OpenGADGET3 User Meeting

Report of Contributions

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

On the transition from proto-clusters to nearby clusters

Monday, 29 July 2024 15:00 (30 minutes)

I will provide an overview of the current status of simulations of proto-clusters and how they evolve to the population of mature low-redshift clusters. In particular, I will critically discuss open issues related to: (a) the strong star formation in proto-clusters; (b) the low level of star formation in nearby BCGs; (c) the metal share in stars and ICM.

Primary author: BORGANI, Stefano (Istituto Nazionale di Astrofisica (INAF))

Presenter: BORGANI, Stefano (Istituto Nazionale di Astrofisica (INAF))

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

Tales from the Spectral Cosmic Ray Model

Thursday, 1 August 2024 10:00 (30 minutes)

I'll give an update on the state of the Spectral Cosmic Ray model in OpenGadget3.

Primary author: BÖSS, Ludwig (University Observatory Munich)

Presenter: BÖSS, Ludwig (University Observatory Munich)

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

Combined Thermal and Kinetic AGN Feedback in OpenGADGET

Wednesday, 31 July 2024 10:00 (30 minutes)

We study different numerical implementations of distributing the feedback energy from a central SMBH to the surrounding gas. We have incorporated a new sub-resolution model for the switching between thermal and kinetic AGN feedback modes depending on the BH accretion rate. Test simulations are being performed with cases of only thermal feedback, only kinetic feedback, and the combined thermal-kinetic scheme. In the meeting, I expect to present some results from these simulations of various AGN feedback models.

Primary author: BARAI, Paramita (Istituto Nazionale di Astrofisica (INAF))

Presenter: BARAI, Paramita (Istituto Nazionale di Astrofisica (INAF))

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

MFM in OpenGadget3

Thursday, 1 August 2024 09:30 (30 minutes)

In this talk, I will present the current status of the implementation of Meshless Finite Mass (MFM) in OpenGadget3, which I implement as an alternative to the already implemented modern SPH solver.

MFM has several advantages over other solvers, such as developing mixing instabilities and capturing the power spectrum of subsonic turbulence. Thus, it also improves the description of turbulence in the ICM of galaxy clusters. I will show some applications on idealized setups and a study of turbulence in galaxy clusters, also comparing the impact of the hydrodynamical scheme.

Primary author: Mr GROTH, Frederick (University-Observatory Munich)

Presenter: Mr GROTH, Frederick (University-Observatory Munich)

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

The Role of Viscosity in Galaxy Clusters

Monday, 29 July 2024 17:00 (30 minutes)

The evolution of galaxy clusters is highly influenced by the dynamics of the Intracluster Medium (ICM), which governs crucial aspects. This includes mixing, turbulence processes, and galaxy interactions within the cluster environment. Among the factors influencing the ICM dynamics, the impact of viscosity is still under debate. Understanding the effect of viscosity on the evolution of galaxy clusters is fundamental for comprehending gas properties and the underlying dynamics within the ICM.

By conducting a thorough study, we aim to highlight the implications that viscosity introduces compared to inviscid simulations. These implications encompass morphological differences, larger density fluctuations, and the intricate interplay with dynamo amplification, among other fundamental effects. Our results challenge prior assumptions, especially concerning the constraints on viscosity within the ICM. This study is expected to enhance our understanding of ICM dynamics and contribute to our knowledge of galaxy cluster evolution.

Primary author: MARIN GILABERT, Tirso (University Observatory of Munich)

Presenter: MARIN GILABERT, Tirso (University Observatory of Munich)

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

Galaxies in high-z clusters and proto-clusters in cosmological hydrodynamical simulations

Monday, 29 July 2024 15:30 (30 minutes)

The study of high-z clusters and proto-clusters is fundamental to understanding the connection between the evolution of galaxies and their environment. Theoretical models of galaxy formation and evolution are still challenged by observations of a highly diverse star formation scenario in (proto-)clusters at z~2, confirming that the physics of galaxy formation is not well understood yet. This cosmic time is characterized by the transition from highly star-forming proto-clusters to mature clusters, and its study is a fundamental step in constraining our knowledge of galaxy evolution. Cosmological hydrodynamical simulations are currently among the most advanced tools to investigate this. In this talk or poster, I will present the analysis of a set of state-of-the-art high-resolution cosmological hydrodynamical simulations of galaxy (proto-)clusters and compare them with an average cosmological volume, acting as a "control field", to isolate the effects of environment on galaxy populations. Monte Carlo radiation transfer of stellar light through a modeled dust distribution was included in post-processing in order to enable a proper comparison with the observed properties of (proto-)cluster galaxies. I will show how the simulations succeed in reproducing some observables related to the star formation and dynamics of galaxy populations, while others remain a challenge, leaving questions open on which key ingredients are still lacking in our theoretical framework. Then, I will discuss predictions from cosmological hydrodynamical simulations on the AGN populations in dense environments that can be used as a theoretical benchmark to plan future observations.

Primary author: ESPOSITO, Michela (Istituto Nazionale di Astrofisica (INAF))

Presenter: ESPOSITO, Michela (Istituto Nazionale di Astrofisica (INAF))

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

Clues on SMBH growth and galaxy quenching from a large scale perspective

Wednesday, 31 July 2024 14:30 (30 minutes)

Galaxy evolution models typically rely on SMBH feedback to quench massive galaxies. Therefore, accurately modeling the growth of these objects in our simulations is essential. In this talk, I will present an analysis of the star formation in local galaxies across different cosmic web environments, namely voids, walls, filaments, and nodes.
Interpreted using a semi-analytic model, the analysis shows that quenching occurs similarly in massive galaxies regardless of the environment. Consequently, the growth of SMBHs, responsible for galaxy quenching, must be environment-independent. These results serve as a critical test for our galaxy evolution simulations.

Primary author: PARENTE, Massimiliano (Istituto Nazionale di Astrofisica (INAF))

Presenter: PARENTE, Massimiliano (Istituto Nazionale di Astrofisica (INAF))

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

Stellar Populations of Shells and Streams - Where They Came from and How They Got There

Tuesday, 30 July 2024 11:00 (30 minutes)

Tidal features in the outskirts of galaxies detected by low surface brightness observations provide a unique pathway to study their assembly history. The upcoming Vera C. Rubin Observatory will provide a vast number of galaxies exhibiting such features, while integral field unit observations enable the study of their stellar population properties. I employ the hydrodynamical cosmological simulation *Magneticum Pathfinder* to study the stellar properties of shells and streams. Tracing the stellar particles of tidal features back in time allows me to identify the progenitor satellite galaxies and connect their properties to the tidal feature they formed. I will present spatially resolved maps of the stellar velocity dispersion, mass, age, and metallicity in galaxies exhibiting shells and streams as well as the behavior of these properties within the tidal features themselves. I find that shells and streams generally appear as depressions in the velocity dispersion, while only some streams and shells appear younger and more metal rich than their surroundings. Furthermore, I will discuss the connection between these properties and the radial velocity fraction, gas and stellar mass, and the depth of the gravitational potential of the features'progenitor satellite galaxies. Finally, I will compare the spatial extent and orientation of the feature to the half-mass radius and the orbit of the progenitor.

Primary author: STOIBER, Johannes (University Observatory, Faculty of Physics, Ludwig-Maximilians-Universität München)

Co-authors: REMUS, Rhea-Silvia (University Observatory, Faculty of Physics, Ludwig-Maximilians-Universität München); VALENZUELA, Lucas (University Observatory, Faculty of Physics, Ludwig-Maximilians-Universität München)

Presenter: STOIBER, Johannes (University Observatory, Faculty of Physics, Ludwig-Maximilians-Universität München)

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

Supermassive black hole spin evolution in cosmological simulations with OpenGadget3

Wednesday, 31 July 2024 09:30 (30 minutes)

Central massive black holes (BHs) and their host galaxies are thought to co-evolve also due to the complex interaction that arises when the BHs accrete gas and release a large amount of energy back into the surrounding environment.
Important actors in this scenario are powerful jets, and the spin of the central black hole is thought to be a key physical parameter that determines their power and direction.
To carry out a self-consistent, statistically meaningful study of the role of BH spins and related jet feedback, I implemented a sub-resolution model for cosmological hydrodynamical simulations, that evolves the BH spin due to the occurrence of misaligned gas accretion.
The model provides a more complete physical description of the accretion process from the resolved scales, adding the important spin parameter to the BHs in simulations. I will present the results of simulations that test such a model in a fully cosmological context, which allows to carry out statistical studies on the distribution of spins and radiative efficiencies.

Primary author: SALA, Luca (Faculty of Physics at the Ludwig-Maximilians-University - University Observatory Munich)

Co-authors: DOLAG, Klaus; VALENTINI, Milena (University of Trieste); BIFFI, Veronica (UniTs; INAF-OATs)

Presenter: SALA, Luca (Faculty of Physics at the Ludwig-Maximilians-University - University Observatory Munich)

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

Neighbourhood Issues: The Impact of Environment on Galaxy Properties at Cosmic Noon

Tuesday, 30 July 2024 09:00 (30 minutes)

Recent observations of galaxies at high redshift have challenged our understanding of galaxy formation: some have extremely high star formation rates unmatched by anything seen at present day, others show signs of rapid inflows or outflows, and indications of very massive black holes. In particular observations of massive quenched galaxies present when the Universe was only 1Gyr old have proven difficult to reproduce. I will show that this is because simulations require both large volumes as well as very high resolutions to capture these observed properties. This is especially true as many of such galaxies live in environments that will eventually collapse into massive groups or clusters at present day, but at high redshift are typically spread over a large area of sky as the protocluster and protogroup structures are only beginning to assemble.

Using one of the largest sets of fully hydrodynamical cosmological simulations, the Magneticum simulation suite, I show how quenched galaxies are formed at such high redshifts, how they are connected to the environment they form in, and how the feedback from these galaxies enriches the surrounding gas with metals. Furthermore, I discuss the properties of the galaxies in the first emerging protocluster cores, demonstrating that the hot gas atmospheres of the protoclusters start to build up at redshifts around z=4, and how this impacts the galaxy populations in these environments. Finally, I will show that the extent of the future collapsing regions can be traced by probing the large scale environment, thus allowing for protocluster regions to be distinguished from proto groups and massive galaxies that will starve in isolation.

Primary author: REMUS, Rhea-Silvia

Presenter: REMUS, Rhea-Silvia

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

Universal Blacksmith: What Metals Reveal About the Histories of Galaxies

Tuesday, 30 July 2024 09:30 (30 minutes)

As increasingly more detailed observational data allows the probing of multiple metal lines in both stars and gas, a new window has opened into understanding the formation and accretion of galaxies' stars. In particular the ratio of alpha-elements such as oxygen and magnesium to iron contain information about the amount of enrichment from faster acting supernovae type II versus slower acting type Ia. Using the hydrodynamical cosmological simulation Magneticum Pathfinder I probe the evolution through cosmic time of different metals both locked into stars as well as within the gas of galaxies. I show how [alpha/Fe] and the stellar mass can constrain the galaxies' formation redshift, how the contribution of SN type Ia rapidly rises until z~1 before saturating, and also how individual galaxies evolve in the [alpha/Fe] vs [Fe/H] plane. Finally, I discuss where the observed high [alpha/Fe] at cosmic dawn originate from and how these earliest galaxies reach super-solar metallicities so quickly.

Primary author: KIMMIG, Lucas

Presenter: KIMMIG, Lucas

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

Intertwined Formation of H2, Dust, and Stars in Cosmological Simulations

Wednesday, 31 July 2024 15:00 (30 minutes)

In the metal-enriched interstellar medium, the abundance of molecular gas is primarily governed by the formation of H2 on dust grains, as well as its self-shielding and shielding by dust against photo-dissociation by the interstellar radiation field. The upcoming presentation intends to describe a sub-resolution model for forming molecular hydrogen in hydrodynamic simulation with dust description and encouraging results in predicting the properties of galaxies in cosmological boxes.

Primary author: RAGONE FIGUEROA, Cinthia (Instituto de Astronomía Teórica y Experimental (IATE) CONICET-UNC)

Presenter: RAGONE FIGUEROA, Cinthia (Instituto de Astronomía Teórica y Experimental (IATE) CONICET-UNC)

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

Modelling X-ray emission from simulations with Phox

Thursday, 1 August 2024 09:00 (30 minutes)

Hydrodynamic Cosmological Simulations offer a unique perspective in studying various aspects of structure formation in the universe. In particular, they hold great value in quantifying statistical properties such as the composition and enrichment of the baryonic matter distribution in the knots and filaments of the cosmic web. While it is observationally challenging to extract information from faint, low-density gas found in filaments and outskirts of galaxies, the projected capabilities of future X-ray missions provide new pathways towards a deeper understanding of these environments. Presented here is a collection of X-ray studies performed on the hydrodynamical simulation suite "Magneticum".
We make use of the matter properties traced by the simulation to investigate various X-ray properties of the CGM and ISM in poster-child disk and elliptical galaxies from the simulation while also taking into account contamination from stellar sources such as X-ray binaries. With these studies we aim to provide constraints and limiting factors towards observational targets.

Primary author: VLADUTESCU-ZOPP, Stephan (University Observatory Munich)

Co-authors: DOLAG, Klaus; BIFFI, Veronica (UniTs; INAF-OATs)

Presenter: VLADUTESCU-ZOPP, Stephan (University Observatory Munich)

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

Utilizing idealized setups for a targeted investigation of formation pathways of dwarf galaxies

Tuesday, 30 July 2024 11:30 (30 minutes)

Observations of interacting galaxies in a cluster environments indicate that the triggered star formation activity inside the tidal tails is extending far beyond what we would expect from mergers in the field. Allowing to probe the possible parameter space, isolated setups are posing as the ideal testing ground to investigate the details and consequences of such behavior, as well as for a targeted examination of observed objects. Utilizing the code OpenGADGET-3, I present three hydrodynamic simulations of a major merger inside a galaxy cluster in high resolution, where the initial conditions were tuned to correspond to the observed merger NGC 5291 in cluster Abell 3574. Compared to isolated galaxy merger simulations, I find strong changes in the merger morphology, as well as drastically increased star formation activities due to ram pressure. In particular, this environmental influence is efficiently assisting the formation of tidal dwarf galaxies, which form in the pre-enriched gas ejected by the merger. By comparing our simulations to observational data, I demonstrate that such a process is capable of reproducing characteristics of a full variety of observed dwarf galaxy types. Comparing their contribution to the observed galaxy mass function in clusters, I estimate that ~30% of dwarf galaxies in galaxy cluster environments may have been formed through stripping from mergers.

Primary author: IVLEVA, Anna (University Observatory Munich)

Presenter: IVLEVA, Anna (University Observatory Munich)

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

The future (and past) of galaxy clusters and superclusters

Monday, 29 July 2024 16:30 (30 minutes)

Galaxy superclusters are exciting laboratories for a number of interesting processes in galaxy and cluster formation and evolution. Using GadgetIO, we simulate a cosmological box implementing constrained initial conditions from the local universe far into the future, obtaining final collapse regions for a number of local structures. While these regions contain interesting information about the environments they collapse in themselves, it is also possible to define a new type of zoom-in initial conditions from their associated lagrangian volumes. These zoom-in simulations of local clusters will provide insight about our cosmic neighborhood in unprecedented detail.

Primary author: SEIDEL, Benjamin (University Observatory Munich)

Presenter: SEIDEL, Benjamin (University Observatory Munich)

Contribution ID: **16** Type: **not specified**

Subresolution description for supernova remnants as sources of cosmic rays

Tuesday, 30 July 2024 14:30 (30 minutes)

In large-scale simulations, that also include spectral cosmic-ray physics, high-energy protons and electrons accelerated at the shocks of supernova remnants have to be described by a sub-grid model. Usually, the injected cosmic rays are represented by a simple power-law spectrum in momentum space. However, in the recent past several models for more realistic cosmic-ray spectra from supernova remnants have been published. They rely heavily on results from state-of-the-art simulations of particle acceleration at strong, collisionless shocks. By combining different approaches, tabulated spectra can be generated, which are the basis for a physically motivated sub-grid description for cosmic-ray seeding by supernova remnants in OpenGadget3. With this code simulations of galaxies in isolated and dense environments can be performed in order to check if the more realistic cosmic-ray spectra lead to quantitative differences in galactic properties and non-thermal radiation.

Primary author: KARNER, Daniel (USM, LMU Munich)

Presenter: KARNER, Daniel (USM, LMU Munich)

Contribution ID: **17** Type: **not specified**

Tracing In- & Outflows of Galaxies in the Magneticum Pathfinder Simulations

Tuesday, 30 July 2024 10:00 (30 minutes)

The process of gas accreting from the cosmic web onto galaxies is a fundamental aspect of galaxy formation. Simulations provide the tools to directly trace gas flows over time and are therefore crucial to test models and assumptions about accretion modes and geometry, which can then be used to interpret observational results. Using the Magneticum Pathfinder simulation box 4 (uhr), I trace gas particles flowing in and out of galaxies to relate modes of accretion to the evolution of galaxy features with respect to scaling relations. By the virtue of gas particles in this simulation suite being able to convert only a fraction of their mass into stars, each particle can undergo the process of being accreted, form stars, absorb stellar feedback and flow out of the ISM. I retrieve accretion rates between the galaxies and their virial radii from particle positions, phase space extrapolation, shell volumes and mass evolution and test the prediction of corresponding star formation rates to compare different methods of mass flow measurements in a Lagrangian simulation. By using the built-in two-phase gas model as well as a simple temperature criterion, I present how the cold and hot accretion modes relate to the formation histories and the connection between environment, circum-galactic medium and interstellar medium as well as the prevalence of the galactic fountain concept.

Primary author: FORTUNÉ, Silvio (USM, LMU Munich)

Presenter: FORTUNÉ, Silvio (USM, LMU Munich)

Contribution ID: **18** Type: **not specified**

OpenGADGET3 in SPACE

Tuesday, 30 July 2024 15:00 (30 minutes)

The next generation of supercomputers will use a heterogeneous design to achieve exaflop capabilities. While this heterogeneous design offers significantly larger computational power it also increases the complexity of such systems. This has a significant impact on simulation codes to be run on these machines. Since the focus in the past was mainly on the scalability of CPUs with the introduction of GPUs new methods have to be found to adapt the code. By not being able to use the available GPUs properly, a significant fraction of computational power would be unusable, which would result in a hard barrier for any large simulations in the future.

Scalable Parallel Astrophysical Codes for Exascale (SPACE) is an EU Centre of Excellence focused on astrophysical and cosmological applications in the advent of exascale computation. In this session, we will introduce the CoE and its mission, as well as results from activities within the CoE for OpenGADGET3.

Primary authors: KARADEMIR, Geray (USM, LMU Munich); Dr TORNATORE, Luca (INAF)

Presenters: KARADEMIR, Geray (USM, LMU Munich); Dr TORNATORE, Luca (INAF)

Contribution ID: **19** Type: **not specified**

Latest results on the massive black holes' dynamics in OpenGadget3

Wednesday, 31 July 2024 09:00 (30 minutes)

The dynamics of Massive Black Holes (MBHs) is primarily driven by the dynamical friction force, the drag induced by the surrounding "sea" of matter. This force anchors MBHs in the core of massive galaxies and leads to the formation of a close-pair binary BH system during mergers. Despite its fundamental role in governing the BH dynamics, the complexity of its description still represents a challenge for both analytical and numerical calculations. Recently, we have developed and extensively tested a new dynamical friction correction in OpenGADGET3 that proved to be an efficient way to control the dynamics of MBH in various environments.

Looking forward to exploiting the impact of an improved tracing of MBH on the galaxy evolution, we started to stress the dynamical friction technique within the context of idealised simulations of dark matter halo and galaxies. These tests provide informations on the sensitivity of BH dynamics and dynamical friction correction to mass resolution and its response to the BH's softening. Moreover, these studies help to establish the MBHs'sinking timescale for dynamical friction, the primary uncertainty in the MBHs'merger rate estimation and resulting gravitational waves emission.

Primary author: DAMIANO, Alice (INAF)

Presenter: DAMIANO, Alice (INAF)

Contribution ID: **20** Type: **not specified**

Projection Bias in galaxy cluster weak-lensing for Euclid Survey

Monday, 29 July 2024 17:30 (30 minutes)

Galaxy clusters are the most massive gravitationally bound objects in the Universe. Their number density offers a sensitive probe for the growth rate of large scale structure and the underlying cosmology. A way to produce this type of analysis is relying on wide-field optical imaging and photometric surveys, since they are capable of providing both large cluster samples and weak gravitational lensing mass calibration. The combination of information from three cosmological observables such as cluster counts, clustering (i.e. 2-point correlation function) of clusters and weak lensing mass makes it possible to break some degeneracies between cosmological parameters and parameters defining scaling relations between lensing masses and richness, allowing for much more refined constraints on them via Bayesian inference techniques. In this scenario the photometric survey of galaxy clusters that is being carried out by the Euclid space telescope [Laureijs et al., 2011], will reach unprecedented sensitivity and, in turn, unprecedented precision on the expected constraints on cosmological parameters. In order to harvest the full potential of Euclid's data a good understanding of systematics is mandatory.

In this perspective, my PhD project will concentrate on the characterisation of the systematics related to projection effects and their impact on the scaling relation between weak lensing masses and observed richness of galaxy clusters to be identified in the Euclid wide survey. As already discussed in the literature [e.g. Fumagalli et al., 2023, and references therein], projection effects occur when multiple foreground and background objects along the same line of sight are mistakenly associated with a galaxy cluster, increasing the apparent richness of the cluster. While this effect is arguably of relative importance in the SDSS cluster survey, it has been shown to produce a significant effect on the cosmological posteriors derived from the Dark Energy Survey (Costanzi et al. [2019, 2021], Salcedo et al. [2023]). We then expect that, if not accurately characterised, projection effects should have an even stronger impact in severely limiting the cosmological constraining power of the Euclid photometric cluster survey.

Different methods to estimate and mitigate the projection effect have been recently proposed (e.g. Sunayama [2023], Wu et al. [2022]). The common approach these method shares, is to find a suitable estimator for the boost in observed lensing signal induced by the bias (e.g the ratio between the observed signal from a richness-selected sample and the signal expected from the underlying halo mass PDF). Once this estimator has been properly crafted, one can think of applying some mitigation methods that can range from simulating different galaxy models to apply multi-wavelength or multi-tracers techniques. The end result for all these methodologies should be a model capable of removing the bias effect from the cosmological parameters inference.

Starting from the work done in the above papers, my PhD project, that will develop within the activities of the Science Working Group of Galaxy Clusters (SWG-CL) of the Euclid Consortium (EC) will consist in finding efficient way (exploring some of the different approaches mentioned above) to quantify projection effects by using suitably designed mocks Euclid photometric galaxy surveys. These synthetic Euclid mock cluster surveys will be generated using a large set of in-house cosmological N-body simulations and populating them with galaxies. In this way, I will aim at quantifying the impact of projection effects on cosmological posteriors, and to define a model to correct for them.

Primary author: INGRAO, Roberto (University of Trieste)

Presenter: INGRAO, Roberto (University of Trieste)