Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
ICSC Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

Enhanced LSS cosmological simulations with ML techniques

Lorenzo Piga, Carmelita Carbone, Matteo Calabrese, Ben Granett

Spoke 3 General Meeting, Elba 5-9 / 05, 2024

Scientific Rationale: Cosmology

- **ΛCDM:** the standard cosmological model due to its remarkably accurate predictions of a variety of observables. Still the nature of Dark Energy (DE) and Dark Matter (DM) are unknown, possibly indicating beyond ΛCDM physics.

- **Upcoming first Euclid data release (May 2025):** simulations help in preparing the pipeline for Euclid data analysis in the presence of massive neutrinos and dynamical Dark Energy.

- **Main goal:** accelerating the production of N-body simulations for simulation-based cosmological parameter inference.

- **Large cosmological simulations:** limited by computational resources (cpu-time and storage).

Technical Objectives, Methodologies and Solutions

- **Neural networks (NN)** can learn from **high-resolution (HR)** images to produce **super-resolution (SR)** versions of different **low-resolution (LR)** images.

- We plan to train **Generative Adversarial Networks (GANs)** in the context of cosmological simulations.

- The GANs consist of two NNs: the **generator** and the **discriminator**. The generator tries to produce increasingly **realistic data**, while the discriminator gets better at distinguishing **real** from **fake**.

Technical Objectives, Methodologies and Solutions

- The **DEMNUni simulations** (Carbone et al. 2016) have been performed using the code **GADGET-3** (possibly accounting for the presence of massive **neutrinos**);

- **standard DEMNUni** (LR) and **High-Res DEMNUni** (HR) simulations will be used as training datasets to produce **SR** simulations with increased **mass resolution** and **volume for both CDM and neutrino particles.**

- **Simulation size**: respectively **2** and **16 Tb** per LR and HR sim (**4** and **32 Tb** if neutrinos are present);

- Over **150k cpu-hrs per HR simulation**;

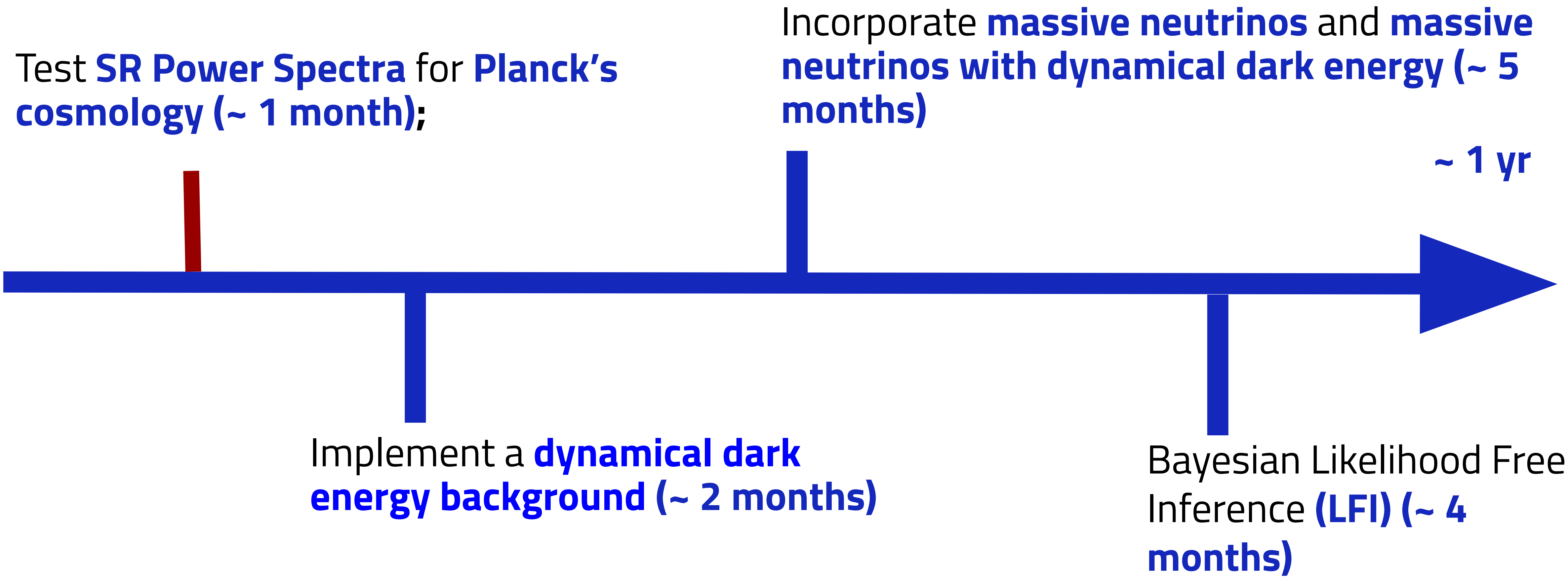
Technical Objectives, Methodologies and Solutions

- The SR output can reproduce small-scale structures with a factor of **8** in **length** (and **512** in **mass**) below the LR scale;

- The SR computational resources are extremely reduced in comparison to a HR simulation: i.e. for a (100 h^{-1} Gpc)^3 volume, it could take **500 core hours** to produce a **LR simulation** and then only **16 hours** with **1 GPU** for the **SR version** (a tiny fraction of the cost of the HR counterpart);

- It is possible to sample multiple "realizations" of the small-scale clustering by varying the **input noise component**;

Timescale, Milestones and KPIs



Timescale, Milestones and KPIs

M8 (March 2024 - June 2024)

- First run with **LR DEMNUni** with a public available code (Li et al. 2020): testing for a different cosmology (**Planck vs WMAP**);

- **USC VIII course**:
  - Computing and High Performance Computing in Astronomy and Astrophysics (Bologna, June - July 2024)

Next Steps and Expected Results

Step 1: Incorporate **dynamically dark energy (DDE)** in the training process and analyze the resulting SR simulations;

Step 2: Implement the presence of **massive neutrinos** in the training of the GANs and test the SR outcomes in terms of different summary statistics (ie Pk, HMF etc);

Step 3: Implement both the presence of **DDE & massive neutrinos** in the training of the GANs and test the SR outcomes in terms of summary statistics

Step 4: Extend the developed techniques to hydrodynamical simulations with **baryons** and **neutrinos** by adopting a mixed-method approach that leverages both NNs and other ML algorithms, i.e. **Lagrangian Deep Learning (LDL)**.

THANKS FOR THE ATTENTION!

Lorenzo Piga
lorenzo.piga@inaf.it

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS
Istituto di Astrofisica Spaziale e Fisica cosmica di Milano