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ICSC
Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

The OpenGADGET3 code for cosmological simulations

- Key Science Projects: SLOTH and EAGER -

Milena Valentini, Stefano Borgani,
T. Castro, A. Damiano, L. Tornatore, A. Saro, G. Taffoni, and the OG3 team

UNIVERSITÀ DEGLI STUDI DI TRIESTE

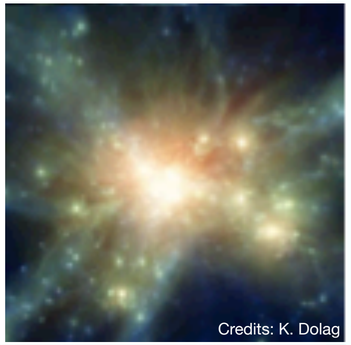
Dipartimento di Fisica
Dipartimento d'Eccellenza 2023-2027

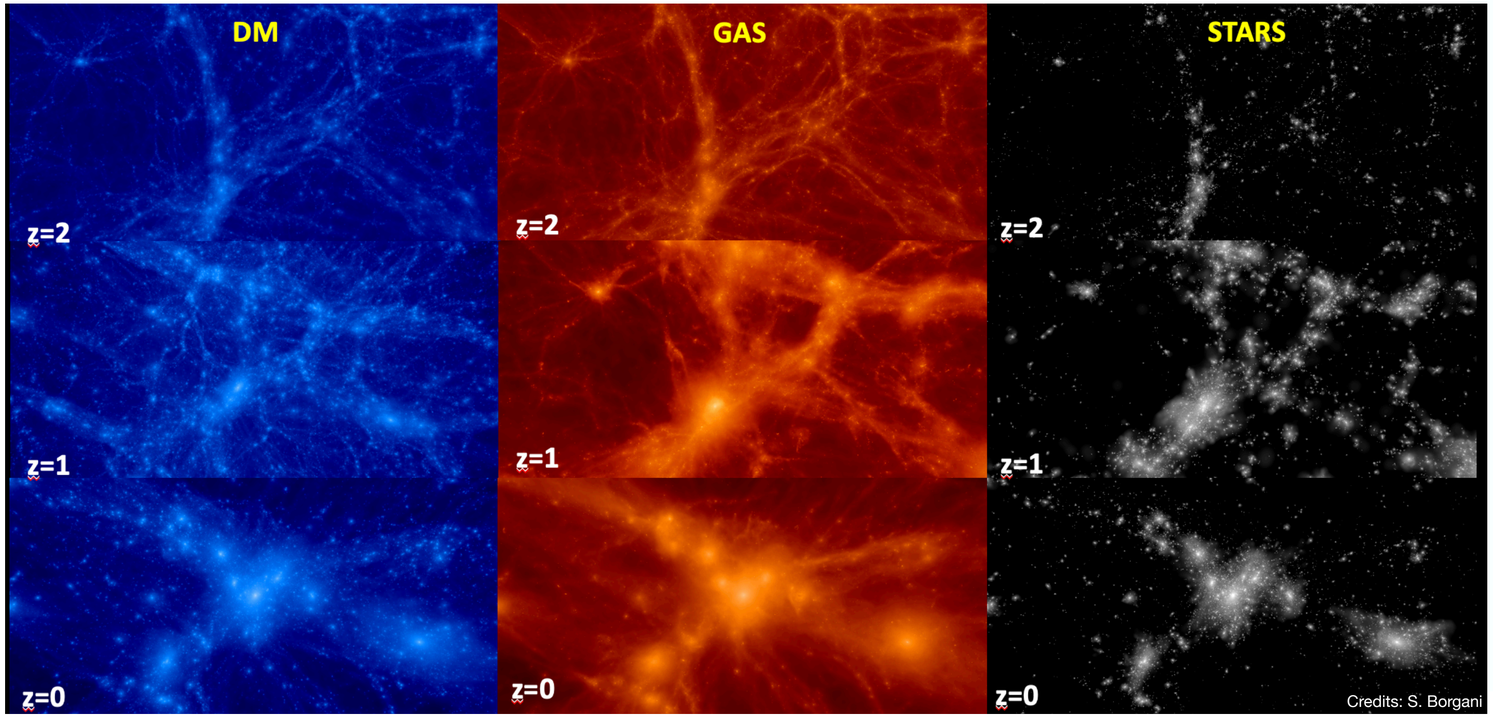
Spoke 3 Technical Workshop, Bologna Dec 17-19, 2024

The *OpenGADGET3* code: a state-of-the-art code for HPC

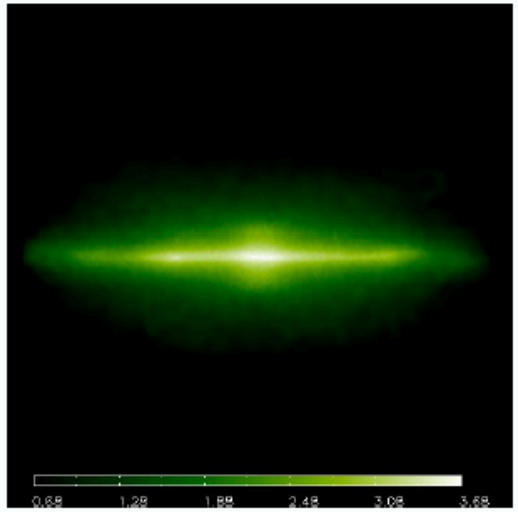
Scientific rationale

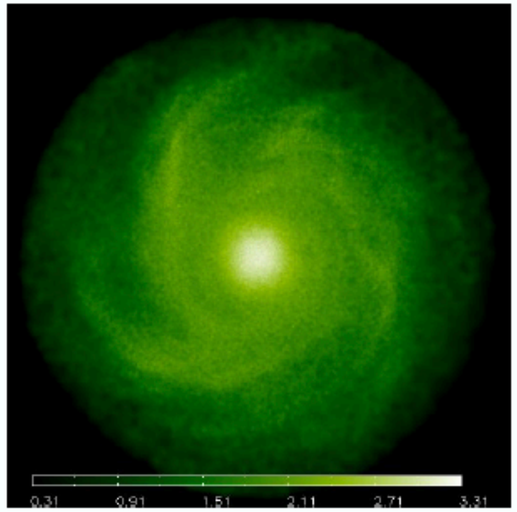
- Numerical cosmology
- Structure formation and evolution

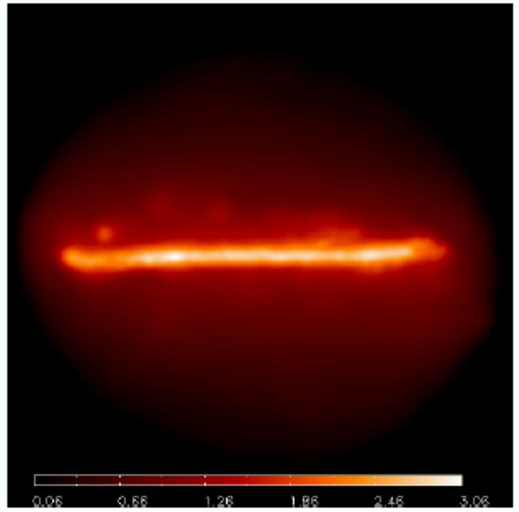

Credits: K. Dolag

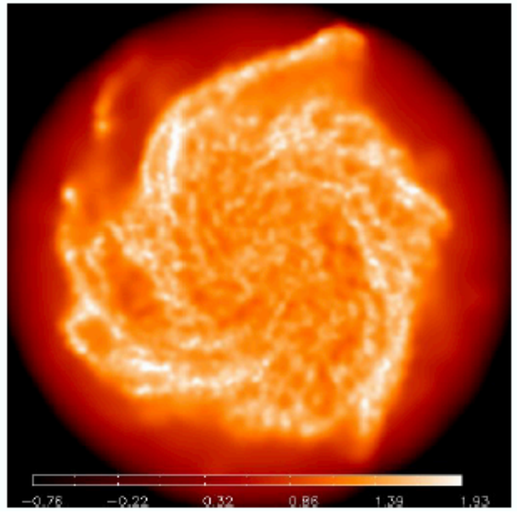


Credits: S. Borgani









Technical Objectives, Methodologies and Solutions

USM LMU UNIVERSITÀ DEGLI STUDI DI TRIESTE

The OpenGadget3 code

- **TreePM+SPH code**
- **Highly optimised code:** MPI parallelised + OpenMP
- **Two hydro solvers:** improved SPH formalism or MFM
- **Two sub-grid models** (Muppi, and one based on Springel&Hernquist 2003)
- **Several modules for sub-resolution physics:** star formation, stellar feedback, BH accretion and feedback, chemical enrichment, dust evolution, magnetic fields, cosmic rays
- **Runs on CPUs and GPUs**

MUPPI sub-resolution model

- description of a multi-phase ISM with H_2-based star formation
- thermal, kinetic, and low-metallicity stellar feedback
- improved cooling table interpolation
- stellar evolution and chemical enrichment

star formation

- angular-momentum-dependent gas accretion, dynamical friction, spin evolution
- isotropic, thermal AGN feedback + mechanical AGN feedback

BH

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

dust

Main tasks within the WP 2 of Spoke 3

Develop Open-GADGET further:

- **including additional physics modules**
- **enhancing code modularity and readability**
- **improving code performance**

Core teams in Trieste and Munich

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Core team in Trieste: S. Borgani, L. Tornatore, G. Murante, M. Valentini, T. Castro, P. Monaco, G. Taffoni, A. Damiano, G. Granato, D. Goz, P. Barai, M. Gitton-R., A. Saro, M. Viel

and collaboration in Munich led by K. Dolag

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Next Steps and Expected Results

Key Science Projects

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

Stefano Borgani, Milena Valentini, Luca Tornatore, Alice Damiano, Alex Saro, Giuliano Taffoni, Tiago Castro

2. → SLOTH: Shedding Light On dark matter wiTH cosmological simulations

Milena Valentini, Stefano Borgani, Tiago Castro, Luca Tornatore, Matteo Viel, Alice Damiano, Pierluigi Monaco, Giuliano Taffoni

Next Steps and Expected Results

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

Stefano Borgani, Milena Valentini, Luca Tornatore, Alice Damiano, Alex Saro, Giuliano Taffoni, Tiago Castro

Main **plans** of the project:

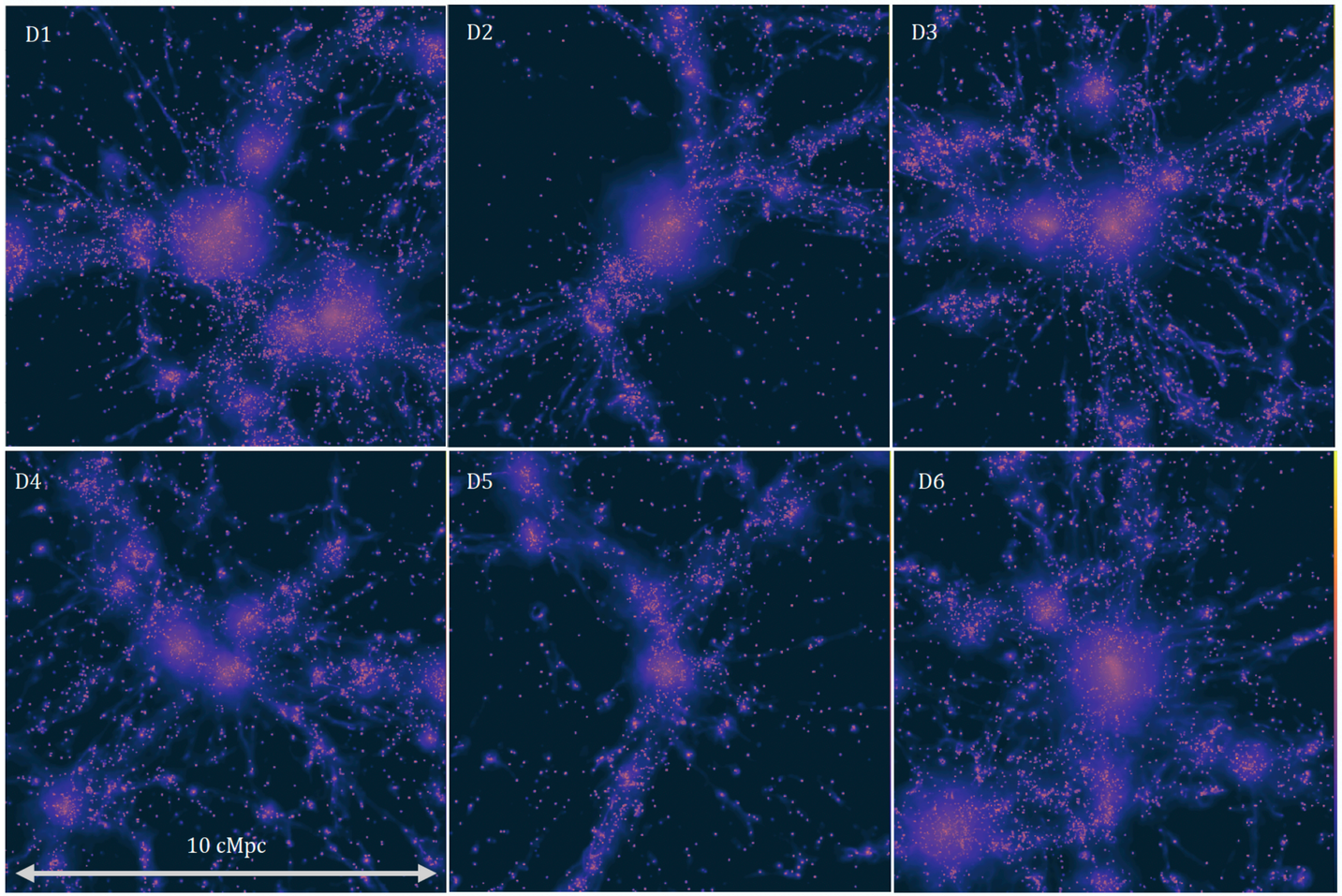
- Suite of cosmological hydrodynamical simulations of **galaxy clusters** to investigate structure formation in high-density regions and the joint evolution of galaxies and their IGM within the extreme cluster environment
- **Cosmological volume**(s) for statistical studies of the properties of evolving 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

Next Steps and Expected Results

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

- Suite of cosmological hydrodynamical simulations of **galaxy clusters**

- **Preparatory work**



Plots made by A. Damiano

Next Steps and Expected Results

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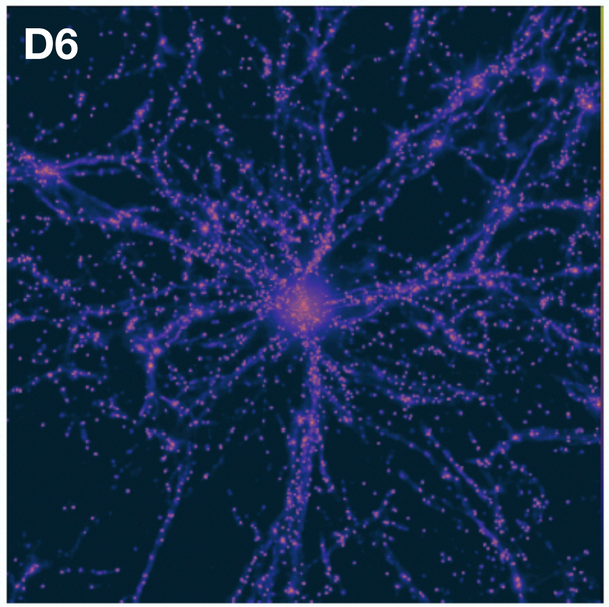

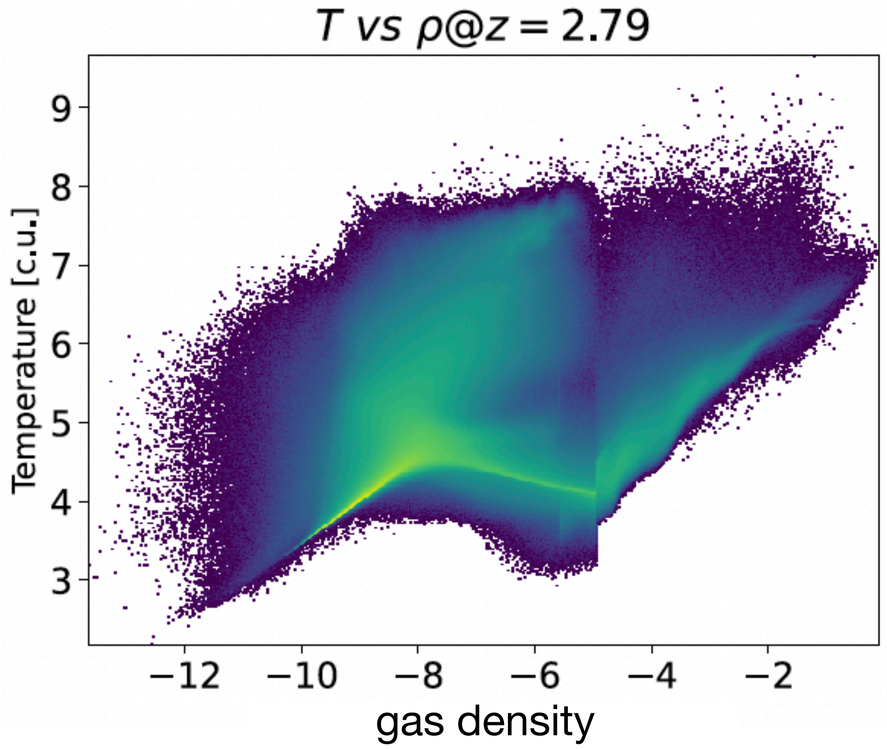

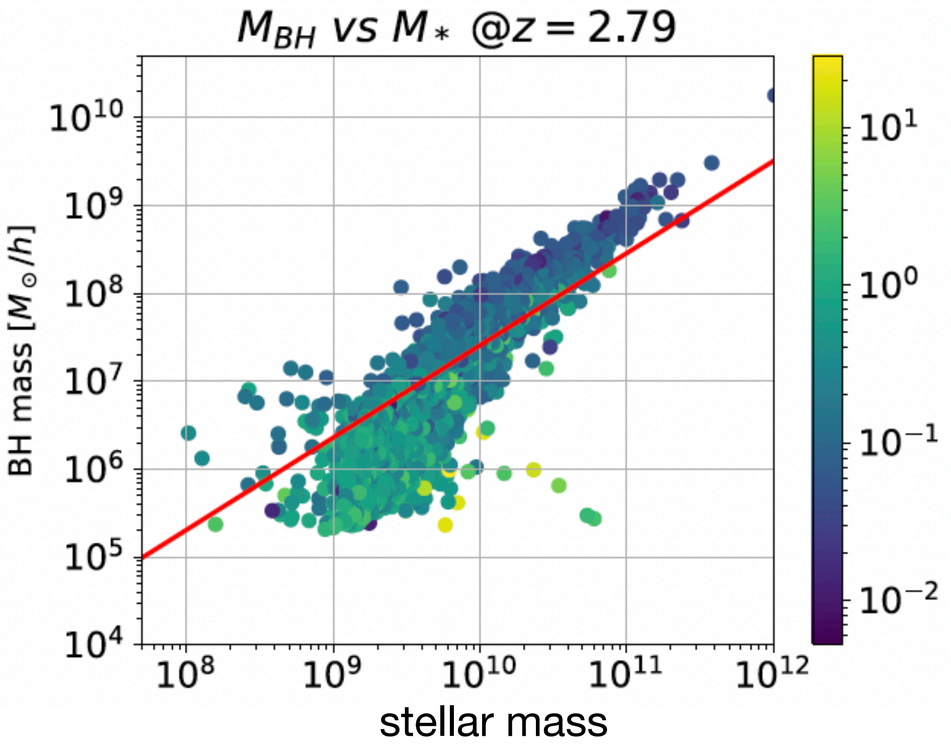

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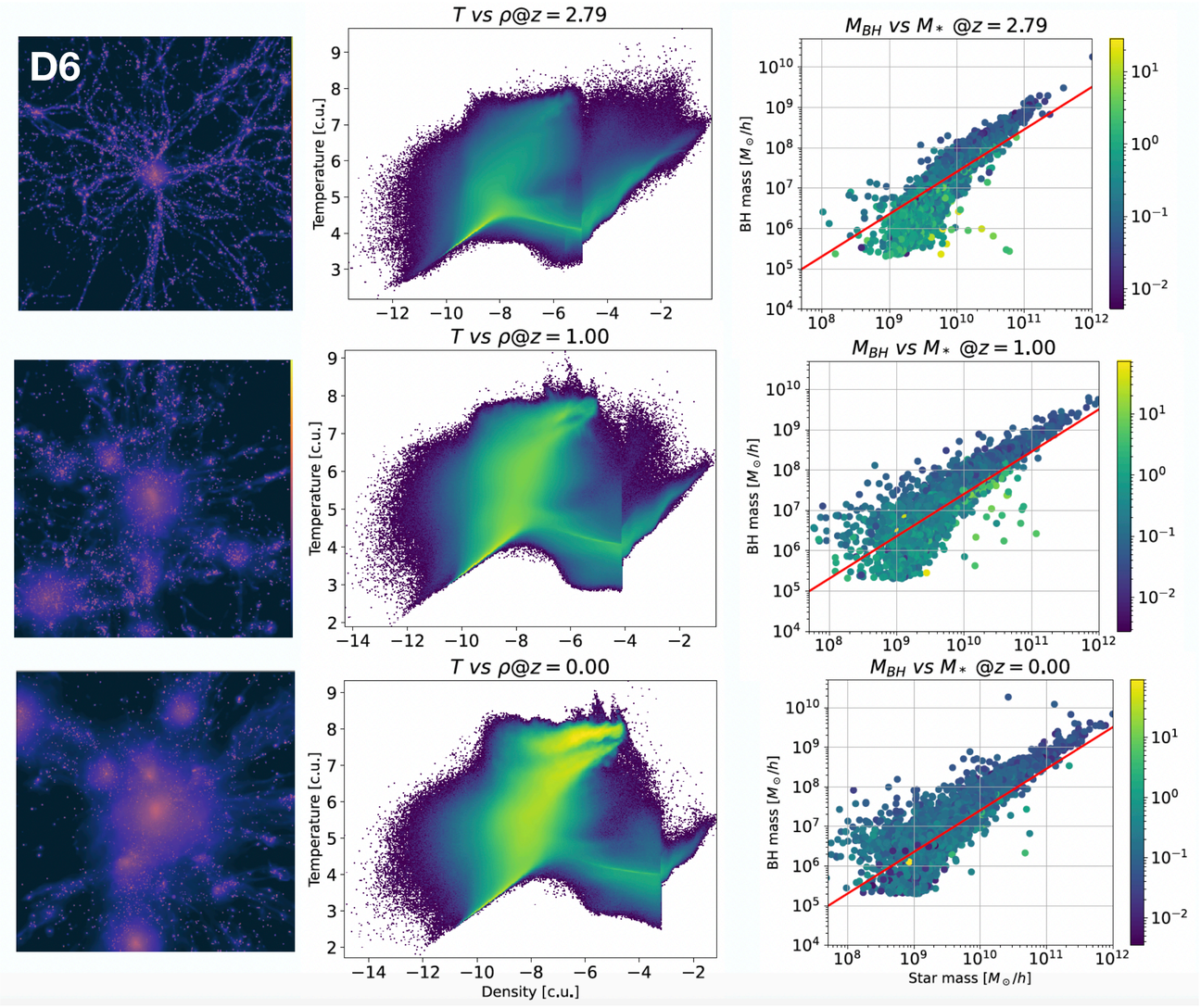

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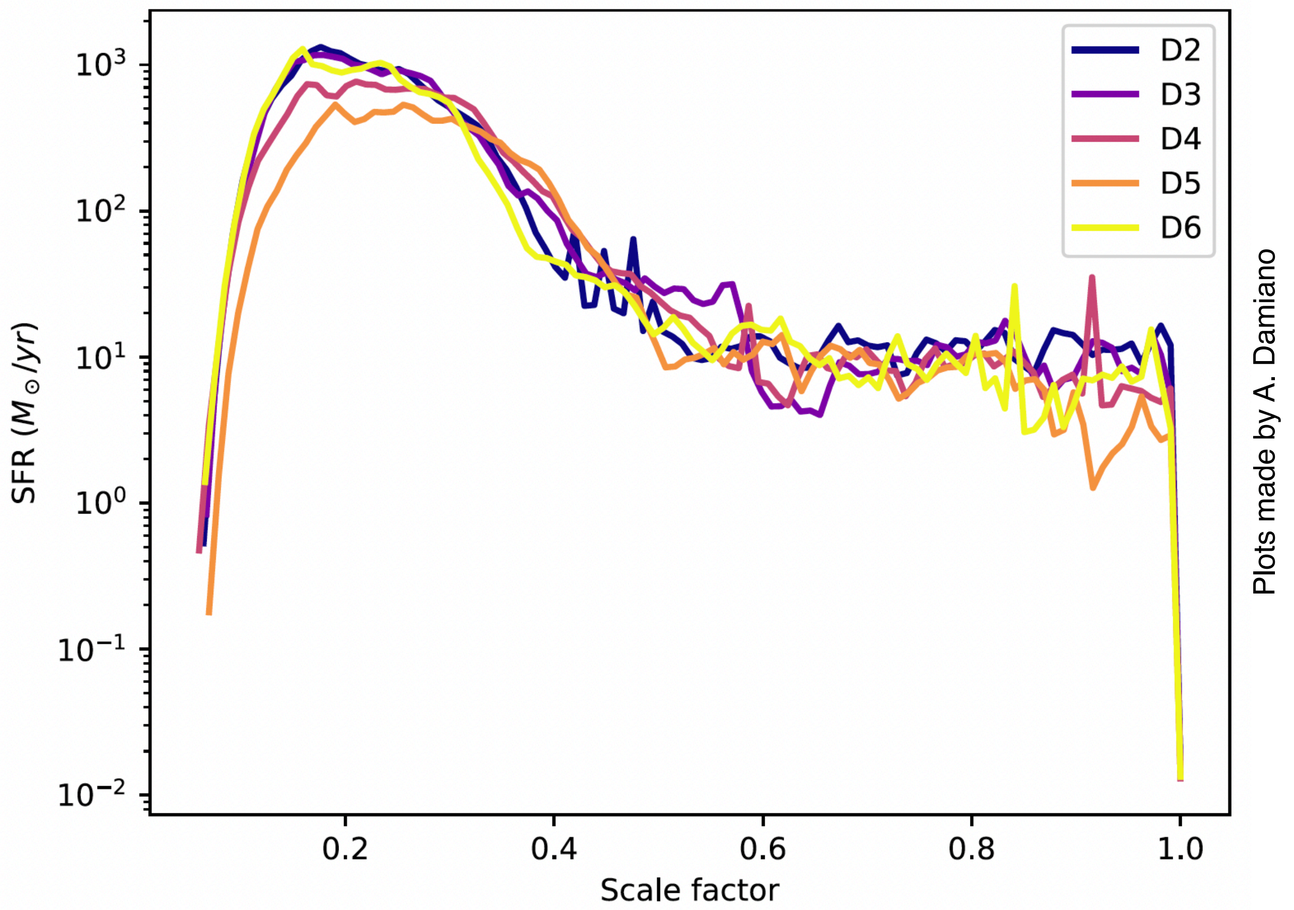
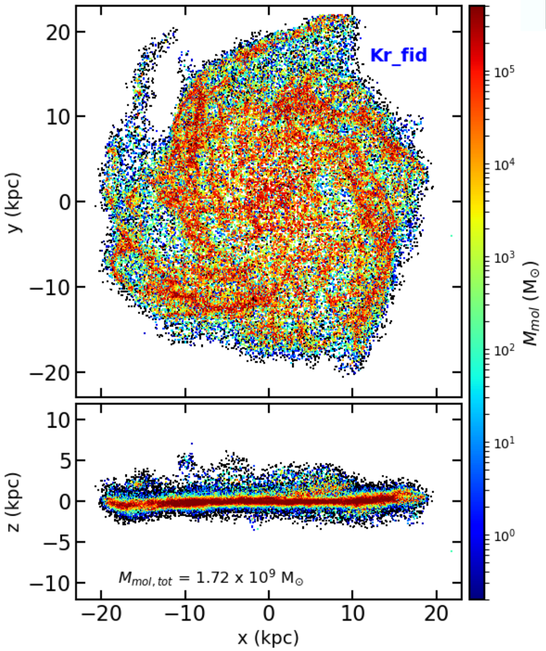
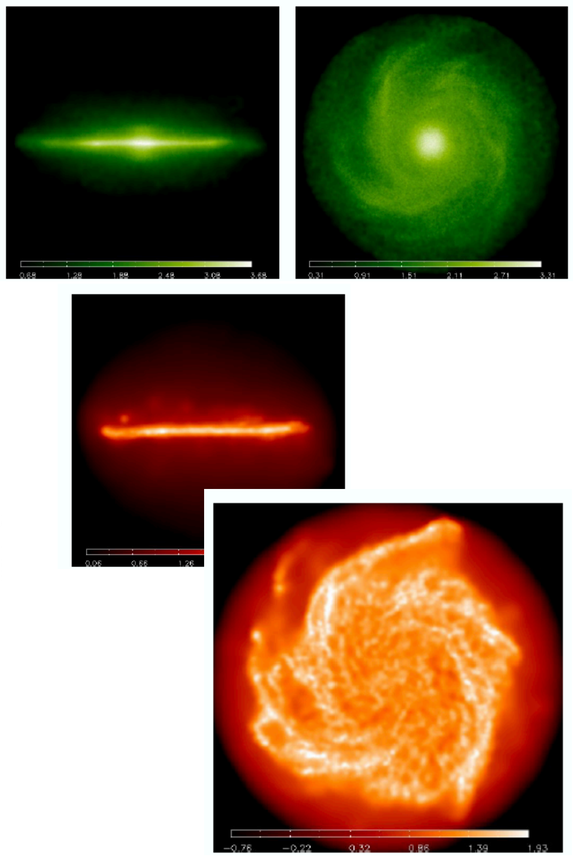


Next Steps and Expected Results

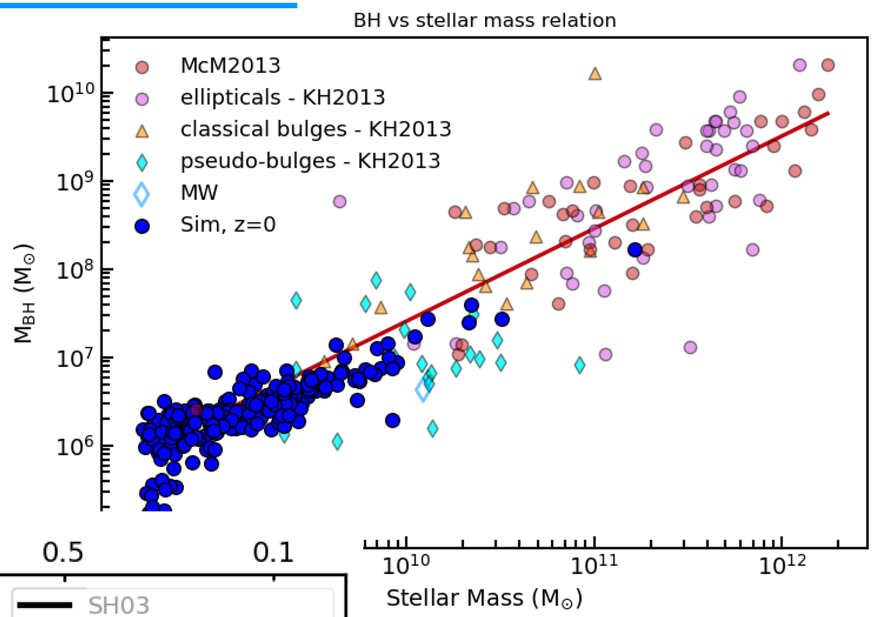
Our sub-resolution model MUPPI **successfully** describes the evolution of discs **and** massive ellipticals

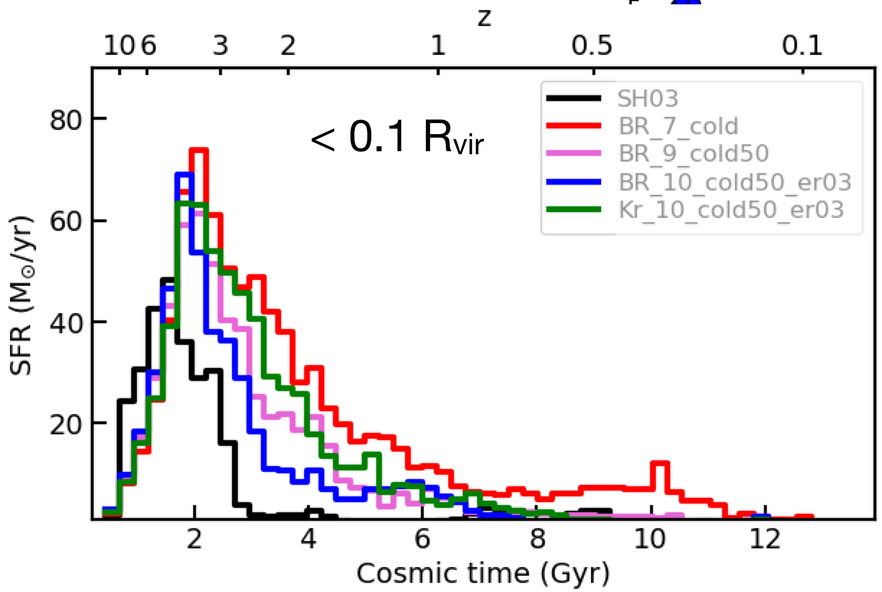




Spiral

Massive elliptical





Next Steps and Expected Results

2. → SLOTH: Shedding Light On dark matter wiTH cosmological simulations

Milena Valentini, Stefano Borgani, Tiago Castro, Luca Tornatore, Matteo Viel, Alice Damiano, Pierluigi Monaco, Giuliano Taffoni

Main **scientific goals** of the project:

- theoretical understanding of primordial structure formation
- characterisation of the nature of dark matter

Next Steps and Expected Results

2. → SLOTH: Shedding Light On dark matter wiTH cosmological simulations

Main **scientific goals** of the project:

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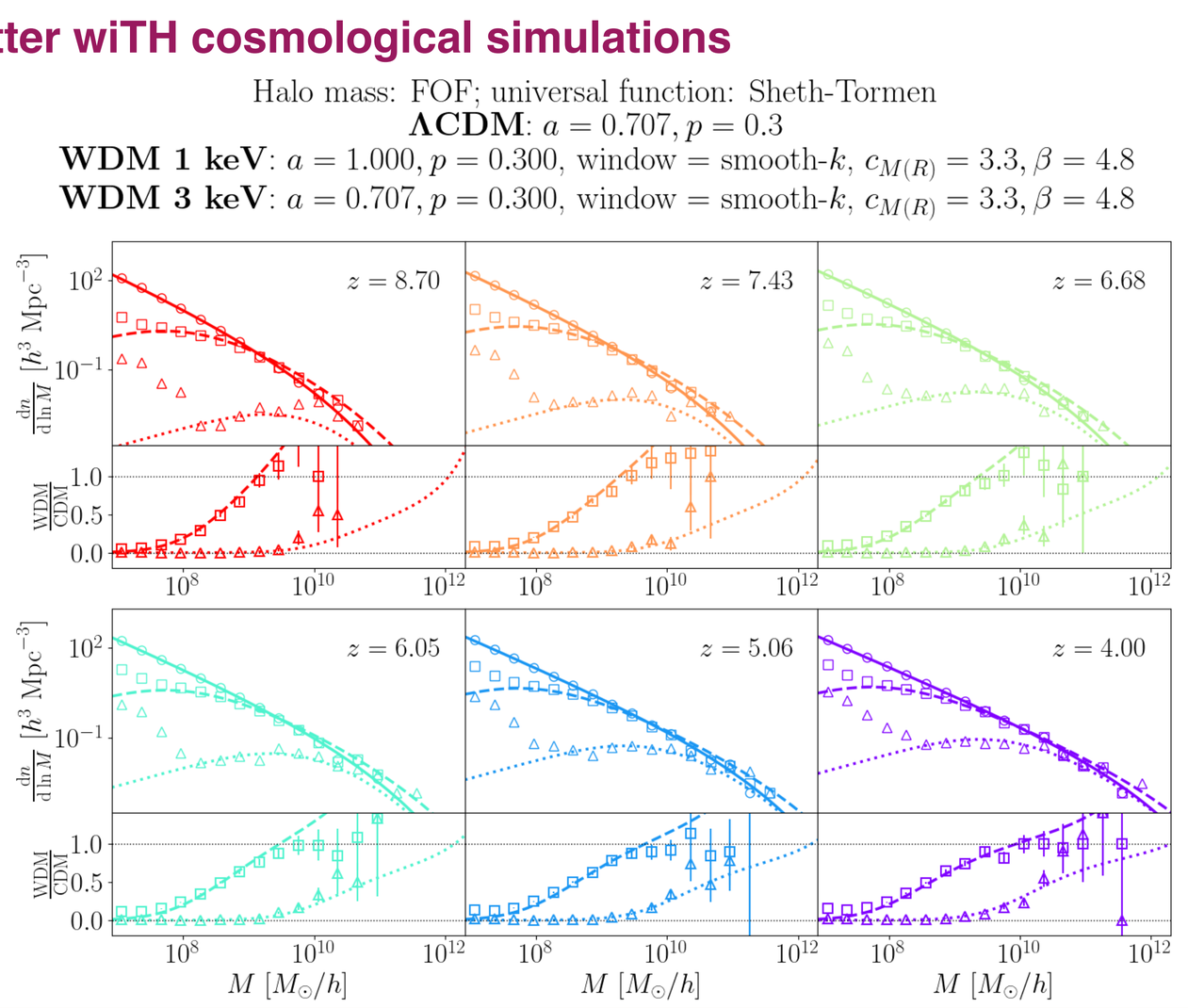
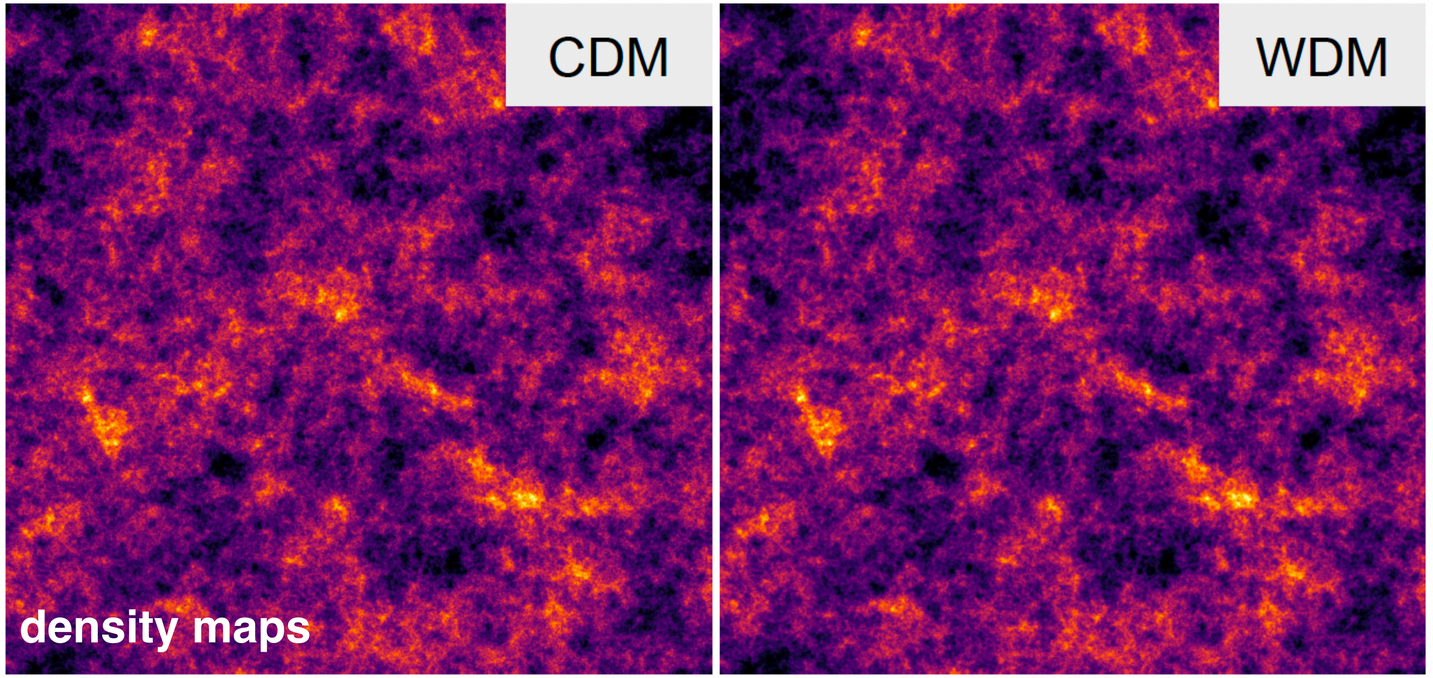
Simulations of warm dark matter (WDM):

- first results on a (10 Mpc/h)^3 box w/ 1024^3 particles



Next Steps and Expected Results

Initial conditions created for the two
Flagship simulations
(6656^3 particles in a box of 65 Mpc/h on a side)

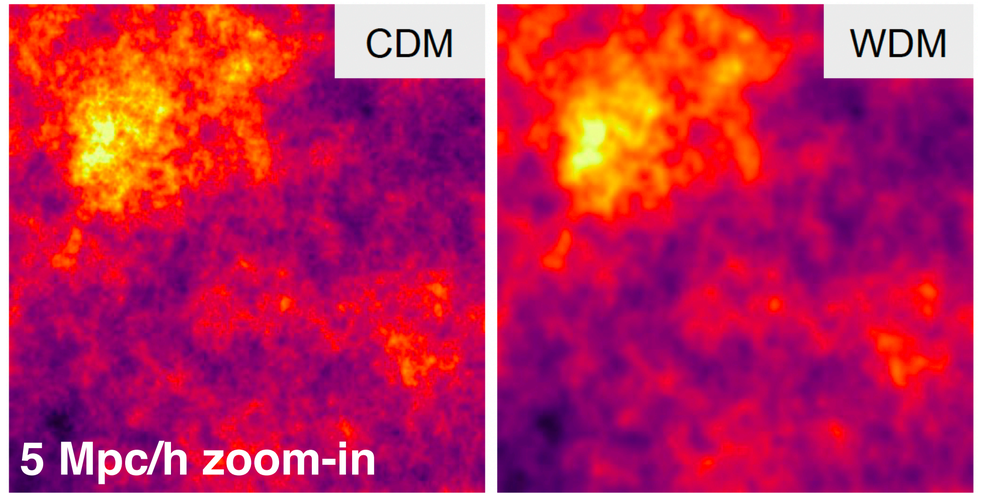


STRESS: inSighT on daRk mattEr with coSmological Simulations

Call for Leonardo Early Access Program

CINECA EuroHPC Joint Undertaking

Project Scope and Plan - Leonardo Early Access Program (LEAP)



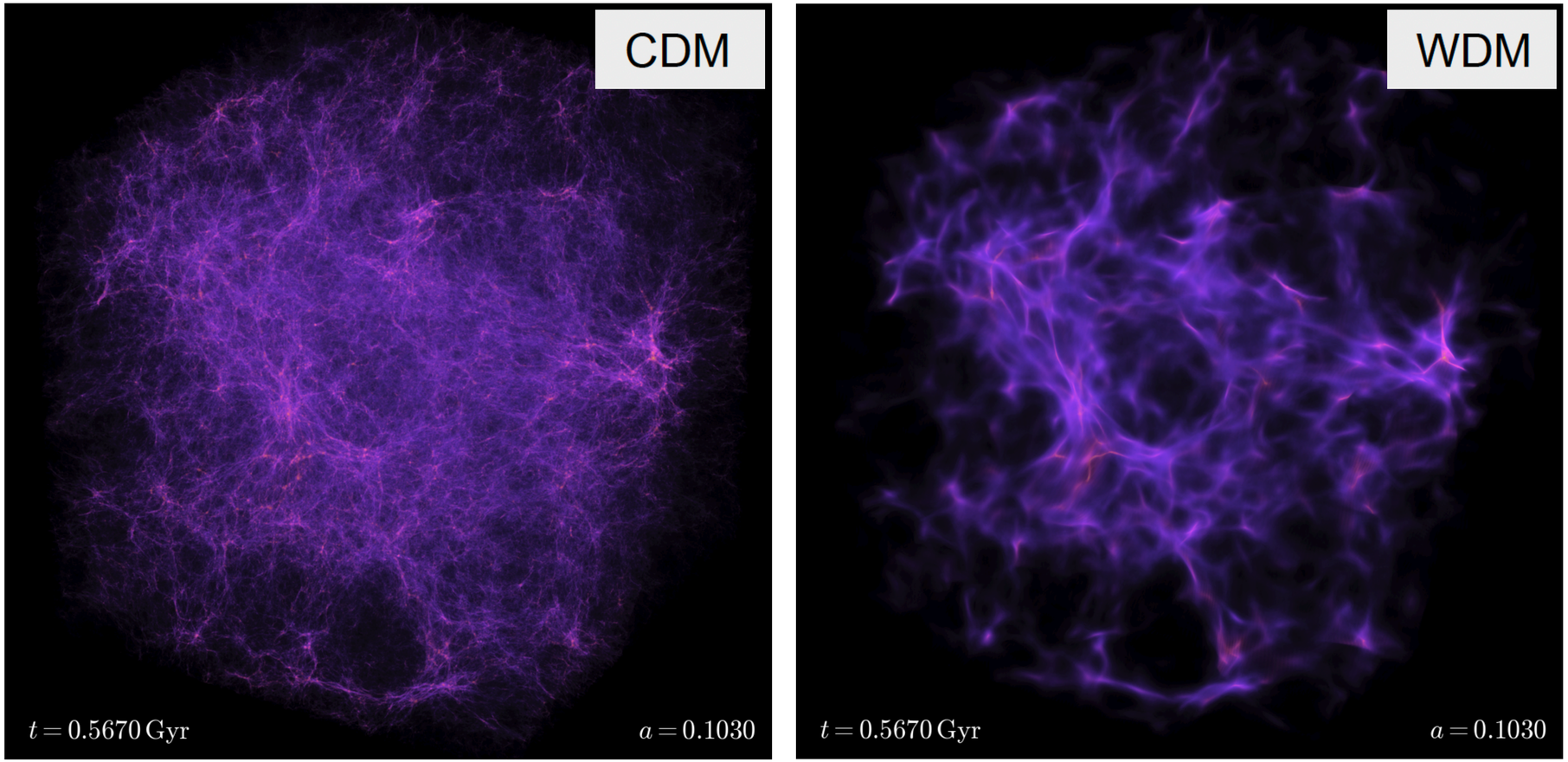
Team: Valentini M., Castro T., Borgani S., Viel M., Tornatore L., Ragagnin A., Dolag K., Parimbelli G., Murante G., Dakin J.

Next Steps and Expected Results

Preparatory simulations to validate the current version of the code and estimate cost

10 Mpc/h boxes with 1024^3 particles

Density maps at z = 9
(produced by T. Castro)



Overall status of our KSPs

Our **KSPs** so far proceeded with a slightly slower pace than foreseen:

- **Computational resource** on Leonardo Booster have been granted (125×10^3 node hours, i.e., 4×10^6 core hours each) and allocated last summer
- **Leonardo Booster** is often under maintenance and features instabilities; we experienced difficulties in running simulations with a large (~200-1024) number of nodes smoothly
- The performance of our code on GPU is improving, but the process required a huge effort, has had a significant speed up only recently (last <~ 2 months), and is somehow **limited to the gravity** sector
- We have considered the option of moving resources on the **DCGP partition** (as running on Booster in a CPU-only mode is not so efficient)**: not a viable solution**