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EAGER: Evolution of gAlaxies and Galaxy clustErs in high-Resolution cosmological simulations

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Scientific Rationale

Open-GADGET USM LMU UNIVERSITÀ DEGLI STUDI DI TRIESTE

Objectives of the KSP

- Exploit OpenGADGET, a high-performing code for cosmological N-body/hydrodynamical simulations, featuring an accurate description of the physical processes which shape cosmic structure formation
- Theoretical predictions for galaxy formation from the high- to low-redshift Universe, and in different environments
- Develop post-processing algorithms for the analysis of the snapshots to ease the comparison between predictions from simulations and observations

Technical Objectives, Methodologies and Solutions

The Lagrangian code Open-GADGET

Code: descendant of our developer version of GADGET-3 (TreePM+SPH, originally from Springel 2005), featuring an improved SPH formulation and several advanced physical modules (e.g. chemical evolution and enrichment by L. Tornatore)

Main differences between Open-GADGET and its predecessor include: restructuring of calls to functions, tasks split in several individual functions, enhanced modularity and OpenMP parallelization…

The code

- **TreePM+SPH code**
- **Descendant of a non-public evolution of GADGET-3 code**
- **State-of-the-art code for cosmological hydrodynamical simulations**
- **Highly optimised code: MPI parallelised + OpenMP**
- **Improved SPH formalism**
- **Several modules for sub-resolution physics: star formation, stellar feedback, BH accretion and feedback, chemical enrichment, dust evolution**
- **Runs on CPUs and GPUs**

Technical Objectives, Methodologies and Solutions

The Lagrangian code Open-GADGET

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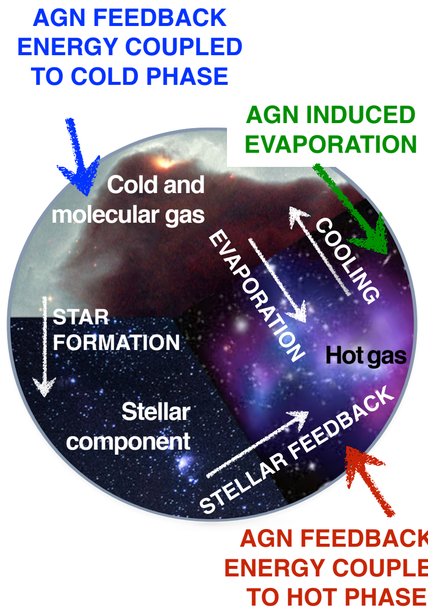
Sub-resolution model

- Model describing a multi-phase ISM and including several astrophysical processes
- MUPPI (Murante+ 2010, 2015, Valentini+ 2017, 2019, 2020, 2023, Granato+ 2021), featuring:



- description of a multi-phase ISM (valid for resolution particles with mass $\sim 10^4 - 10^7\ M_\odot$)
- H_2 - based star formation
- thermal and kinetic stellar feedback
- stellar feedback from low-metallicity environments
- stellar evolution and chemical enrichment

star formation

- angular-momentum-dependent gas accretion
- isotropic, thermal AGN feedback

BH

- formation and evolution of dust, and dust-assisted cooling

dust

Planned Work and Expected Results

Main **plans** of the project:

- Suite of cosmological hydrodynamical simulations of **galaxy clusters** to investigate structure formation in high-density regions and the joint evolution of galaxies and their IGM within the extreme cluster environment
- **Cosmological volume**(s) for statistical studies of the properties of evolving galaxies in field environment
- Simulated boxes containing galaxies, galaxy groups and poor clusters will allow us to bridge between the **mass scale** of massive galaxies and galaxy clusters
- Investigate the connection between **super-massive BHs and host galaxies**, and the large-scale environment

Timescale, Milestones and KPIs

Milestones

- run high-resolution cosmological simulations of galaxy and galaxy cluster formation with OpenGADGET + MUPPI
- 5 galaxy clusters and 1 or 2 cosmological box(es)
- work on reference post-processing/analysis automatised pipelines
- match observational evidence with the same code setup across systems of different masses

Timescale

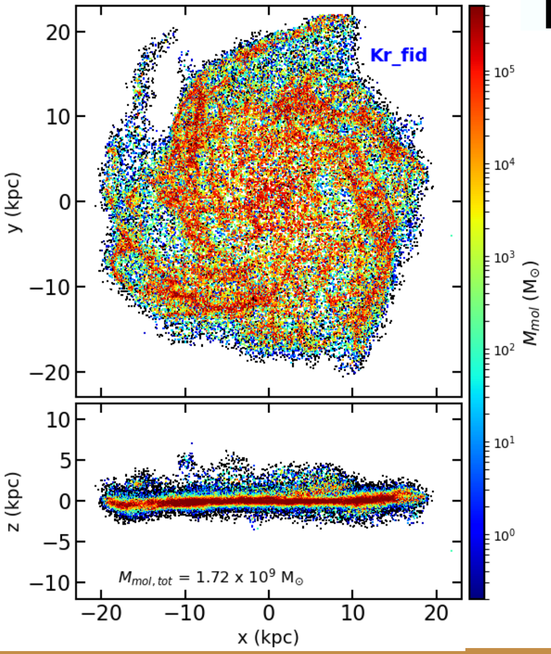
- end of 2024: simulation campaign completed
- mid/end 2025: post-processing and analysis of simulation results

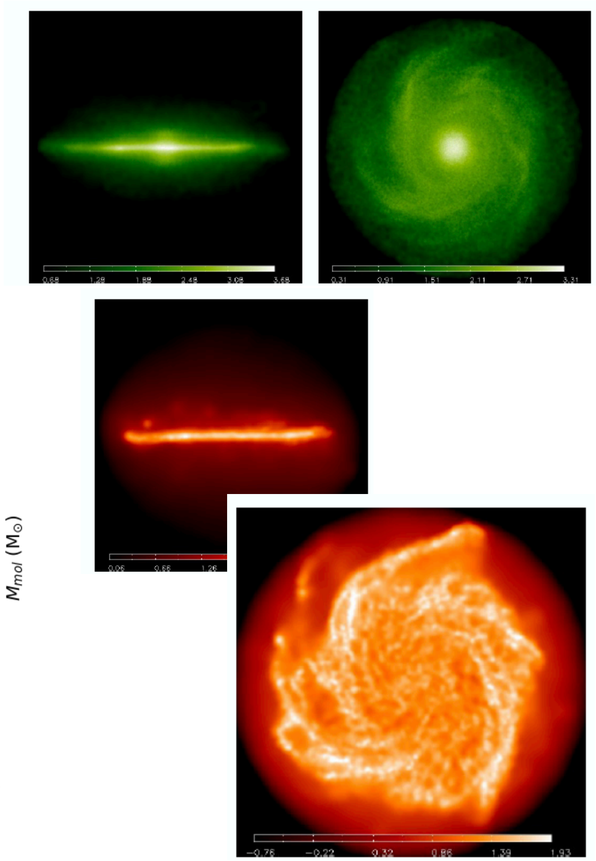
Key Performance Indicators

- availability of simulation output within the collaboration and with interested users
- publication of scientific papers on refereed journals
- post-processing pipeline, theoretical predictions and data access shared with interested users.

Accomplished Results

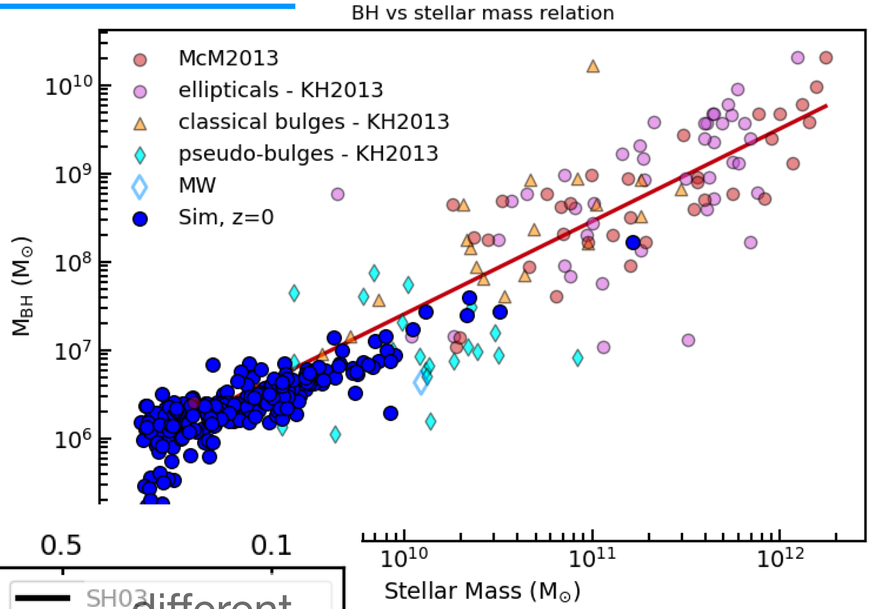
Our sub-resolution model MUPPI **successfully** describes the evolution of discs **and** massive ellipticals

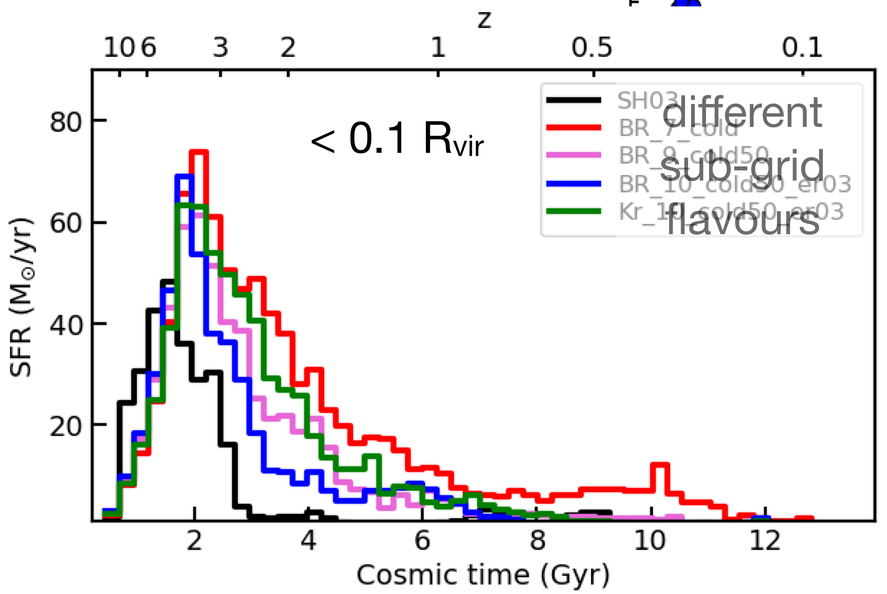




Spiral

Massive elliptical





Next Steps (by next checkpoints)

→ **Code configuration: OpenGADGET** (TreePM+SPH, MPI+OpenMP) with **MUPPI-AGN,** including

- improved radiative cooling
- SF based on the availability of molecular gas
- thermal, kinetic, low-metallicity stellar feedback
- dust formation and evolution
- (angular-momentum limited) gas accretion onto BH
- BH dynamics controlled via dynamical friction
- BH spin evolution
- thermal (+ two flavours of kinetic?) AGN feedback
- ? physical viscosity
- ? MHD
- + MFM as an alternative

→ Where to carry out these simulations? CPU only?
Profit from the results of the ongoing simulation campaign with CPU resources granted from LRZ on SuperMUC-NG