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

*PINOCCHIO: recent developments and plans  
towards the Key Science Project*  
*Marius D. Lepinzan, UniTS + ICSC/Spoke1, P. Moñaco, T. Castro,  
L. Tornatore*

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

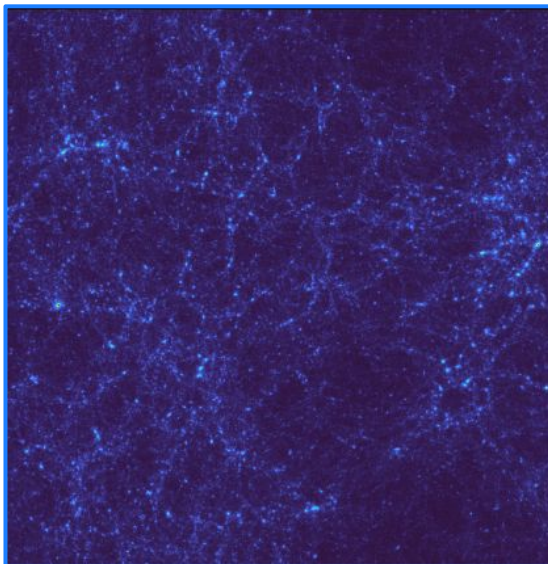
## Scientific Rationale

**PINOCCHIO** is a **code**, based on **Lagrangian Perturbation Theory (LPT)**, for simulating **Dark Matter halos** in **cosmological boxes** and **past light cones** (*Monaco et al. 2002, 2013; Munari et al. 2017*)

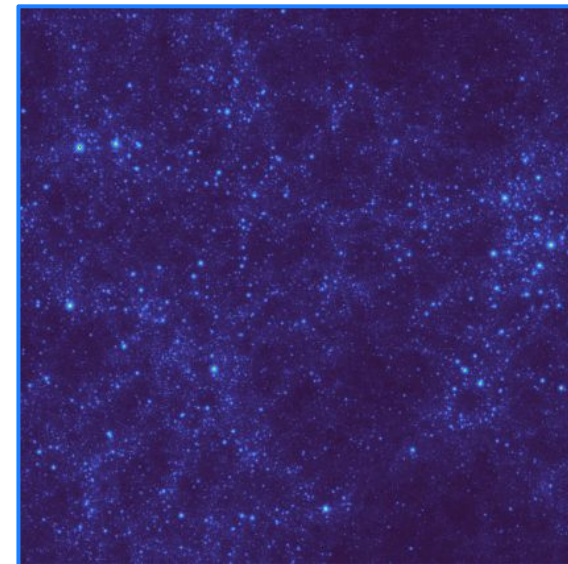
Comparison with full N-body simulations:

- **~1000** faster
- **5 – 10%** accuracy in reproducing 2-point statistics, mass function and bias

Gadget



Pinocchio

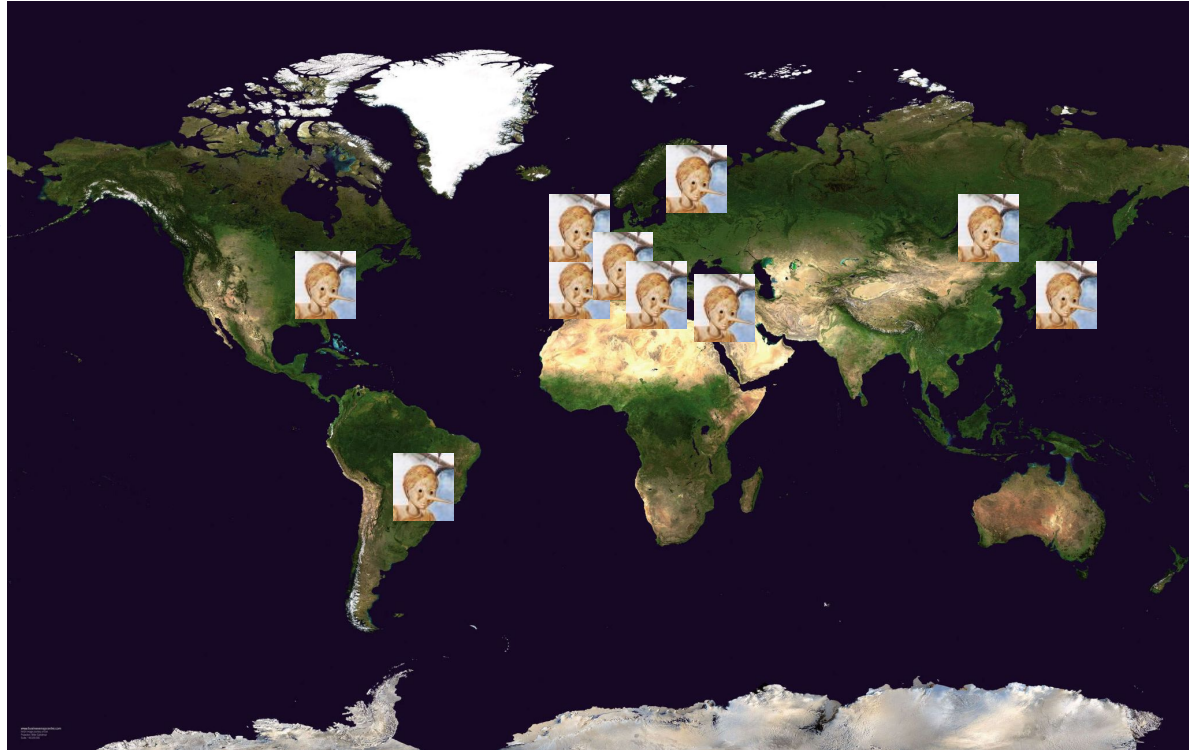


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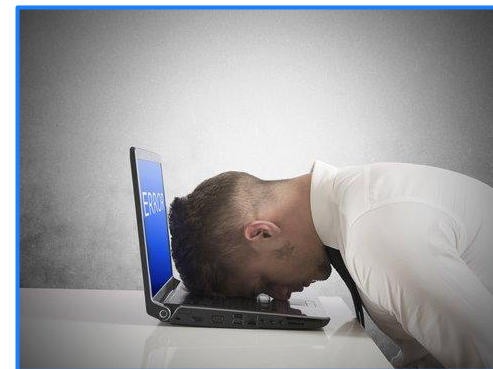
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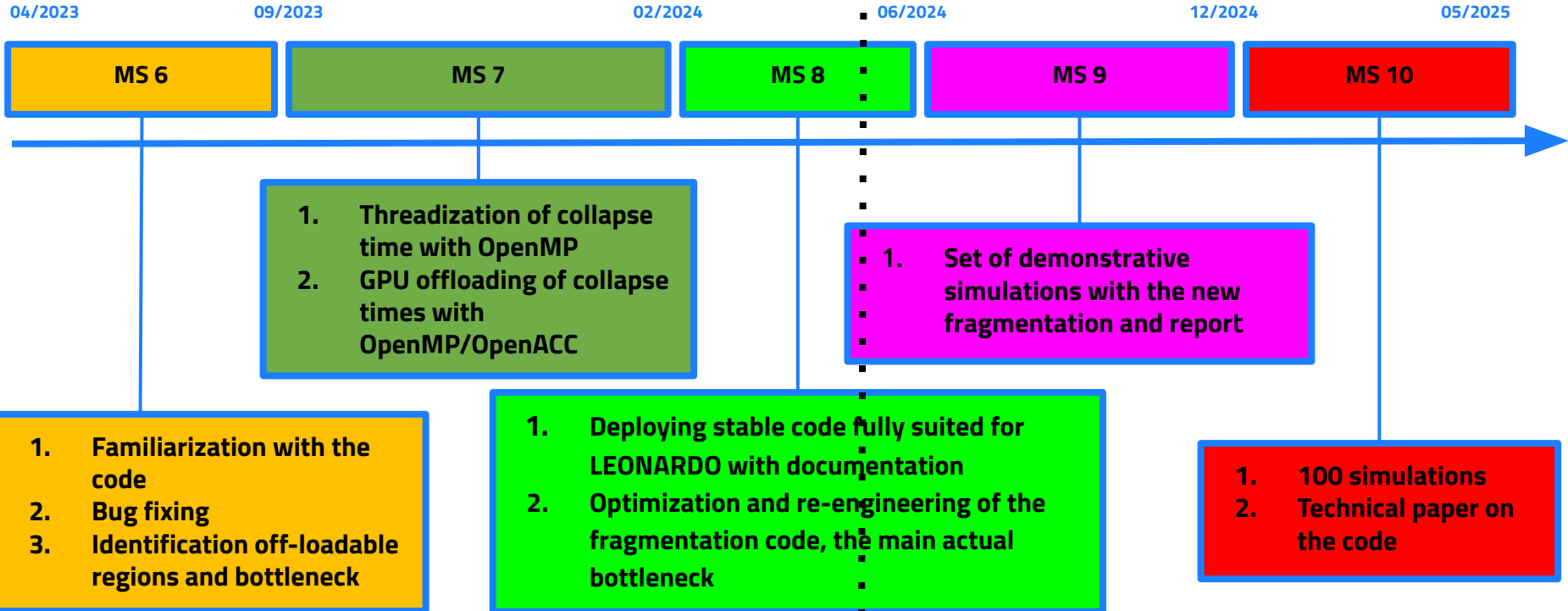


# Technical Objectives, Methodologies and Solutions

- **Optimize the code and allow it to run on architectures with GPUs:**
- **Improve code performance:** *suitable threadization? main bottlenecks?*
- **Identify off-loadable regions:** *what can be ported to GPUs?*
- **Improve scientific output:** *Adopting new algorithm?*
- **Adopted solutions:**
  - **Improve the MPI framework:** **OpenMP**
  - **Porting collapse times to GPU:** **OpenMP/OpenACC**
  - **Optimize and investigate** a new fragmentation algorithm: **Deblending**
  - **Testing, bug fixing, testing, bug fixing... !!**



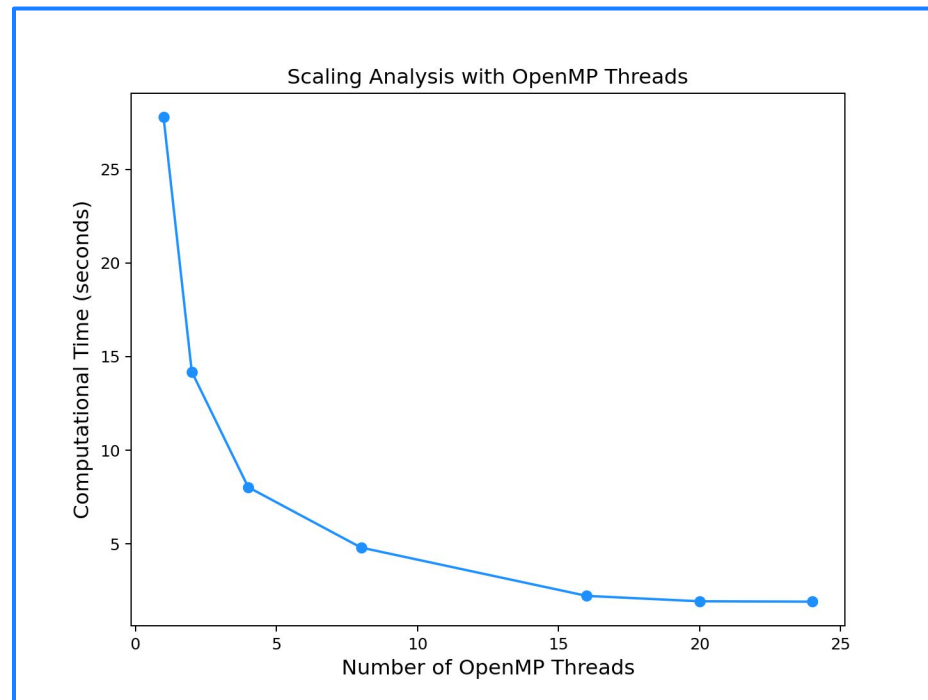
# Timescale, Milestones and KPIs



## Accomplished Work, Results

We have extended the existing parallel computing paradigm by integrating **OpenMP** into the **collapse times calculation**

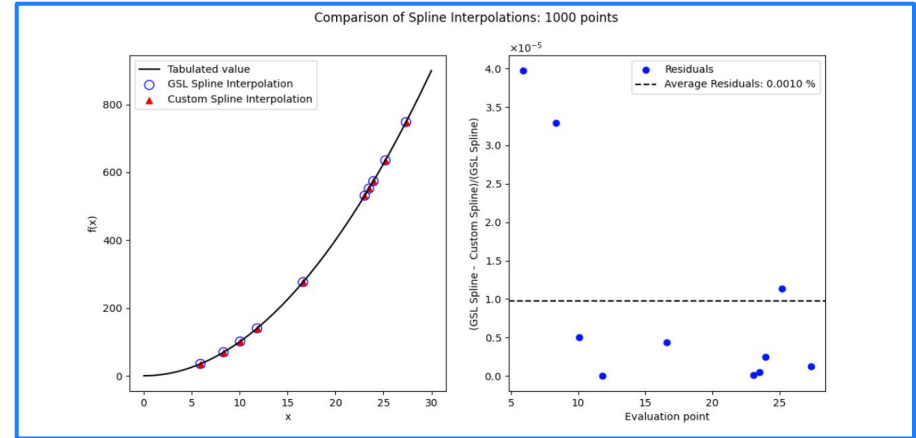
- Nearly **ideal** scaling up to **~20 threads** per single MPI Task
- **Expected** nearly ideal scaling up to **36 threads**
- Large Euclid Box ( box ~ 4 Gpc,  $4096^3$  particles )  
**computational time: ~ 8%** out of ~ 40 minutes
- Computational time **improvement: ~ 9x speed-up**
- Thousands of mocks: **~ 50 hours less**



# Accomplished Work, Results

## Offloading of collapse times calculation on GPU with OpenMP/OpenACC

- Submission of proposal for **GPU hours (ISCRA C): accepted**
- Set up the environment to **compile** the code on **LEONARDO**
- **Offloading implemented (needed a custom cubic spline interpolation)**
- **GPU offloading** test out of PINOCCHIO and comparison with GSL: **done**
- **Integration** in PINOCCHIO and **test on CPU: done**
- **Minor issues** at run time still need to be fixed but..



REMINDER: **Leonardo** scheduled maintenance until March 4th

27 February 2024

Dear Users,

This is to remind you that tomorrow, February 28th, partition will be unavailable for maintenance operations until 11:00 am. As announced, the operations will take longer and both partitions will go back into production on March 4th.

REMINDER: **Leonardo** scheduled maintenance, February 6th 7th

5 February 2024

Dear Users,

This is to remind you that on February 6th and 7th, 2024 **Leonardo** will be stopped for scheduled maintenance operations. **Leonardo** will be unavailable from 8:00 a.m. February 6th and it will be back to production within the afternoon of February 7th. Please note that, during the maintenance operations, the login nodes and the data mover service will not be accessible until noon on February 7th.

**Leonardo** partial unavailability for maintenance from April 15 to 19

8 April 2024

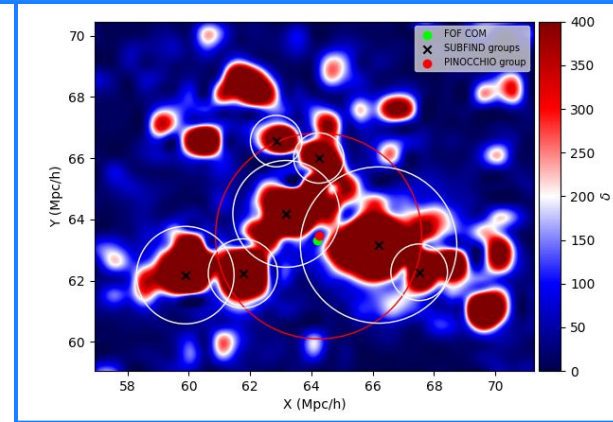
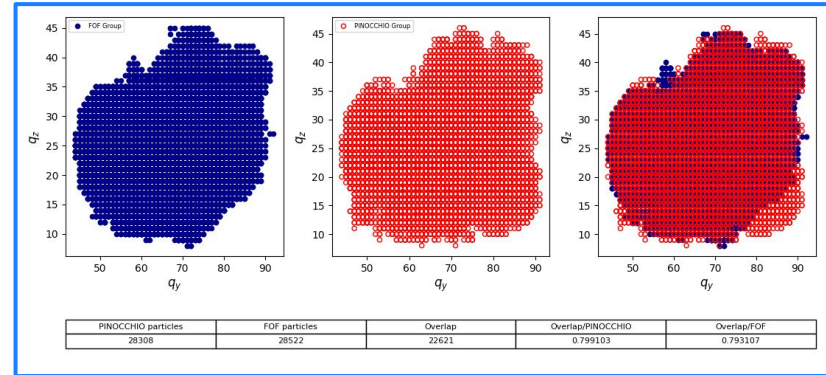
Dear Users,

We inform you that on April 15,16,18,19 **Leonardo** will be under partial maintenance. On each of those days a limited part of the compute nodes will not be available and you may experience longer queue times. On April 17th all compute nodes will be available.

# Accomplished Work, Results

## Optimization and re-engineering of the fragmentation code segment

- Particle by particle **comparison** with an **N-body** code (OpenGadget3)
- **Initial condition** for the N-body generated with **PINOCCHIO**
- **Visualization** of the halos **eulerian** and **lagrangian** patch

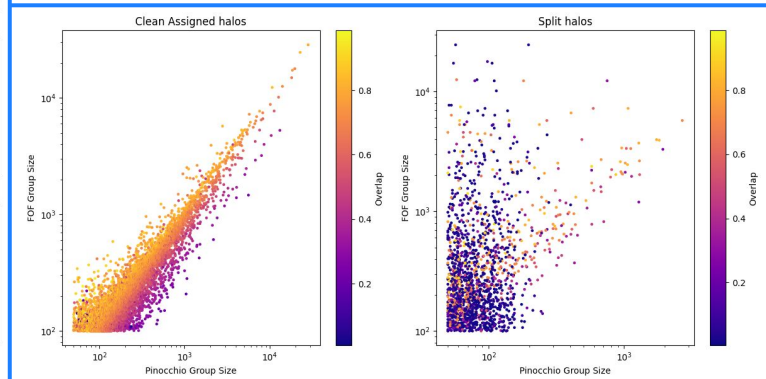
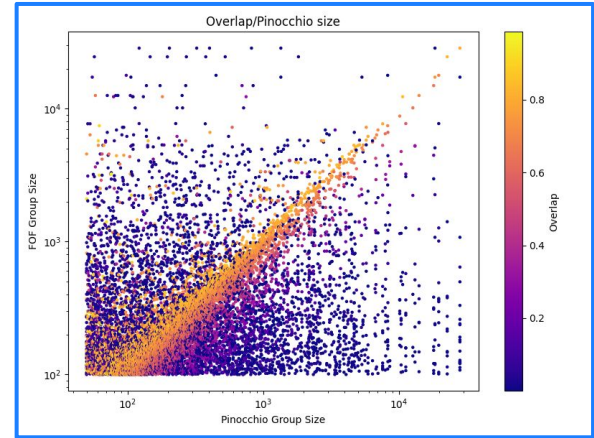
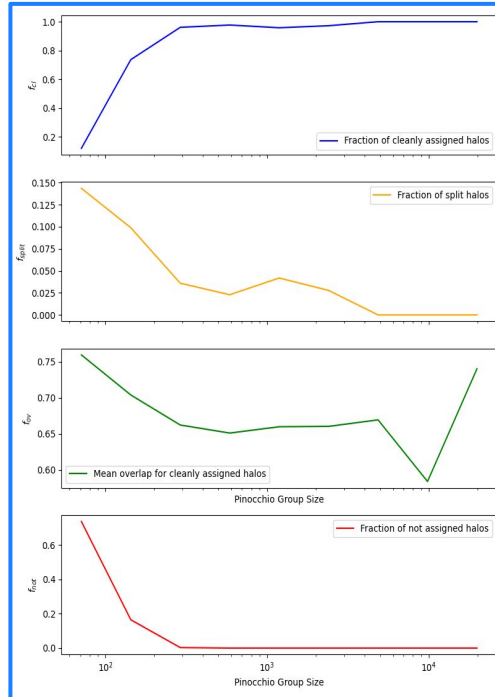




# Accomplished Work, Results

## Optimization and re-engineering of the fragmentation code segment

- Estimation of PINOCCHIO accuracy in building up the halos compared to FOF halo finder
- Overlap matrix and fraction statistics



## Key Science Project: EuMocks

Euclid will survey the universe down to redshift  $z \sim 2$ , **mapping the large-scale structure** ( $\sim 15,000$  sq deg of the sky) to measure its geometry and growth rate to shed light on dark sector

Control of **systematic errors** will be the issue to tackle to provide convincing and potentially groundbreaking results

Key Science Project goal: **3500 simulations** ( $\sim 4\text{Gpc}$  with  $\sim 10^{12}$  particles), **resolving halos of  $\sim 10^{11} M_{\text{sun}}/h$** , in a past-light-cone covering **half of the sky** starting at  $z=3$

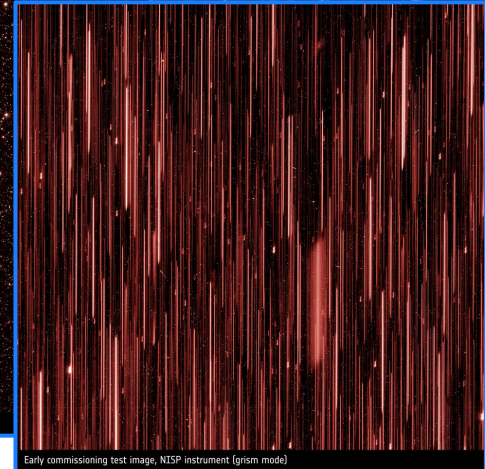
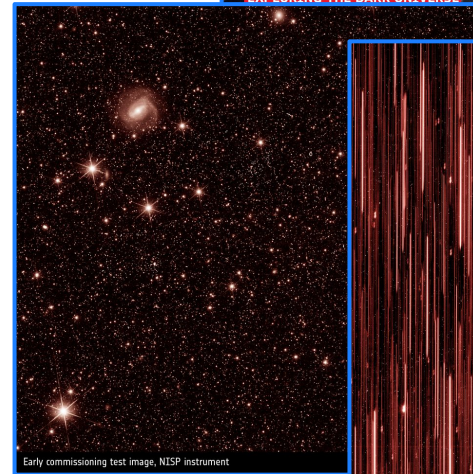
Development is needed (Spoke3 + Spoke1, PRIN PNRR 2022):

### SCIENCE:

- improve and optimize **the reconstruction of halos**
- implement a **Particle-Mesh** code to move halos (instead of 3LPT)
- add **lensing** and relativistic effect

### CODING:

- port on **GPUs** specific code segment
- improve the **fragmentation**



# Key Science Project: EuMocks

Massively parallel code, every step must be optimized before burning so much computing time

Computing time: ~30,000,000 core hours  
Memory: ~128 TB  
Storage: >~1PB

Petabyte-scale output **to be offered to the community**

-> National / Interoperable Data Lake

example: Cosmohub.pic.es

The screenshot shows a web browser window displaying the CosmoHub website. The page title is "FS2.1 WIDE 2.1.1.0". The main content area contains the following text:

This is the Flagship Mock Galaxy Catalogue (version 2.1.1.0) with updated IA properties and NN2 data.

The mock catalogue is based on the record-setting Flagship2 N-body simulation that includes ~4 trillion (4E12) dark-matter particles. In particular, it uses as input the dark-matter halo catalogue (v2.0) and projected dark-matter counts maps (in Healpix format) derived from this N-body simulation. This new version of the Flagship mock represents a major improvement of the modelled galaxy properties with respect to the previous released version (i.e. Flagship 1).

The mock galaxy catalogue has been generated at PIC using the SciPIC pipeline on top of a Big Data platform based on Apache Hadoop.

The **main important differences** in the mock galaxy catalog compared to version 2.0.0 are:

- The redshift distribution of galaxies when cutting in  $\log_{10}(\text{halph}_3 \text{ ext})$  is smoother
- Galaxy velocities have been improved (including line of sight anisotropies)
- Emission line fluxes distribution have been improved
- Several emission lines have been also included
- An approximation of the intergalactic medium (GM) attenuation in the galaxy fluxes has been included

**Some numbers of the catalogue:**

It contains 483533756 (~4.8B) galaxies up to  $\text{euclid\_nisp\_h} < 26.6$  (i.e. no emission lines, no MW extinction). The cut in H-band is actually a bit deeper than 26 to allow for a selection at the same magnitude also when considering the contribution of emission lines. The total number of objects when cutting at  $(-2.5 * \log_{10}(\text{euclid\_nisp\_h}) - 48.6 <= 26)$  is 3327771052 (3.3B).

The mock covers 1 octant of the sky ( $-5.157 \text{ rad deg}$ ) centred at approximately the North Galactic Pole ( $145 < \text{RA} < 235 \text{ deg}$ ,  $0 < \text{DEC} < 90 \text{ deg}$ ), and samples a wide redshift range:  $0 < z < 3$ .

Note that there is a small region ( $150 < \text{RA} < 155 \text{ deg}$ ,  $5 < \text{DEC} < 10 \text{ deg}$ ) that has no magnitude or line flux cut. A contribution to the total number of galaxies is coming from this uncut area.

Show full description

**Value Added Data** *Directly download useful or necessary files to analyse the catalog*

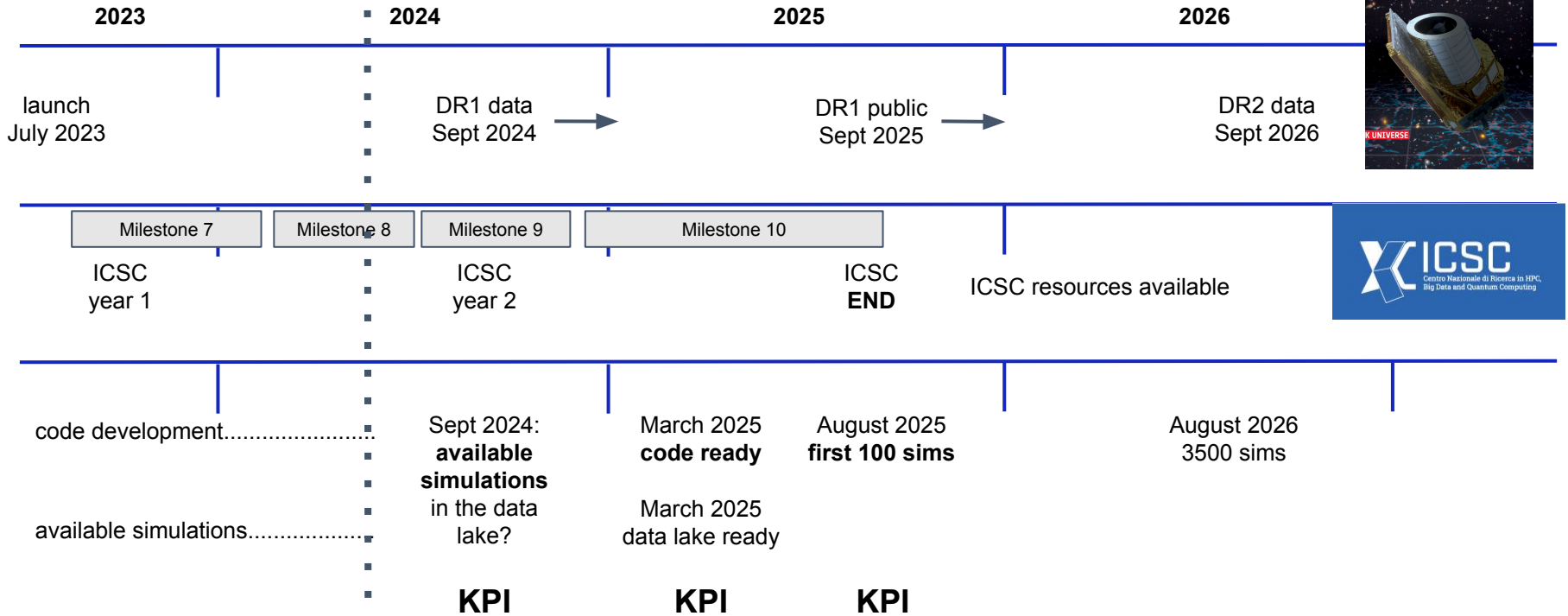
Name	Version	Description	Size	Download
sed_extlaws_filtercurves.zip	FS2_2.1.1.0	SEDs, Extinction Laws and Filter Curves used to estimate fluxes in FS2_2.1.1.0	1,15 MB	Download Readme

**Catalog Playground** *Create and analyze your own sample of the catalog following some basic steps*

Step 0: Datasets - Load a particular sample of the catalog

You can find below particular sets of the catalog.  
If you click in the "Load" button you will jump to the Analysis Step 1.

# Key Science Project: EuMocks



## Next Steps and Expected Results

- **Application** to the upcoming **CINECA GPU HACKATHON** (with *David Goz and Giovanni Lacopo*):
- **Finalizing** and **optimizing** the already in place **GPU** version of the collapse time calculation
- **Porting** on **GPU** the **FFT calculation** using cuFFT
- **Optimization** and **re-engineering** of the fragmentation code segment:
- **Fine tune** the present physical based threshold for **particle accretion** and **halo merging**
- **Introduce** a halo **concentration** proxy in order to minimize the **LPT displacements** errors
- **Adopt** a new format for the **PINOCCHIO** scientific output
- **FITS catalog** obtained at a post processing phase with a **custom developed code**