Mock Innsbruck

Mock Innsbruck is the fifth instalment of the Mock series after Mock Santiago, Perth, Durham, and Cordoba. The goal of Mock Innsbruck is to bring together leading researchers in computational studies of galaxy formation and cosmology and key representatives from current and future surveys to promote discussions and collaborations. The main focus of Mock Innsbruck will be on the galaxy-halo connection. In this meeting we will discuss:

- The implications of the galaxy-halo connection on galaxy formation models and cosmology
- The role of galaxy and halo assembly bias on empirical galaxy-halo models (e.g., SHAM, HOD)
- What we can learn from the next generation of wide-field galaxy surveys to understand the galaxy-halo connection
- Alternative new techniques to connect galaxy properties with dark matter haloes
- Galaxy-halo models to interpret galaxy surveys and their spatial statistics
- Mock galaxies to explore different open questions in astrophysics

Organizing committee

SOC

Maria Celeste Artale
Sergio Contreras
Rosa Domínguez Tenreiro
Claudia Lagos
Nelson Padilla
Carlton Baugh
Gabriella de Lucia
Violeta Gonzalez-Perez
Peder Norberg
Idit Zehavi

LOC

Maria Celeste Artale
Gabriella Hirsch
Nadeen Sabha
Doris Stoppacher

Useful Information

Talks will be held at the **Claudiasaal** in Palais Claudiana (Herzog-Friedrich-Straße 3, Innsbruck). It is situated on the second floor of the building.

Coffee breaks and lunches will be offered in the Türingsaal saal on the first floor. We will have available a small room in the basement of the building for spontaneous meetings.

Wi-Fi will be available during the conference. The University of Innsbruck also provides access to eduroam network.

The **conference dinner** will be held at **Bierstindl**, Klostergasse 6, Innsbruck on Thursday at 20:00hr.

Timetable

Tuesday, 10th of March

9:00–9:25	**Registration**		
9:25–9:30	**Welcome remarks**		
9:30–9:50	GDM	**Nelson Padilla**	The evolution of the baryon fraction as a cause of scatter in the galaxy stellar mass in EAGLE
9:50–10:10	GDM	**Miguel Angel de Icaza Lizaola**	Sparse Regression for modeling the relation between Stellar Mass and Halo Evolution
10:10–10:30	GDM	**Jonas Chaves Montero**	The influence of star formation history on galaxy colors
10:30–11:00	**Coffee**		
11:00–11:20	GDM	**Benjamin Moster**	Connecting galaxies and dark matter haloes with deep neural networks and reinforcement learning
11:20–11:40	GDM	**Carolina Cuesta-Lazaro**	A tree grows in Illustris TNG: the galaxy-halo connection learned by boosted decision trees
11:40–12:00	GDM	**Tilman Troester**	Painting with baryons: augmenting N-body simulations with gas using deep generative models
12:00–12:45	**Group discussion: Gal-DM halo mocks**		
12:45–14:00	**Lunch**		
14:00–14:20	LSS	**Wojciech Hellwing**	On halo and galaxy connection with the cosmic web
14:20–14:40	LSS	**Enrique Paillas**	Redshift-space distortions around voids
14:40–15:00	LSS	**Andrés Balaguera-Antolinez**	Cosmological Catalogs for Large Scale Structure
15:00–15:30	**Coffee**		
15:30–15:50	LSS	**Christian Arnold**	Zoomed hydrodynamical simulations of the local group in f(R) modified gravity
15:50–16:10	LSS	**Joaquín Armijo Torres**	The CODEX-BOSS marked cross-correlation function to unveil the form of gravity
16:10–17:00	**Group discussion: LSS**		

Wednesday, 11 of March

9:30–9:50	GFM	**Matthieu Schaller**	The EAGLE-XL simulations - Galaxy formation in a cosmological volume
9:50–10:10	GFM	**Weiguang Cui**	On the scatters of these relations for connection BH, galaxy and dark matter halos
10:10–10:30	GFM	**Lucie Barnes**	Characterising haloes and subhaloes by their interaction histories
10:30–11:00	**Coffee**		
11:00–11:20	ELG	**Violeta Gonzalez-Perez**	Model star-forming emission lines at $z \sim 1$
11:20–11:40	ELG	**Ginevra Favole**	Modelling the clustering properties and the halo occupation distribution of emission line galaxies in next-generation cosmological surveys
11:40–12:00	ELG	**Santiago Avila**	The Halo Occupation Distribution of Emission Line Galaxies with eBOSS
12:00–12:45	**Group discussion: Resolution (from hydro to HOD mocks)**		
12:45–14:00	**Lunch**		
14:00–14:20	AB	**Idit Zehavi**	On encapsulating assembly bias in the galaxy-halo connection
14:20–14:40	AB	**Xiaoju Xu**	Effects of secondary halo properties on galaxy assembly bias
14:40–15:00	AB	**Doris Stoppacher**	Luminous Red Galaxies on the edge of the assembly bias – A perspective on the formation history of massive galaxies throughout cosmic history
15:00–15:30	**Coffee**		
15:30–16:00	**Gender Bias: Oral presentation given by Dr. Heidi Siller**		
16:00–16:30	**Gender Bias: general discussion with the participants**		

Thursday, 12 of March

9:30–9:50	AB	**Frank van den Bosch**	Probing the Galaxy-Halo Connection with Basilisk
9:50–10:10	AB	**Antonio Montero-Dorta**	The manifestation of secondary halo bias on the galaxy population
10:10–10:30	AB	**Kevin McCarthy**	On the constraints of galaxy assembly bias in velocity-space
10:30–11:00	**Coffee**		
11:00–11:20	AB	**Andreas Berlind**	Harnessing the full power of galaxy clustering to constrain the galaxy-halo connection

11:20–11:40	AB	**Gillian Beltz-Mohmann**	Taking HOD modeling to the next level: comparing to hydrodynamic simulations
11:40–12:00	AB	**Ivan Lacerna**	Galactic conformity around the most massive structures in the local Universe
12:00–12:45	**Group discussion: Assembly Bias**		
12:45–14:00	**Lunch**		
14:00–14:20	GFM	**Jingjing Shi**	The Formation History of Subhalos and the Evolution of Satellite Galaxies
14:20–14:40	GFM	**Marta Spinelli**	Modelling the HI content of the post-reionization Universe for Intensity Mapping
14:40–15:00	GFM	**Diego Pallero**	Too dense to go through
15:00–15:30	**Coffee**		
15:30–15:50	GFM	**Celeste Artale**	Mocks for the host galaxies of merging compact objects
15:50–16:10	GFM	**Filippo Santoliquido**	The cosmic merger rate density of compact binaries
16:10–17:00	**Group discussion: Galaxy Formation**		
20:00	**Conference Dinner**		

Friday, 13 of March

9:30–9:50	ELG	**Johan Comparat**	Mock catalogs for eROSITA clusters and AGNs
9:50–10:10	ELG	**Pauline Zarrouk (TBC)**	Galaxy-halo connection: which interpretation for quasars?
10:10–10:30	CC	**Jeremy Tinker**	Galaxy Clustering with the Aemulus Project
10:30–11:00	**Coffee**		
11:00–11:20	CC	**Raul Angulo**	Numerical Simulations for Large-Scale Structure Analyses
11:20–11:40	CC	**Giovanni Aricò**	Modelling the large scale structure of the Universe as a function of cosmology and baryonic physics
11:40–12:00	CC	**Sergio Contreras**	Using a new generation of abundance matching mocks to constrain cosmology
12:00–12:45	**Group discussion: Cosmological Constrains**		
12:45–14:00	**Lunch**		

List of sessions:

GDM: Galaxy-Dark matter halo mocks
LSS: Large-Scale Structure of the universe
GFM: Galaxy formation models
ELG: ELGs & Quasars
AB: Assembly bias
CC: Cosmological constraints

Chairs:

10 March morning session: Kevin McCarthy
10 March afternoon session:

11 March morning session: Tilman Troester
11 March afternoon session: Antonio Montero-Dorta
11 March Assembly Bias session: Doris Stoppacher

12 March morning session: Weiguang Cui
12 March afternoon session: Xiaoju Xu

13 March morning session: Ivan Lacerna

Leaders for group discussions:

Gal-DM halo mocks: Padilla, Chaves Montero, Cuesta
LSS: Hellwing, Armijo Torres, Balaguera-Antolínez
Resolution (from hydro to HOD mocks): Gonzalez-Perez, Schaller, Favole, Zarrouk(TBC)
Assembly Bias: Zehavi, Stoppacher, van den Bosch, Berlind
Galaxy Formation: Artale, Spinelli, Shi
Cosmological Constrains: Comparat, Tinker, Aricò, Angulo

Details about the Gender Bias session:

The goal of this session is to discuss several aspects of gender diversity in science. We will have first an oral presentation from an expert in the area, Dr. Heidi Siller, and a panel discussion among the participants afterwards.
Dr. Siller is a clinical and health psychologist and researcher. She works at the Gender Medicine Unit, Medical University of Innsbruck. Her research focuses on violence in different settings as well as on career progression, inequality in career pursuit and discrimination in careers. She is also a member in the advisory board of the Research Platform Center for Gender Studies Innsbruck (CGI).

List of Abstracts – Talks

Numerical Simulations for Large-Scale Structure Analyses

Angulo, Raul

Donostia International Physics Center, Spain

In this talk, I will discuss several advances in cosmological numerical simulations. Specifically, I will address recent progress in improving the accuracy of N-body simulations, and the respective modelling of galaxy clustering and weak lensing measurements.

Modelling the large scale structure of the Universe as a function of cosmology and baryonic physics

Aricò, Giovanni

Donostia International Physics Center, Spain

We present a framework that models the three-dimensional distribution of mass in the Universe as a function of cosmological and astrophysical parameters. Our approach combines two different techniques: a rescaling algorithm that modifies the cosmology of gravity-only N-body simulations, and a "baryonification" algorithm which mimics the effects of astrophysical processes induced by baryons, such as star formation and AGN feedback. We show how this approach can accurately reproduce the effects of baryons on the matter power spectrum of various state-of-the-art hydrodynamical simulations (EAGLE, Illustris, Illustris-TNG, Horizon-AGN, and OWLS, Cosmo-OWLS and BAHAMAS), to better than 1% from very large down to small, highly nonlinear, scales ($k \sim 5hMpc^{-1}$), and from $z = 0$ up to $z \sim 2$. We highlight that we can obtain these predictions for arbitrary baryonic models and cosmology (including massive neutrinos and dynamical dark energy models) with an almost negligible CPU cost. This method paves the way to the fast creation of X-ray, weak lensing, and kinetic and thermal Sunyaev-Zeldovich maps.

The CODEX-BOSS marked cross-correlation function to unveil the form of gravity

Armijo Torres, Joaquín Andrés

Durham University, UK

The marked correlation function has shown to be useful to tell apart between modified gravity models and Einstein's general relativity (Armijo+ 2018; Hernandez-Aguayo+ 2018) in mock universes. It can be seen on these previous studies, that a smart choice of weights to compute the clustering leads to visible differences between gravity models, highlighting the mass of host haloes and galaxy local density to mark pairs of galaxies. The next question to answer is, if this test can be used on the current and future large-scale galaxy surveys to constraint the form of gravity. In this talk I will discuss about the implementation of this method between SDSS CODEX galaxy cluster sample and the BOSS LRG galaxies to compute a marked cross-correlation function. We select this samples to exploit their halo mass estimations and use it to mark galaxy clusters, to then cross-correlate them with galaxies marked by its local density. I also will show the elaboration of suitable mock catalogues to compare and predict results from the observations.

Zoomed hydrodynamical simulations of the local group in f(R) modified gravity

Arnold, Christian

Durham University, UK

Recently, the Shibone cosmological hydrodynamical simulations allowed us to study the formation of galaxies in f(R) modified gravity employing the state-of-the-art Illustris-TNG galaxy formation model. In this talk I will present an extension of these studies on galaxy formation in modified gravity theories to the local group and the Milky Way in particular, employing a new set of zoomed simulations based on Auriga and Apostle initial conditions. The simulations show that f(R)-gravity has, depending on the specific model, a significant impact on the dynamics of the local group. The formation of local group like structures is nevertheless still possible. Due to the - compared to the previous cosmological hydrodynamical simulations - significantly better resolution the new simulations enable us to study the effects f(R)-gravity has in unscreened regions of galaxies in detail. This allows us to better understand how enhanced gravitational forces lead to higher gas densities and consequently to higher start formation rates in the outer regions of Milky-Way type galaxies and their satellites, leading e.g. to a significantly enhanced satellite luminosity function.

Mocks for the host galaxies of merging compact objects

Artale, Maria Celeste

University of Innsbruck, Austria

In the new era of gravitational wave (GW) astronomy, knowing the properties of the host galaxies of merging compact objects is fundamental for the electromagnetic follow-up of the GW detections. In this talk, I will present a method to investigate the host galaxies of merging compact objects by combining galaxy catalogs from hydrodynamical cosmological simulations together with state-of-the-art population synthesis models. This method tracks the population of merging binary systems within their host in a robust and self consistent way. I will show that the stellar mass of the host galaxy is an excellent tracer of the merger rate per galaxy of double neutron stars (DNS), double black holes (DBH) and black hole-neutron star binaries (BHNS). Our methodology has shown to be consistent with the DNS merger rate for Milky-Way like galaxies (16-121 Myr^{-1}) and the DNS merger rate inferred from GW170817.

The Halo Occupation Distribution of Emission Line Galaxies with eBOSS

Avila, Santiago

Universidad Autónoma de Madrid, Spain

In the current era of galaxy surveys, a particular interest has been put on Emission Line Galaxies (ELGs) to map the Large Scale Structure (LSS) of the Universe. They represent an attractive target when one wants to map the Universe beyond z=0.6 in order to measure the BAO or redshift space distortions. ELGs roughly represent a star formation rate selected sample. The properties of ELGs inherit from galaxy evolution are very different to those of LRGs, the most common tracer used for LSS at low redshift, that roughly represents a cut in stellar mass. Hence, it is unknown the exact way in which ELGs map the dark matter field, and whether this could have an impact on Cosmology. Usually, this is studied in the context of the Halo Occupation Distribution (HOD) model, relating the galaxy properties to dark matter halo properties.

The extended Baryonic Accoustic Oscillations Spectroscopic Survey (eBOSS) has collected the largest ELG redshift catalogue to date with $\sim 240,000$ galaxies over ~ 700 square degrees in the $0.6 < z < 1.1$. In this talk I present a Halo Occupation Distribution study of the final eBOSS ELG data catalogue.

Cosmological Catalogs for Large Scale Structure

Balaguera-Antolínez, Andres

Instituto de Astrofísica de Canarias, Spain

We present COSMICATLAS, a project aimed at generating mock catalogues of dark matter tracers based on the novel Bias Assignment Method (BAM). We shall discuss the main properties of the method, focusing on its capability to generate ensemble of cosmological mock catalogues at low computational cost (both in terms of time and memory consumption), keeping the accuracy and precision requested for the forthcoming galaxy surveys such as Euclid and DESI.

Taking HOD modeling to the next level: comparing to hydrodynamic simulations

Beltz-Mohrmann, Gillian Dora

Vanderbilt University, USA

Halo models provide a simple and computationally inexpensive way to investigate the connection between galaxies and their dark matter halos. However, they make the assumption that the role of baryons can be easily parameterized in the modeling procedure. In our recent work, we have examined the accuracy with which standard halo occupation distribution (HOD) modeling can predict a variety of galaxy clustering statistics when compared to hydrodynamic simulations. We have found that baryonic physics significantly impacts the halo mass function in hydrodynamic simulations compared to dark matter only (DMO) simulations, and that this effect varies widely across different hydrodynamic simulations. Because of this, the correct HOD model is unable to reproduce the clustering found in hydrodynamic simulations until the DMO halo masses are adjusted. We have found that if we apply a mass correction to all of our DMO halos, and if we additionally consider effects like assembly bias and spatial/velocity bias, then our HOD model is able to accurately reproduce the galaxy clustering found in hydrodynamic simulations. However, the exact mass correction and bias parameters required depend on the particular hydrodynamic simulation in question. These results have implications for any work using DMO simulations and HOD models to investigate the galaxy-halo connection in increasingly accurate surveys.

Harnessing the full power of galaxy clustering to constrain the galaxy-halo connection

Berlind, Andreas

Vanderbilt University, USA

Galaxy clustering measurements have the potential to constrain the relationship between galaxy properties and halo mass, as well as subtle features of the galaxy-halo connection, like assembly bias or satellite velocity bias. However, to do this we must maximize the information that we extract from the galaxy density field, while minimizing systematic errors in the modeling. I will discuss our progress along both these directions and report on new results modeling SDSS galaxies that have yielded substantially tighter constraints on the galaxy-halo connection than previous works.

The influence of star formation history on galaxy colors

Chaves Montero, Julio Jonas

Argonne National Laboratory, USA

The spectral energy distribution of a galaxy emerges from the complex interplay of many physical ingredients, including its star formation history (SFH), metallicity evolution, and dust properties. Using Galaxpy, a new stellar population synthesis model, and SFHs predicted by the empirical model UniverseMachine and the cosmological hydrodynamical simulation IllustrisTNG, we isolate the influence of SFH on broad-band colors at z = 0. By carrying out a principal component analysis, we show that physically-motivated SFH variations modify broad-band colors along a single direction in color space: the SFH-direction. We find that the projection of a galaxy's present-day colors onto the SFH-direction is almost entirely regulated by the fraction of stellar mass that the galaxy formed over the last billion years. Together with cosmic downsizing, this results in galaxies becoming redder as their host halo mass increases. We additionally study the change in galaxy colors due to variations in metallicity, dust attenuation, and nebular emission lines, finding that these properties vary broad-band colors along distinct directions in color space relative to the SFH-direction. Finally, we show that the colors of low-redshift SDSS galaxies span an ellipsoid with significant extent along two independent dimensions and that the SFH-direction is well-aligned with the major axis of this ellipsoid. Our analysis supports the conclusion that variations in star formation history are the dominant influence on present-day galaxy colors, and that the nature of this influence is strikingly simple.

Mock catalogs for eROSITA clusters and AGNs

Comparat, Johan

MPE/MPG, Germany

In this talk I present the methodology to create multi-wavelength mock catalogs for eROSITA AGN and clusters of galaxies. I discuss a cosmological application, that is to measure cosmological parameters with the latest set of clusters observed by SDSS-IV/SPIDERS.

A tree grows in Illustris TNG: the galaxy-halo connection learned by boosted decision trees

Cuesta, Carolina

Durham University, UK

I present an analysis of the central galaxy occupation of dark matter haloes in the state-of-the-art full physics Illustris TNG simulation comparing a novel Machine Learning technique to traditional Halo Occupation Distribution (HOD) models. Using the matched catalogues between Illustris TNG dark matter only runs and the corresponding full physics simulations we found that current HOD models (which assign galaxies to dark matter haloes according solely to their mass) under-predict the two point correlation function of central galaxies in the simulation by about 15% on scales smaller than 30 Mpc/h. The error introduced by this technique is therefore too large for the requirements of future surveys. In this talk, I present an alternative Machine Learning technique based on decision trees that uses several basic properties from the Dark Matter Only simulation to predict the stellar mass of the central galaxy. This information can then be translated into a model for the occupation of central galaxies, based only on dark matter halo properties. The Machine Learning model can reproduce the actual TNG galaxy correlation function to a few percent and allows to analyse the importance of the different features in predicting the stellar mass of the halo.

On the scatters of these relations for connection BH, galaxy and dark matter halos

Cui, Weiguang

University of Edinburgh, UK

Understanding the processes of galaxy formation is an important task in astronomy researches from both observation and theoretical sides as it directly connects to many other different researches in astronomy from BHs at small scale to cosmology at large scale. We currently have a brief idea on how galaxy forms and evolves along with dark matter halos. However, it is still unclear in details as well as reproducing different observational relations simultaneously. Using the state-of-art cosmological hydrodynamic simulation – Simba (Dave et al. 2019) which is in agreement with observations in many aspects, especially the BH-galaxy relations, we seek to understand the connections between BH, galaxy and halos. We focus on the scatters in these relations and try to connect them with different galaxy properties and their formation histories.

Sparse Regression for modeling the relation between Stellar Mass and Halo Evolution

de Icaza Lizaola, Miguel Angel C.

Durham University, UK

Sparse regression algorithms have been proposed as a viable tool to find the governing equations of a physical phenomenon using data, and without having any previous knowledge of the physical process (Brunton et al. 2016). We investigate an accurate relation between the Dark Matter (DM) evolution of halos and the stellar mass of the galaxies that they host. Our data set comes from the hydrodynamical EAGLE simulation and includes the stellar mass at z=0 of central galaxies, which is considered our dependent variable. Our aim is to build a model that once tested on Eagle can be applied to infer similar relations from any simulation for which information on the evolution of the DM halos is available or to populate DM-only simulations with galaxies that statistically reproduce some of the galaxy properties (initially the stellar mass) inferred from EAGLE. This method contrasts with other Machine Learning algorithms like a random forest, where physics is harder to extract.

In order to avoid cause and effect biases, the DM halos hosting these galaxies are mapped (one-to-one) with halos from the EAGLE DM-only simulation. For each of these galaxies, we find the mapped mass and spin in twenty redshift bins (from $z = 0$ to $z = 5.5$). Our algorithm uses sparse regression to find the governing equations relating to stellar-mass and DM only properties. Our preliminary results show that our governing equations prefer using Halo Mass at a subset of well spaced out redshifts, together with some spin information.

Modelling the clustering properties and the halo occupation distribution of emission line galaxies in next-generation cosmological surveys

Favole, Ginevra

Portsmouth University, UK

Emission line galaxies (ELGs) will be among the main targets of the next generation of cosmological surveys, such as DESI, Euclid, 4MOST, J-PAS, Subaru PFS, LSST, WFIRST. All these instruments will observe [OII], [OIII] and Hα ELGs out to redshift $z \sim 2$ to reconstruct the cosmic star formation history and fully understand the galaxy formation/evolution mechanisms. This will enable us to build 3D maps of the Universe with unprecedented accuracy, to probe the growth of structure, and hopefully unveil the nature of dark energy. In order to optimally exploit the upcoming missions, it is crucial to understand how to precisely model the clustering properties of ELGs and how they populate their host dark matter haloes. I will address these issues by interpreting state-of-the-art data using large-volume, high-resolution, cosmological simulations and semi-analytic models of galaxy formation. I will present a modified sub-halo abundance matching (SHAM) prescription that allows us to connect emission line galaxies to haloes accounting for their stellar mass incompleteness. I will conclude by showing how SHAM can also be used to infer the growth history of the Universe, $\sigma_8(z)$.

Model star-forming emission lines at z∼1

Gonzalez-Perez, Violeta

Liverpool John Moores University, UK

Current and future cosmological surveys are targeting star-forming galaxies at $z \sim 1$ with nebular emission lines. In this work we use a state-of-the-art model of galaxy formation and evolution to explore the large scale environment of star-forming emission line galaxies (ELGs). Model galaxies are selected with cuts such that the samples can be directly compared with the DEEP2, VVDS, eBOSS-SGC and DESI surveys. Their large scale environment have been classified using a velocity-shear-tensor and a tidal-tensor algorithms. Half of model ELGs live in filaments and about a third in sheets. Model ELGs in knots have the largest satellite fractions. We find that the shape of the mean halo occupation distribution of model ELGs varies widely for different large scale environments. To put these results in context, we have compared fixed number density samples of galaxies, generated by either imposing an extra cut in stellar mass, star formation rate (SFR) or L[OII] to the ELGs, or by imposing a single cut in these quantities to the total model galaxy population. For the fixed number density samples, ELGs are close to L[OII] and SFR selected samples for densities above $10^{-4.2} h^3 Mpc^{-3}$. ELGs with an extra cut in stellar mass to fix their number density, present differences in sheets and knots with respect to the other samples. ELGs, SFR and L[OII] selected samples with equal number density, have similar large scale bias but their clustering below separations of 1Mpc/h is different.

Using a new generation of abundance matching mocks to constrain cosmology

Contreras, Sergio

Donostia International Physics Center, Spain

Predicting the spatial distribution of objects as a function of cosmology is an essential ingredient for the exploitation of future galaxy surveys. In this talk, we show that a specially-designed suite of gravity-only simulations together with cosmology-rescaling algorithms can provide the clustering of galaxies with high precision using a new generation of abundance matching mocks. These subhaloes abundance matching codes are able to reproduce the clustering of a hydrodynamic simulation run with complete different resolution. We will use these mock along with the scaling technique (Angulo & White 2010, Contreras et al. 2020) to predict cosmological parameters of a hydrodynamic simulation.

On halo and galaxy connection with the cosmic web

Hellwing, Wojciech

Center for Theoretical Physics PAS, Poland

The Cosmic Web – an intricate network of clusters, filaments, walls and walls – can have many aspects. Most of the features the Web and associated impact they induce on the formation and evolution of haloes and galaxies are subject of ongoing debate. The differences being mostly driven by a specific choice among many existing working definitions of the Cosmic Web. Nonetheless, it is clear that different segments of this net establish different intimate environments and ecosystems for the local halo and galaxy formation. In this talk I will demonstrate, using NEXUS+ definition for the Cosmic Web identification, how indeed the disparate environments affect the local formation histories and hence properties of dark matter clumps and galaxies living within. I will focus on internal kinematics and morphology properties.

Galactic conformity around the most massive structures in the local Universe

Lacerna, Ivan

Universidad de Atacama, Chile

The hostile environment within galaxy clusters can quench the star formation of galaxies. However, the environmental effects beyond the virial radius of clusters are less evident. One way to quantify the scale in which the environment plays a crucial role in the star formation quenching is measuring the quenched fraction of galaxies as a function of the distance of central galaxies. Both observations and simulations agree with the presence of galactic conformity within the virial radius, i.e., a correlation between the quenching in central galaxies and their satellite galaxies. Interestingly, the conformity seems to extend out to scales of 3-4 Mpc, but it is debated if this two-halo conformity is real or dominated by systematics. In the former case, the two- halo conformity would be stronger in the infall region of galaxy clusters. In this talk, I will present a project using the SAG semi- analytic model applied on the MultiDark simulations to address the question if galaxies at z 0 are quenched preferentially around the most massive structures than around less dense environments.

On the constraints of galaxy assembly bias in velocity-space

McCarthy, Kevin Spencer

University of Utah, USA

Attempts to detect galaxy assembly bias (AB) through the measurement of the galaxy-galaxy two-point correlation function (2PCF) are, so far, inconclusive. Prior investigations have been solely limited to projected-space, where the velocity field of the dark matter does not contribute to the observed signal. In this space, splitting galaxy samples by some assembly-dependent parameter has failed to produce AB as predicted from theory, either because the signal does not exist, the samples have not been split according to the proper halo assembly history proxy, or the signal is too small to stand above the errors. In this talk, I will present our attempt to detect the presence of galaxy assembly bias in velocity-space seen in the redshift-space 2PCF, where the clustering is sensitive to the relative motion between the dark matter and the galaxies observed. Specifically, I look to determine if Early/Late central galaxy samples with consistent mean host halo masses split according star-formation history (SFH) or specific star-formation rate (sSFR) show inconsistent central galaxy velocity bias (α_c), a result that would indicate the positive presence of galaxy velocity AB.

The manifestation of secondary halo bias on the galaxy population

Montero Dorta, Antonio

University of Sao Paulo, Brazil

At fixed halo mass, the bias of dark-matter halos is known to depend on multiple secondary halo properties, including formation time, concentration, and spin (e.g., Sato-Polito, Montero-Dorta et al., 2018). The manifestation of secondary halo bias on the galaxy population is, however, yet to be confirmed observationally. In this talk, I will present recent predictions from hydro-dynamical simulations indicating that the effect of halo assembly bias (the secondary dependence on halo formation history) should leave a detectable imprint on the clustering properties of galaxies (Montero-Dorta et al., 2020). I will also briefly discuss our attempts to probe this galaxy assembly bias effect using BOSS (Montero-Dorta et al., 2017; Niemiec et al., 2018) and highlight the issues that hinder its observational confirmation.

Connecting galaxies and dark matter haloes with deep neural networks and reinforcement learning

Moster, Benjamin Philipp

LMU Munich

In the last decade, the field of artificial intelligence and machine learning has expanded rapidly. Recently, several machine learning methods developed by the data science community have been adapted for astrophysical problems. The big advantage of machine learning methods is that they give computers the ability to learn without being explicitly programmed. Whereas for classical numerical methods, such as hydrodynamic simulations and semi-analytic models we need to know all (complex) 'rules' beforehand, a machine learning algorithm can detect patterns automatically. This makes them the ideal tool for many analysis tasks and improvements in numerical astrophysics. Empirical galaxy formation models connect the properties of simulated haloes to those of observed galaxies. However, it is often unclear how these relations should be parameterised. Therefore we develop a novel method and adopt a wide and deep neural network. The input nodes consist of different halo properties (e.g. halo mass and concentration), while the output nodes yield the galaxy properties (e.g. stellar mass and SFR). The model is implemented with TensorFlow and directly runs on NVIDIA Volta graphics cards, accelerated by tensor cores. Training the model on labeled data provided by the galaxy formation code EMERGE, galaxy properties can be reproduced very well. If we train the model directly on observed statistical data (e.g. mass functions, clustering) using a reinforcement learning approach with particle swarm optimisation, the network reproduces observations much more accurately. We run the network on the HugeMDPL simulation to predict the galaxy bias for active and passive galaxies up to high redshift.

The evolution of the baryon fraction as a cause of scatter in the galaxy stellar mass in EAGLE

Padilla, Nelson David

Pontificia Universidad Católica de Chile, Chile

We use the EAGLE simulation suite to revisit the origin of the scatter in the M_* – V$_{max}$ relation where M_* is the stellar mass of a central galaxy in the EAGLE hydro simulation, and Vmax is measured using the same halo in the dark-matter only (DMO) EAGLE simulation, at $z = 0.1$. At the redshift of $z = 1$, we find that the progenitor baryonic mass accounts for 75% of the variance in the z = 0.1 M_* – V$_{max,DMO}$ relation. The scatter in the baryonic mass, in turn, is primarily set by differences in feedback strength and gas accretion over the course of the evolution of each halo.

Redshift-space distortions around voids

Paillas, Enrique

Pontificia Universidad Católica de Chile, Chile

Cosmic voids are the most under-dense regions of the large-scale distribution of galaxies in the Universe. By studying the redshift-space distortions (RSD) of galaxy clustering around voids, we can place constraints on the growth of cosmic structure. We will present estimates of the growth of structure around voids in the BOSS and eBOSS surveys, using a variety of RSD models and void finders, highlighting the strengths and weaknesses of each method.

Too dense to go through

Pallero Astargo, Diego Ignacio

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One of the fundamental problems in modern astrophysics is the understanding of the role that the environment plays on the evolution of galaxies. Many works, both theoretical and observational, have focused on this topic. Nevertheless, it is not clear yet which are the main physical mechanisms that lead to the cessation of star formation, or quenching, in galaxies that reside in dense environments. State-of-the-art hydrodynamical simulations are perfect tools to study the evolution of galaxies in extremely dense environments such as galaxy clusters. Using both theoretically- and empirically- based definitions to select star forming and passive (quenched) galaxies, we separate our sample into galaxies that suffer the largest effects on their star formation histories either inside or outside the cluster. We find that > 70% of galaxies are processed before they are accreted onto the clusters regardless of the cluster mass. However, most galaxy reach their quenching state in dense environments, several gigayears after this processing event, indicating that pre-processing plays an important role in establishing the time-scales and the history of star formation quenching in massive structures. On the other hand, the definitive cease of star formation is mainly driven by an environmental effect; we find that there is a minimum threshold in the gas density of the ICM, of (ICM) > $10^{-28}\ gr\ cm^{-3}$ to quench the star formation of galaxies. Typically, this threshold takes place near the cluster R_{200}, regardless of their M_{200}.

The cosmic merger rate density of compact binaries

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The next generation of ground-based gravitational wave interferometers will possibly observe mergers of binary black holes to redshift > 10. Hence, it will be possible to use compact object mergers as tracers of the cosmic evolution of their progenitor stars and host galaxies. In this talk, I will present a new data-driven model that investigates the cosmic evolution of compact binaries (CBs) by evaluating the merger rate density (MRD) across cosmic time. This model combines catalogues of CBs simulated through our population-synthesis code MOBSE, with observational constraints on the cosmic star formation rate density and on the average metallicity evolution of the Universe. I will discuss the impact of metallicity evolution and star formation rate observational uncertainties on the cosmic MRD. I will also consider different prescriptions for common envelope and supernova kicks. The local MRD of binary black holes is consistent with the one inferred from gravitational-wave data only if the average metallicity in the local Universe is assumed to be $Z \sim 0.02$. In contrast, the local MRD of binary neutron stars is not particularly sensitive to the metallicity evolution, while it is wildly affected by natal kicks. The MRD increases with redshift up to $z \sim 2$. This can be explained with an interplay between the cosmic star formation rate evolution and the delay time of binary compact objects.

The EAGLE-XL simulations - Galaxy formation in a cosmological volume

Schaller, Matthieu

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In recent years, direct numerical cosmological simulations have become one of the major tools for theorists trying to understand the complex processes of galaxy formation and building links with observations. In this talk, I will introduce the EAGLE-XL simulations. These simulations build up on the success of the EAGLE model but were run in a much larger volume and with improvements to the physics and analysis methods. The much larger population simulated in this way allows not only to study the mean population of galaxies but also to start understanding the scatter and outliers, providing much more insight into how the observed diverse population is shaped.

The Formation History of Subhalos and the Evolution of Satellite Galaxies

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Satellites constitute an important fraction of the overall galaxy population and are believed to form in dark matter subhalos. Here we use the cosmological hydrodynamic simulation TNG100 to investigate how the formation histories of subhalos affect the properties and evolution of their host galaxies. We use a scaled formation time (a_{nf}) to characterize the mass assembly histories of the subhalos before they are accreted by massive host halos. We find that satellite galaxies in young subhalos (low anf) are less massive and more gas rich, and have stronger star formation and a higher fraction of ex situ stellar mass than satellites in old subhalos (high a_{nf}). Furthermore, these low anf satellites require longer timescales to be quenched as a population than the high anf counterparts. We find very different merger histories between satellites in fast accretion (FA, a_{nf} <1.3) and slow accretion (SA, a_{nf} >1.3) subhalos. For FA satellites, the galaxy merger frequency dramatically increases just after accretion, which enhances the star formation at accretion. While, for SA satellites, the mergers occur smoothly and continuously across the accretion time. Moreover, mergers with FA satellites happen mainly after accretion, while a contrary trend is found for SA satellites. Our results provide insight into the evolution and star formation quenching of the satellite population.

Modelling the HI content of the post-reionization Universe for Intensity Mapping

Spinelli, Marta

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21cm Intensity Mapping (IM) surveys will probe the large scale structure of the Universe, through the redshifted 21cm line of atomic hydrogen (HI). This technique will constrain cosmology with competitive precision, especially in cross-correlation with galaxy surveys. In this talk I will present a comprehensive analysis of HI properties using a semi-analytical model of galaxy formation and N-body simulations covering a large cosmological volume at high resolution. I will examine the HI mass function and the HI density, characterizing both their redshift evolution and their dependence on hosting halo mass. I will discuss the HI content of dark matter halos in the local Universe and up to redshift $z = 5$, analyzing the contribution of different galaxy properties. I will present results on the HI clustering properties relevant for future 21cm IM experiments, including the HI bias and the shot noise level. I will detail the contribution from various galaxy properties on the HI power spectrum and their relation to the halo bias. Finally, I will present the 21cm signal in redshift space, a fundamental prediction to be tested against data from future radio telescopes such as SKA.

Luminous Red Galaxies on the edge of the assembly bias – A perspective on the formation history of massive galaxies throughtout cosmic history

Stoppacher, Doris

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"A semi-analytical perspective on ..." is a series of publications on the analysis and interpretation of semi-analytical models (SAMs) and had been my main research topic within my PhD focusing on luminous red galaxies (LRGs). Predictions from SAMs have been proven to be very useful to the community when dealing with so-called "sub-grid" physics, i.e. the part of physics currently poorly understood or beyond resolution limits. It was particularly interesting to study the clustering of LRGs, because the signal provides information on the assembly of large-scale structures and subsequently how dark matter halo properties manifest themselves onto a certain galaxy population. Thereby mock LRG-samples were extracted from a SAM using the original photometric selection of an observed galaxy sample. The simulated LRGs show correlations of star formation related properties with halo mass and environment. What remains unclear is, if and to what degree, this dependency results from the assembly of their dark matter halos or emerges from the model itself. Therefore, a more complex analysis regarding the synergy of halo and galaxy properties is work in progress. This will close the gap between the framework of galaxy formation and evolution with studies on the galaxy assembly bias, a highly debated topic, via analysing the cosmic histories of properties from prominent galaxy populations of simulated LRGs out to $z \sim 4$. Furthermore, studies on the star formation and merger history of LRGs from SAMs, run on a simulation as large as presented in this project have not been conducted before and will also enable further works in the context of galaxy evolution focusing on environment, which have not yet been discussed sufficiently in the context of galaxy formation modelling.

Galaxy Clustering with the Aemulus Project

Tinker, Jeremy

New York University, USA

I will show the current status of our galaxy clustering emulator from the Aemulus Project. I will demonstrate the impact of including galaxy assembly bias on cosmological constraints, and ways to constrain the extra free parameters this introduces. I will also discuss the optimal survey design for constraining growth of structure from small-scale clustering.

Painting with baryons: augmenting N-body simulations with gas using deep generative models

Troester, Tilman

University of Edinburgh, UK

Running hydrodynamical simulations to produce mock data of large-scale structure and baryonic probes, such as the tSZ effect, at cosmological scales is computationally challenging. We propose to leverage the expressive power of deep generative models to find an effective description of the large-scale gas distribution and temperature. We train two deep generative models, a variational auto-encoder and a generative adversarial network, on pairs of matter density and pressure slices from the BAHAMAS hydrodynamical simulation. We then apply the trained models on 100 lines-of-sight from SLICS, a suite of N-body simulations optimised for weak lensing covariance estimation, to generate maps of the tSZ effect. We consider a specific observable, the cross-correlation between weak lensing and the tSZ effect and its variance, where we find excellent agreement between the predictions from BAHAMAS and SLICS, thus enabling the use of SLICS for tSZ covariance estimation.

Probing the Galaxy-Halo Connection with Basilisk

van den Bosch, Frank

Yale University, USA

During the last two decades we have made huge progress in establishing a robust link between galaxies and dark matter halos. However, when combining clustering and galaxy-galaxy lensing to constrain cosmological parameters, we consistently obtain results in clear tension with the Planck CMB constraints. I discuss the potential impact of assembly bias, and present satellite kinematics as a complementary and competitive probe of the galaxy-halo connection. I present two new analyses, and show how they can be used to improve our constraints on both the galaxy-halo connection and cosmology.

Effects of secondary halo properties on galaxy assembly bias

Xu, Xiaoju

Case Western Reserve University

Galaxy assembly bias is an important feature of galaxy clustering in SAM galaxy formation model caused by halo assembly bias and occupation variation. In this talk, we explore galaxy assembly bias as the difference between galaxy clustering of original sample and that of a shuffled sample. We will show a set of shuffled clustering not only at fixed halo mass, but also at fixed secondary halo properties. This allow us to identify which halo property is the most important for galaxy assembly bias, and then we will show the clustering of mock samples built by populating halos with this most important secondary halo property.

Galaxy-halo connection: which interpretation for quasars?

Zarrouk, Pauline

Durham University, UK

Because quasars are a special type of active galaxies powered by a supermassive black hole in their centre, their formation process and interactions with the host galaxy are among the most violent phenomena in the universe and are not as well known as for typical galaxies. However, once people realised that quasars could be just a phase in the normal cycle of a galaxy, they started using them as cosmological tracers by studying their clustering. One of the first attempt to interpret the clustering of quasars in terms of Halo Occupancy Distribution (HOD) led to unphysical parameters because one was missing, which accounts for the rarity of hosting a quasar in a dark matter halo compared to a standard galaxy and which is called the duty cycle. In this talk, I will review the interpretation of the galaxy-halo connection for quasars as developed in the analysis of the eBOSS quasar sample both in terms of HOD (Zarrouk et al. 2018) and Sub-Halo Abundance Matching (SHAM, Rodriguez- Torres et al. 2017). I will also present the results of a mock challenge where we investigated the impact of 20 HODs on the clustering properties of the final eBOSS quasar sample (Smith et al. 2020).

On encapsulating assembly bias in the galaxy-halo connection

Zehavi, Idit

Case Western Reserve University, USA

Assembly bias remains a challenge for contemporary models of galaxy clustering. We examine the different manifestations of this phenomenon in the galaxy-halo connection using semi-analytic models of galaxy formation. In particular, we investigate the variation of the halo occupation functions with halo properties, the trends in the stellar mass-halo mass relation and the impact on galaxy clustering. We present a new attempt to encapsulate the occupancy variations via a conceptual modification of the halo occupation approach, using the halos maximal circular velocity as an alternative to halo mass. We find that while it reduces the occupancy variation for central galaxies, it only minimally impacts the level of galaxy assembly bias.

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