosmic Gas with generative Deep Learning — *Oct. 2019 - Oct. 2023*

Supervisor: Robert Feldmann, Lucio Mayer, Jan Dirk Wegner

- Focus on Deep Learning and neural networks, galaxy formation simulations, astrophysical processes
- I developed a neural network based framework termed *EMBER* to emulate dark matter simulations with baryon information

Master of Natural Sciences in Astrophysics and Cosmology — *University of Zurich*

Thesis: Thinking inside the Box: Machine Learning applications in cosmological Structure Formation — *Sep. 2017 - Oct. 2019*

Supervisor: Lucio Mayer

- Focus on theoretical physics, astrophysical processes, large-scale structure formation and Cosmology
- In my master thesis I developed a neural network to predict collapsing regions in initial conditions of N-body simulations

Bachelor of Natural Sciences in Physics — *University of Zurich*

Thesis: Characterization of the local velocity field with TGAS-RAVE — *Sep. 2013 - Sep. 2017*

Supervisor: Prasenjit Saha

- Focus on theoretical and particle physics
- My bachelor thesis involved computing galactic dynamics from a subset of the Gaia catalogue and identifying new stellar streams

Skills

Languages	Swiss and High German (native), Italian (fluent), English (fluent), French (basic)
Soft	Critical thinking, scientific writing, public speaking, teaching, team/project management
Coding languages	Python, Cython, C++, Bash, LaTeX, SQL
API's	PyTorch, Tensorflow
Tools	Linux, Git, Conda, Vim
Simulation codes	FIRE-2 and FIRE-3

Research Interests

- Galaxy formation; stellar physics and feedback
- Feedback from Active Galactic Nuclei; Super-massive Black Holes and how to model them numerically
- Numerical Galaxy formation simulations; subgrid physics

- Machine and especially Deep Learning; Generative models such as GANs, VAEs and Diffusion
- Shallow learning; Neural Fields and implicit models
- Equivariance of neural networks and applications to physical systems
- Using Machine Learning to accelerate / emulate numerical simulation counterparts

Grants and Awards

Production project on CSCS *Zurich*

Project name: FIREbox-AGN: Constraining the physics of active galactic nuclei with cosmological simulations and machine learning *Sep. 2023 - Sep. 2024*

PI: ***Mauro Bernardini****, Co-PI: Robert Feldmann*

- This (ongoing) project seeks to train our Machine Learning framework *EMBER-2* on a large suite of cosmological volume simulations with varying AGN physics
- We were granted a total of **168'000 node hours** over 1 year on the Eiger@Alps - Multicore supercomputer

Publications

First author papers

"EMBER-2: Emulating baryons from dark matter across cosmic time with deep modulation networks" *2024*

Mauro Bernardini*, et al.*

- In this work we improved the *EMBER* by modeling multiple baryon fields including temperature, cold gas and dynamical information over a large redshift range ($6 \geq z \geq 0$).

IN PREP.

"From EMBER to FIRE: predicting high resolution baryon fields from dark matter simulations with deep learning" *2020*

Mauro Bernardini*, et al.*

- The official *EMBER* paper. A study about a neural network based methodology to enrich dark matter simulations with baryon fields.

PUBLISHED IN MNRAS: DOI.ORG/10.1093/MNRAS/STAA1911

"Predicting dark matter halo formation in N-body simulations with deep regression networks" *2019*

Mauro Bernardini*, Lucio Mayer Darren Reed and Robert Feldmann*

- A study investigating the mapping from initial conditions in cosmological simulations to final halo populations using a deep regression network based on the U-net architecture.

PUBLISHED IN MNRAS: DOI.ORG/10.1093/MNRAS/STAA1911

"Towards a polarization prediction for LISA via intensity interferometry" *2019*

Sandra Baumgartner, ***Mauro Bernardini****, et al. (equal contribution)*

- A study about a novel approach for testing General Relativity via LISA verification binaries by measuring polarization amplitudes of gravitational waves. This approach proposes to include ground based telescopes (in particular the Cherenkov Telescope Array) for resolving the binary orientation on the sky.

PUBLISHED IN MNRAS: DOI.ORG/10.1093/MNRAS/STAA2638

Contributed papers

"Inflow and outflow properties, not total gas fractions, drive the evolution of the mass–metallicity relation" *2024*

Luigi Bassini, et al., ***Mauro Bernardini***

- A study about the origin of the mass-metallicity relation in the FIRE-2 model.

PUBLISHED IN MNRAS: DOI.ORG/10.1093/MNRASL/SLAE036

"The HI covering fraction of Lyman Limit Systems in FIRE haloes" *2024*

Lucas Tortora, et al., ***Mauro Bernardini*** *(co-supervisor)*

- A study about the spatial distribution of atomic hydrogen in FIRE-2 galaxies across redshift and mass range.
- This paper was the result of a co-supervised master thesis.

SUBMITTED TO MNRAS DOI.ORG/10.48550/ARXIV.2311.18000

"Starburst-induced Gas–Star Kinematic Misalignment" *2023*

Elia Cenci, et al., ***Mauro Bernardini***

- A study about starburst galaxies with counter-rotating gas and stellar components.

PUBLISHED IN APJ: DOI.ORG/10.3847/2041-8213/AD1FFB

"Starbursts driven by central gas compaction" *2023*

Elia Cenci, et al., ***Mauro Bernardini***

- A study describing the main astrophysical drivers in starburst galaxies.

PUBLISHED IN MNRAS: DOI.ORG/10.1093/MNRAS/STAD3709

"The inefficiency of stellar feedback in driving galactic outflows in massive galaxies at high redshift" *2023*

Luigi Bassini, et al., ***Mauro Bernardini***

- A study analyzing the role of stellar feedback in the early stage of galaxy formation in the FIRE-2 model.

PUBLISHED IN MNRAS: DOI.ORG/10.1093/MNRAS/STAD2617

"FIREbox: simulating galaxies at high dynamic range in a cosmological volume" *2023*

Robert Feldmann, et al., ***Mauro Bernardini***

- The official FIREbox pathfinder simulation paper. A small volume simulation with high baryon resolution run with FIRE-2.

PUBLISHED IN MNRAS: DOI.ORG/10.1093/MNRAS/STAD1205

Conferences

International Conference on Machine Learning for Astrophysics - ML4Astro *Catania, IT*

Talk: *"EMBER: emulating baryons from dark matter-only simulations over cosmic time"* *2024*

- Conference topics: Star Formation, Stellar Feedback, Galaxy formation, Machine Learning, Deep Learning

SKACH Spring meeting *Winterthur, CH*

Talk: *"EMBER-2: mapping HI from dark matter-only simulations over cosmic time"* *2024*

- Conference topics: Science with the Square Kilometer Array (SKA) and Switzerlands role in it

Star Formation across cosmic scales: Machine Learning insights and applications *Budapest, HU*

Talk: *"EMBER: emulating gas fields from dark matter simulations"* *2024*

- Conference topics: Star Formation, Stellar Feedback, Star clusters, Machine Learning

The Wheel of Star Formation *Prag, CZ*

Talk: *"EMBER: emulating gas fields from dark matter simulations"* → `slides` *2022*

- Conference topics: Star Formation, Stellar Feedback, Galaxy Clusters

Swiss SKA-days *Lugano, CH*

Talk: *"EMBER: emulating gas fields from dark matter simulations"* → `slides` *2022*

- Conference topics: Science with the Square Kilometer Array (SKA) and Switzerlands role in it

Swiss SKA-days *Lausanne, CH*

Talk: *"EMBER: emulating gas fields from dark matter simulations"* → `slides` *2021*

- Conference topics: Science with the Square Kilometer Array (SKA) and Switzerlands role in it

Debating the potential of Machine Learning in Astronomical Surveys *Paris, FR*

Talk: *"Accelerating the modeling of HI on cosmological scales via Deep Learning"* *2021*

- Conference topics: Star Formation, Stellar Feedback, Galaxy Clusters

Academic teaching

2023, SS ESC 403: Introduction to Data Science
2022, FS AST 241: Introduction to Astrophysics
2022, SS AST 210: Astronomy Field Trips
2021, FS AST 246: Computational Astrophysics
2021, SS AST 210: Astronomy Field Trips
2020, FS AST 210: Astronomy Field Trips
2020, SS ESC 403: Introduction to Data Science
2019, FS AST 210: Astronomy Field Trips