STRUCTURES | NEWS

STRUCTURES CLUSTER OF EXCELLENCE

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

Image credit: TNG Collaboration

RESEARCH SPOTLIGHT Page 2
What can observations of galaxies tell us about their history?

April 2023

Contents

Upcoming

April 24 to July 19 (1 to 1:30 pm): Akademische Mittagspause 2023: „Strukturen in der Welt"
April 27: Girls' Day
July 20, 21: STRUCTURES Days

More information can be found on the **STRUCTURES website:** www.structures.uni-heidelberg.de

Follow STRUCTURES on Social Media:
@structures_hd
@structures_heidelberg
structures.uni-heidelberg.de/blog

STRUCTURES COMMUNITY

New STRUCTURES Members

STRUCTURES welcomes its new members elected by the last General Assembly, Caroline Heneka (ITP) and Jakob Zech (IWR):

Caroline Heneka leads the new research group *Changing the way we look at the sky - Computer Vision Astrophysics* as a six year *VW Freigeist Fellow* at ITP. Her research focuses on using machine learning and artificial intelligence to map out cosmic structures back to the epoch of reionization (and earlier), aiming at an integrated understanding of astrophysical processes and cosmology.

Jakob Zech is Juniorprofessor at the Interdisciplinary Center for Scientific Computing at Heidelberg University. His research focuses on the methodological foundations and theory of forward and inverse problems in uncertainty quantification. He is interested in developing and analysing algorithms for high-dimensional approximation based on sparse-grid techniques, neural networks and transport methods.

We wish both of them a good start and look forward to many joint projects.

STRUCTURES EVENTS, OUTREACH

Akademische Mittagspause 2023 - "Strukturen in der Welt"

Structures occur in all kinds of forms and shape the universe in diverse and crucial ways. The emergence of structure, collective phenomena, and complexity from fundamental laws will be the topic of this year's *Akademische Mittagspause* hosted by STRUCTURES. The event consists of a series of public outreach talks taking place every Mo-Fr from April 24 to July 19 at Peterskirche. The talks, which will be in German, are going to provide exciting insights into the study of structures across a broad spectrum of natural phenomena – from subatomic particles to cosmology, and from fundamental quantum physics to neuroscience. The programme will be complemented with contributions by *Hochschule für Kirchenmusik* about structures in music.

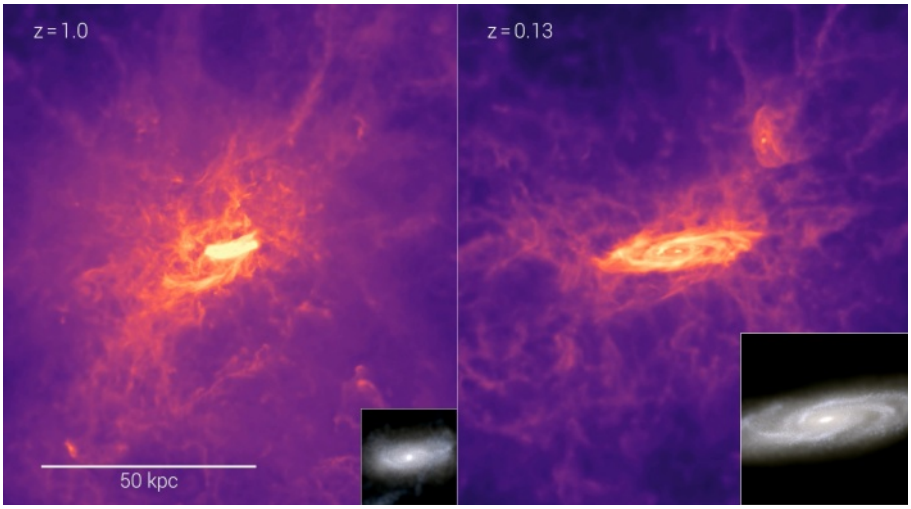
STRUCTURES PROJECTS

From EP 3.4: What can observations of galaxies tell us about their history?

Invited article by Lukas Eisert et al.:

What can observations of galaxies tell us about their history?

This is the central question of the project of STRUCTURES members Lukas Eisert and Annalisa Pillepich from the Max Planck Institute for Astronomy. Within their EP 3.4 about ERGO-ML (*Extracting Reality from Galaxy Observables with Machine Learning*), they have developed, with the help of cutting edge machine learning models, methods to transfer information about the evolutionary history from simulated to observed galaxies.



Snapshots from *TNG50* showing a single galaxy at two different times. Having undergone a chaotic formation phase, the galaxy settles into a quiet assembly history without major mergers, and hence into equilibrium. The main panels show gas densities, the insets show the stellar distribution (Credit: TNG Collaboration, adapted from https://www.tng-project.org.)

Galaxies evolve on timescales of millions to billions of years. This entails an extraordinary challenge if one wants to infer the history of a galaxy: it is particularly challenging with observations, as one can only observe objects at one specific time in cosmic history. To circumvent this problem, the team of Annalisa Pillepich has developed and used cosmological simulations (specifically the *IllustrisTNG* simulations: www.tng-project.org) to study the evolution and interactions of thousands of galaxies in representative large volumes of a model universe across cosmic time.

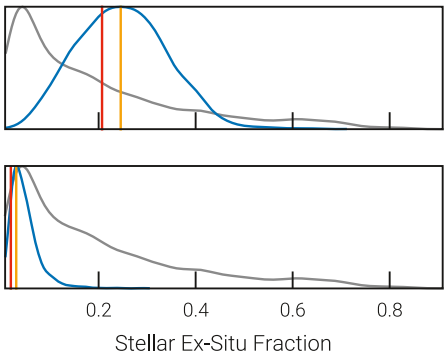


Fig 1: Predictions of the cINN model for the fraction of accreted stars of two simulated TNG galaxies (called exsitu fraction). At the top an example for a galaxy with a high exsitu fraction, at the bottom an example for a galaxy with a low exsitu fraction. We show the posterior inferred by our model as blue curve and the ground truth from the simulation as red vertical line. We find that we can reconstruct the exsitu fraction property very well for a large range of galaxies.

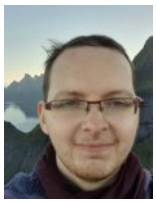
In their first paper of the ERGO-ML series [1], Lukas Eisert and Annalisa Pillepich show that it's in principle possible to infer the unobservable stellar assembly and merger history of galaxies from their observable properties by training machine learning models on the evolutionary histories of simulated galaxies.

For this they use a selected set of observable integral properties of galaxies (e.g. their total stellar mass or their stellar "diskyness") to infer unobservable properties, such as the fraction of accreted stars or the time and mass of the last most massive merging galaxy. They use conditional Invertible Neural Networks (cINN), developed also in Heidelberg, to model and understand the connections between observable and unobservable parameters in the simulated data. The model trained on the simulations allow then to answer the question: What is the probability for a galaxy to have a certain type of history given its observed properties?

Original Publication

[1] Eisert, L., Pillepich, A., Nelson, D., et al. 2023, Monthly Notices of the Royal Astronomical Society, 519, 2199.

ABOUT THE AUTHOR



Lukas Eisert is a PhD student in the "Galaxies and Cosmology Theory" group of Annalisa Pillepich at the Max Planck Institute for Astronomy (MPIA).

EXPLORATORY PROJECTS

This research is from STRUCTURES EP 3.4: *From the fine-structure features of stellar haloes to the assembly histories of their galaxies*.

In addition to the Comprehensive projects (CPs), Exploratory projects (EPs) play an important role within STRUCTURES. The format of EPs is flexible. Their scope ranges from focused projects that pursue ideas not (yet) represented in the CPs, collaborations that establish new links between researchers in different fields, joint workshop and group activities to explore and develop new interdisciplinary topics, to projects that link the cluster to other parts of academia.

STRUCTURES COMMUNITY

We Are STRUCTURES

In each issue of our newsletter, we introduce three random members of the Young Researchers Convent (YRC), a subgroup of STRUCTURES that brings together students and postdocs. For this issue, we interviewed Nadine Nussbaumer, Shayan Hemmatyar and Alexey Kazarnikov:

Interview with Nadine Nussbaumer:

Nadine Nussbaumer
PhD student, AG Heisenberg, ITP

What are you working on?
I am currently working with quantum field theories (QFTs) on curved backgrounds in the context of inflation, massive gravity and modified gravity. My projects either focus on checking the quantum stability of these theories or on computing late-time correlation functions in de Sitter space that allow us to bridge the gap between the theory of inflation and present-day cosmological observations.

What are you an expert for?
Vegan baking! Otherwise, I'm trying to become a Mathematica expert so I don't have to compute all my QFT loop integrals by hand anymore.

What is your connection to STRUCTURES?
When I started my PhD in Prof Lavinia Heisenberg's group this year, my dear friends Ricardo and David quickly introduced me to the STRUCTURES YRC programme. I'm really looking forward to meeting new people through this programme!

What has been your greatest scientific success up to now?
Completing my master's thesis on late-time correlators in $\lambda\varphi^4$-theory in de Sitter space and (hopefully!) soon turning it into a paper.

How does one recognize you?
If you happen to see someone with flowery Doc Martens notoriously speaking Swiss German, that's me😉.

Interview with Shayan Hemmatyar:

Shayan Hemmatyar
PhD student, AG Heisenberg, ITP

What are you working on?
I am currently working on Kinetic Field Theory (KFT) for cosmic structure formation, and Quantum Field Theory in curved spacetime, where I investigate the quantum stability of Generalized Proca theories in the presence of gravity. I also work on gravitational waves.

What are you an expert for?
I am primarily an expert in quantum field theory, with some background in string theory. I have also worked extensively with general relativity to investigate the behaviour of particles and fields in curved spacetime.

What is your connection to STRUCTURES?
I joined STRUCTURES through my PhD advisor, Prof Lavinia Heisenberg, who is a member. STRUCTURES has provided me with valuable connections to other physicists and kept me informed on their research.

What has been your greatest scientific success up to now?
I am honoured by the recognition received for our KFT paper being listed among the Editors' Suggestion for outstanding articles, and humbled by the positive impact I had on my students' academic journey through excellent evaluation results.

How does one recognize you?
You can recognize me as the physics enthusiast who often discusses the intricacies of the universe with students in the hallways. Look for the guy with the shiny head and don't hesitate to stop me for a chat!

Interview with Alexey Kazarnikov:

Alexey Kazarnikov
Postdoc, AG Marciniak-Czochra, IAM

What are you working on?
I am working on computational models of biological pattern formation. More precisely, I am looking for a statistically sound way to compare mechanisms of self-organization and to fit models to the experimental data. The limited amount of information available in such problems requires a non-standard approach.

What are you an expert for?
I am not sure if I would call myself an expert, but the focus of my studies lies at the intersection of applied analysis, numerical methods, and statistical techniques. The multidisciplinarity of my research is an exciting challenge.

What is your connection to STRUCTURES?
I am part of the Applied Analysis and Modelling in Biosciences Research Group and of an exploratory project in CP3.

What has been your greatest scientific success up to now?
Perhaps joining Heidelberg University and having the opportunity to work on my current project. We have already obtained promising results, and there are more to come.

How does one recognize you?
Until very recently one could recognize me by a very noisy and huge laptop, which I was using for developing GPU-powered programmes. My new computer is much smaller and quieter, thus new representative features are probably needed.

JOIN THE YRC:

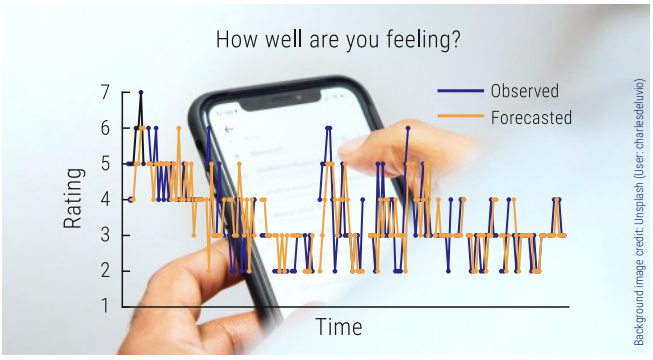
Any student or postdoc who is part of the group of a STRUCTURES member or who works on topics closely related to STRUCTURES is welcome to apply for membership in the YRC. Contact us at: *structuresyrc(at)thphys.uni-heidelberg.de.*

STRUCTURES MEMBER INTERVIEWS

STRUCTURES Asks: Georgia Koppe

In our newsletter, we regularly interview faculty members of STRUCTURES to introduce people and their research. For this edition, we interviewed Georgia Koppe, who leads the research group "Computational Psychiatry" at the Theoretical Neuroscience department of the Central Institute of Mental Health (ZI) in Mannheim. Georgia Koppe is an expert in neuroscience and computational psychology. She joined STRUCTURES in 2022.

Georgia Koppe (ZI Mannheim)



Behavioural time series (data collected together with the PMH department, ZI).

Q: What are you working on? What are typical questions in your research?

A: I am working on understanding the dynamics underlying (mostly) human behavioural and neural time series. We address questions such as: What algorithmic principles account for an individual's choices in an experiment? Can we infer statistical regularities based on observed time series which allow us to predict future behaviour or entire behavioural trajectories? And how do neural networks implement specific cognitive (dys)functions?

Q: What fascinates you about computational neuroscience?

A: To be honest, I started working in experimental psychology and cognitive neuroscience, where I found many of the concepts to be quite abstract. Computational neuroscience greatly contributes to defining the problems we are trying to address. So I guess the field fascinates me as it helps me to get a tighter grip on psychology, enabling to address specific hypotheses at brain and behavioural mechanisms, and also delineate bounds on the type of questions we can ask.

Q: How well do we understand human behaviour & memory? Is it possible to trace mental disorder symptoms directly to the dynamics of neurons?

A: With respect to the first question I would argue that in some domains we understand it fairly well, and in others, not at all. If you think for instance about the complexity of a simple social interaction – all subtle inferences, heuristics, and motivations involved – it becomes pretty complicated very soon. Regarding the second question – our best guess is yes (since we still assume these to have a neural substrate). Of course in humans, we usually cannot record from single neurons or manipulate their activity with the necessary precision (with few exceptions). But again, there are psychiatric symptoms which are probably explained reasonably well through local changes in brain dynamics while others are exceedingly more complicated.

Q: To what extent do concepts of social sciences play a role in your research?

A: They play a huge role. Ultimately, psychiatric symptoms are never a simple function of personal dispositions such as genetic alterations, but hugely depend on environmental and societal interactions, including (adverse) learning experiences throughout life.

Q: What do you like best about your job?

A: I love thinking about problems and finding new creative solutions to address pressing issues. I also love digging into data myself to figure out and explain how the things we observe come about. It feels a bit like being a detective trying to put different pieces of a puzzle together… unfortunately, often with a lot of missing pieces.

Q: Do you have any advice for young researchers on choosing their career path?

A: Take active steps and choices which will connect you to the topics that you are most passionate about.

Q: Imagine you get 48 extra hours as a present - what would you do with it?

A: I would read a book on human behaviour which is currently waiting on my bedside, go for a run, and visit a zoo – or anything which includes animals – with my daughter.

STRUCTURES ON THE WEB
https://structures.uni-heidelberg.de
@structures_hd
@structures_heidelberg

The production of this newsletter is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy EXC 2181/1 - 390900948 (the Heidelberg STRUCTURES Excellence Cluster).

IMPRESSUM & CONTACT
Exzellenzcluster STRUCTURES
Universität Heidelberg
Philosophenweg 12 & Berliner Straße 47
D-69120 Heidelberg
office@structures.uni-heidelberg.de

Text & Editing Sebastian Stapelberg, STRUCTURES Office, Guest Authors and Spokespersons