Cosmological computing within InDark

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INDARK

Responsabile nazionale: NICOLA BARTOLO

▶Summary for external referees

Pagina	Modulo equivalente
- Ricercatori	
• Bologna	
• Ferrara	
• Lab. Naz. del Gran Sasso	
• Padova	(Moduli EC7 delle singole sezioni)
• Roma II	
• Roma III	
• Torino	
• Trieste	

- **Eight nodes**
- **Over 60 connected researchers (staff, postdoc, Phd)**
- **Focus on cosmology and astroparticle physics:**
  - Objectives: constraints on dark matter, dark energy, neutrino properties, modified gravity, fundamental symmetries, …
  - Probes: cosmic microwave background, large scale structure of the universe
  - Significant computational (HPC) side: simulations, model to data comparisons, …

Indark activities and HPC

Indark participants are strongly involved in a large amount of computationally intensive activities.

- ✓ Ongoing activities for cosmological and theoretical interpretation of data, and constraints on fundamental parameters
- ✓ This **does not** include activities on data reduction and validation which are traditionally bound to experiments (though they also require HPC: not all experiments are happy with HTC!)
- ✓ Two main souls: CMB and LSS

CMB. Scientific goals

Measurements of cosmological Parameters in ΛCDM, e.g. :

- **Initial conditions: n_s, r, n_t …**
- Geometry: Ω_k,
- Evolution: Ω_b,Ω_c,Ω_Λ

Initial conditions:

- Did Inflation take place?
- Constraints on Inflationary models.

Primordial CMB

Tests of our cosmological paradigm:

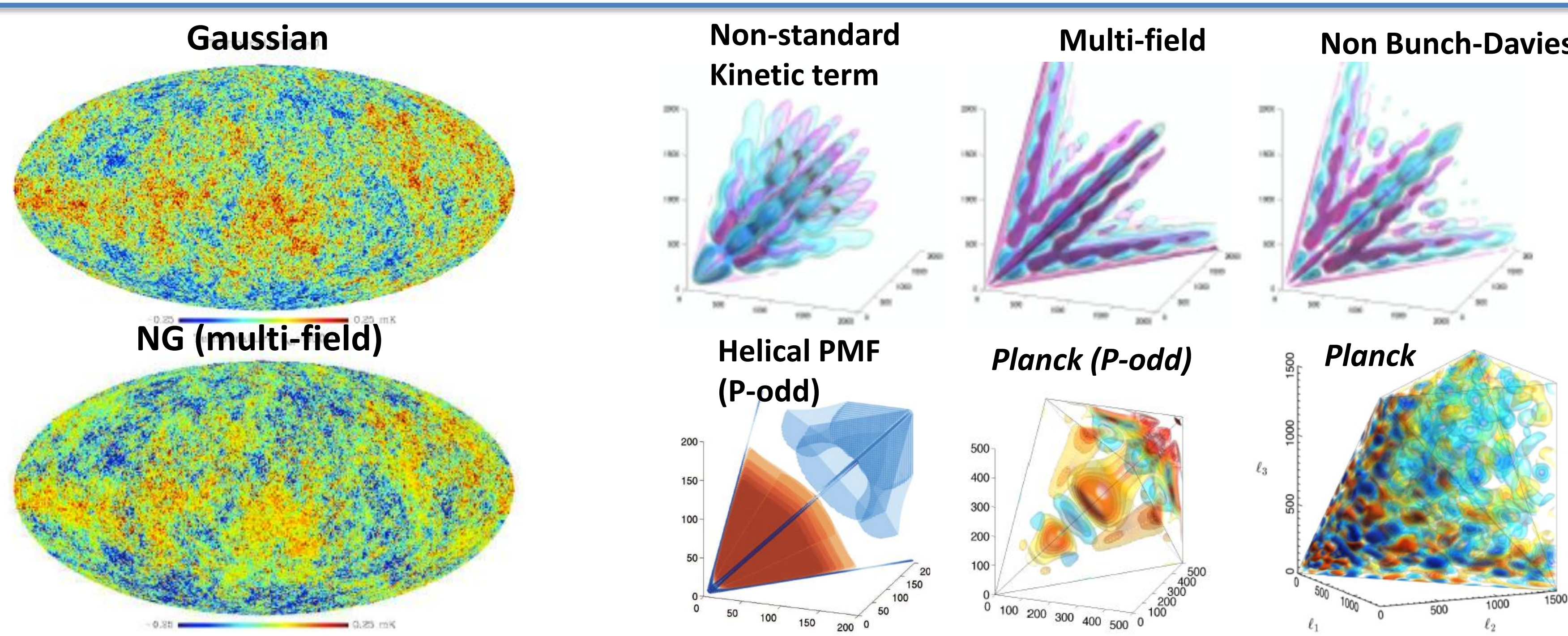
- Isotropy
- Gaussianity

Non-standard/new Physics:

- Parity breaking
- Topology
- Cosmic strings
- …

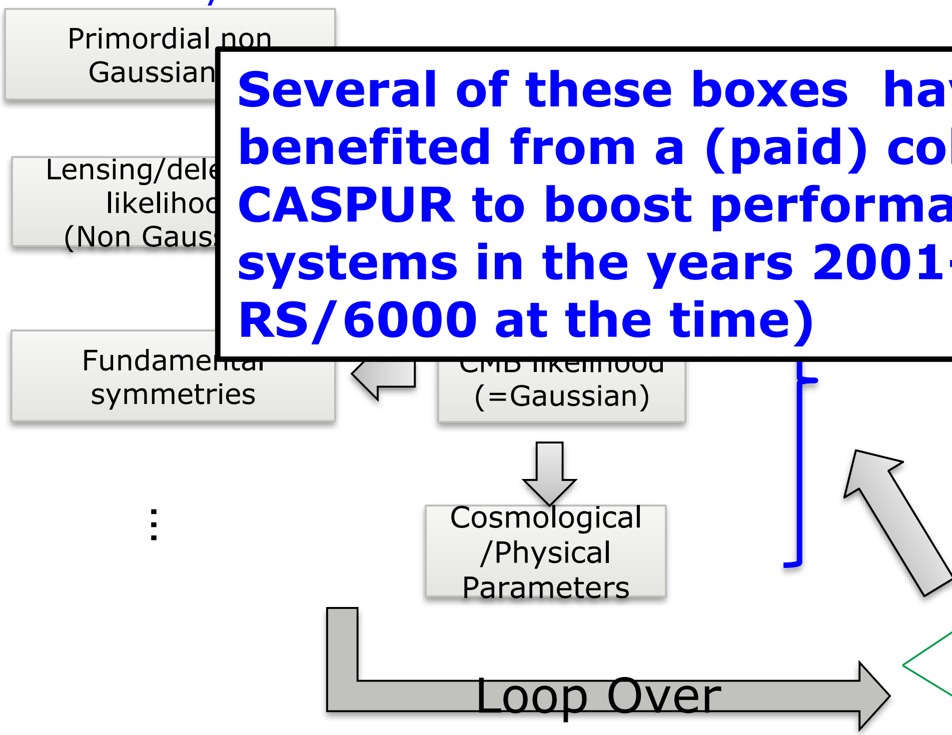
Indark. CMB activities and HPC.

- <u>Cosmic Microwave Background. Aim: tests of Inflation, fundamental and astroparticle Physics</u>
  - ✓ CMB simulations: propagation of synthetic data and theoretical signals (e.g. CMB non Gaussianity)
  - ✓ Development of 3-point and 4-point function NG estimators studies.
  - ✓ Parity breaking CMB spectra, bispectra and trispectra
  - ✓ Inflationary parameters, preparation and forecasts for B-mode surveys.
  - ✓ NG tests for CMB spectral distortions.
  - ✓ Development of statistical methods for component separation
  - ✓ Constraints on non standard neutrino interactions
  - ✓ CMB Anomalies and connections to pre-inflationary phases (e.g. string theory motivated scenarios)

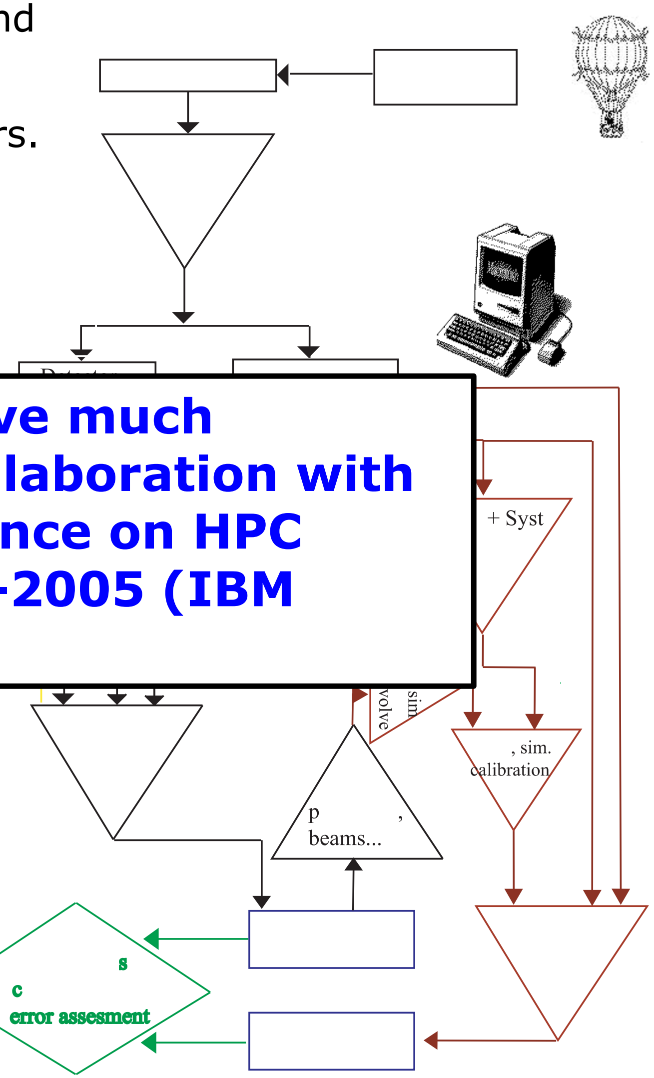


CMB analysis pipeline

- Pipeline flows through several domain: time and frequency to pixel and harmonic.
- Radical compression: from Pb to "few" numbers.
- Accurate propagation of error budget (covariances)
- Heavily relies on simulations

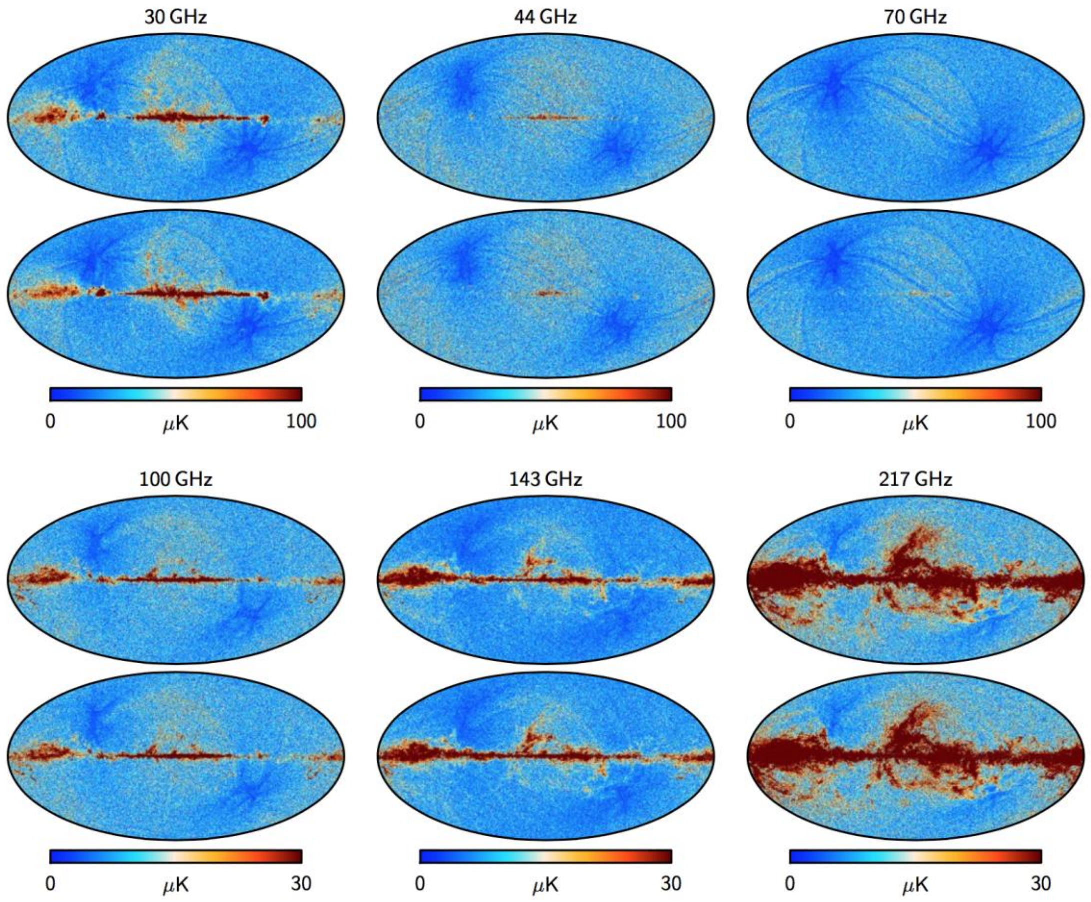


Several of these boxes have much benefited from a (paid) collaboration with CASPUR to boost performance on HPC systems in the years 2001-2005 (IBM RS/6000 at the time)



Example: Planck Full Focal Plane simulations

1. End to end effort for all Planck channels [arXiv:1509.06348]
2. Major computational burden was set of 10^4 Monte Carlo maps: 1 million CPU-days on world class super computer (NERSC/DOE Cray XC30)
3. Supported Planck cosmological analysis towards its legacy



Computational needs for CMB

- CMB activities alone, specifically for **theoretical interpretation** of data, required over 3 million CPU hours per year, between 2013 and 2015.
- Most pipelines were run so far at NERSC (Cray XC30, ~ 130 Kcore "Edison", XC40 ~ 60 Kcore "Cori"). NERSC provides about 12 M mpp-hour/year "free" for CMB activities, plu 50 M mpp-hours/year reserved to Planck (which are abused for non Planck theoretical activities anyway…). The PI of this grant is Julian Borrill, LBNL/UC Berkeley.
- **Stable availability of these facilities in the future very unlikely, especially now that Planck is coming to an end.**
- PRACE/DECI calls have also been exploited, but were largely focused on data reduction more than theoretical modeling/exploitation (e.g. Monte Carlo support for data processing centers).
- Already a significant amount of time was invested in code porting so far, due to changes in availability of CPU hours on different infrastructures.

LSS. Scientific goals

Astroparticle:

- Neutrino masses
- Nature of Dark Matter.

Measurements of cosmological Parameters

Large Scale Structure

Study formation, growth and clustering of cosmic structures

Understanding acceleration:

- Dark Energy
- Modified Gravity

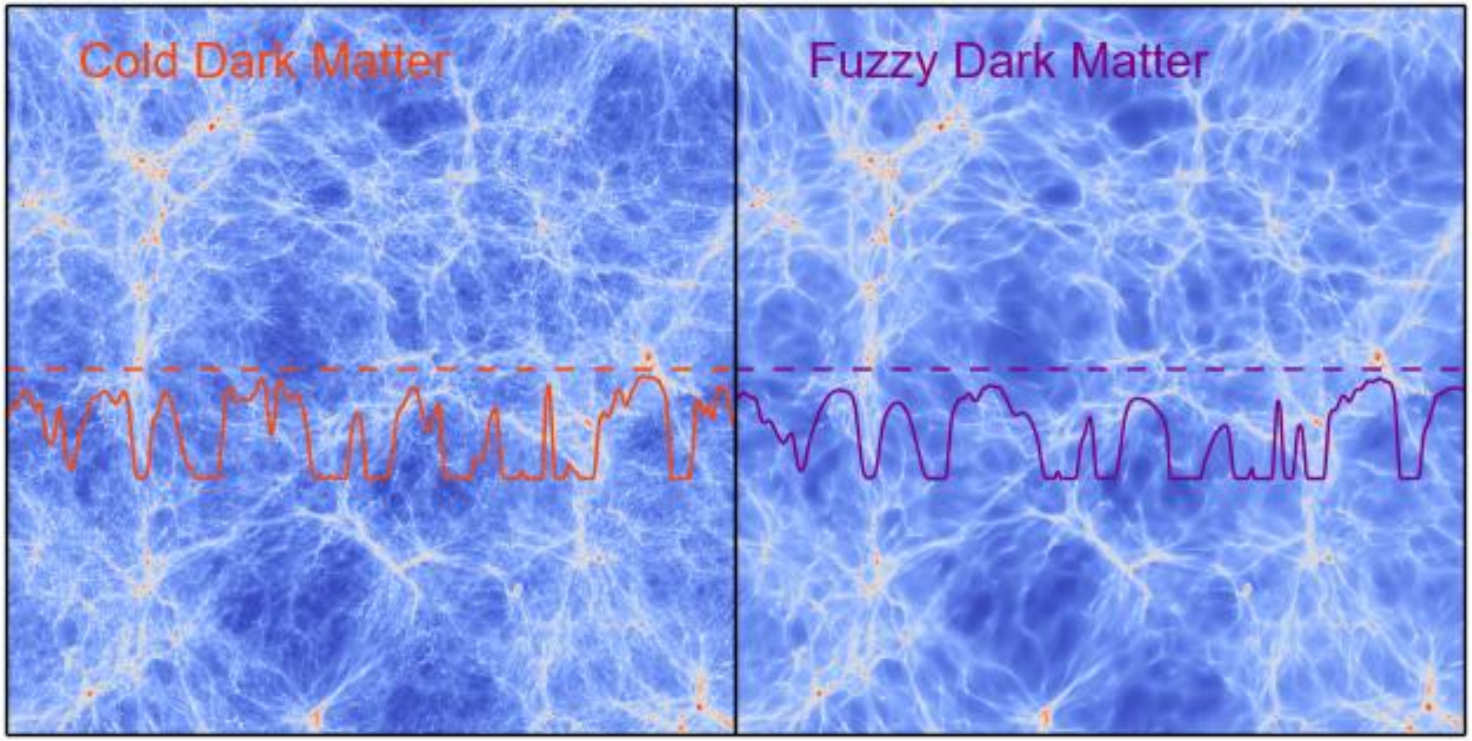
InDark. LSS Activities and HPC

Ongoing activities for cosmological and theoretical interpretation of data, and constraints on fundamental parameters (not including activities on data reduction and validation which are traditionally bound to experiments):

- <u>Large Scale Structure. Aims: dark matter and neutrino studies, tests of Inflation and structure formation.</u>
  - ✓ Production and analysis of N-body simulations
  - ✓ Development for future (Euclid, SKA) analysis beyond power spectrum .

- <u>Cross-correlation of large cosmological and external datasets. Aims: dark matter, dark energy/modified gravity studies, Inflation</u>
  - ✓ CMB-LSS (spectroscopic, radio) cross-correlation tests for MG constraints
  - ✓ Development of Einstein-Boltzmann integrators in Effective Field Theory of MG, for cross-correlation forecasts
  - ✓ LSS/CMB-gamma ray cross correlation tests for searches of DM annihilation/decay signal
  - ✓ Predictions of GW from Inflation, combine predictions: interferometers + CMB B-mode.

light-axion Dark Matter



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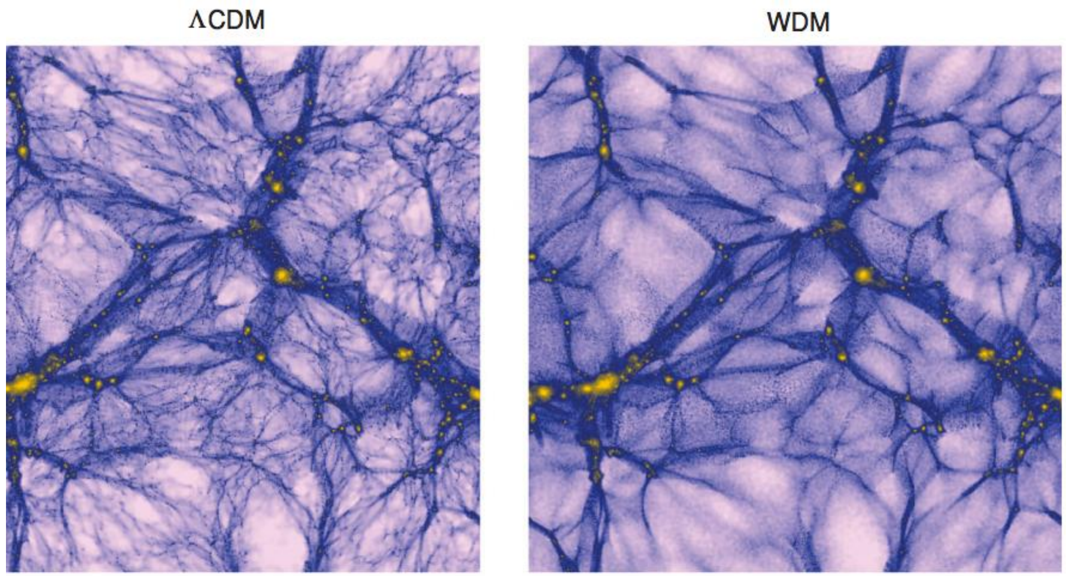
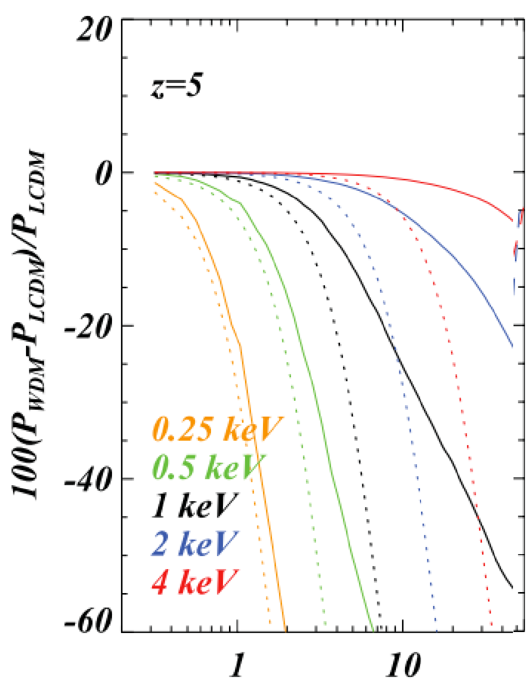
- **Scalar dark matter obeying Schrodinger-Poisson equation:** quantum pressure term with associated De Broglie wavelength (lambda ~ 1 kpc).

- Dynamical properties of Dwarf galaxies seem to be in better agreement with masses 1-10x1.e-22 eV for the ultra-light boson.

Solution to small scale crisis: Make Dark Matter Warm

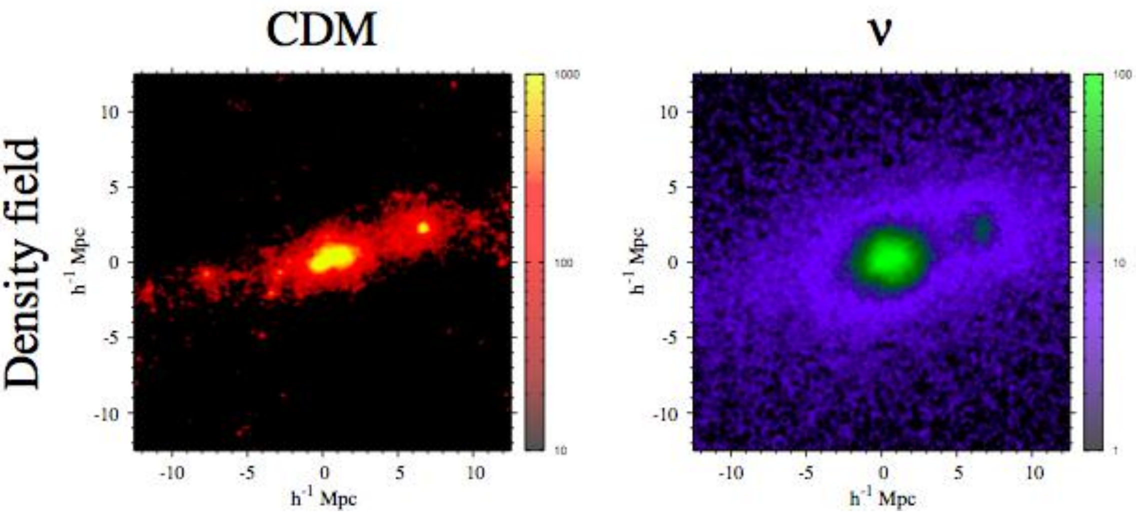




Viel+12 Suppression of power: z-evolution in the linear (dotted) and non linear regimes for a thermal relic

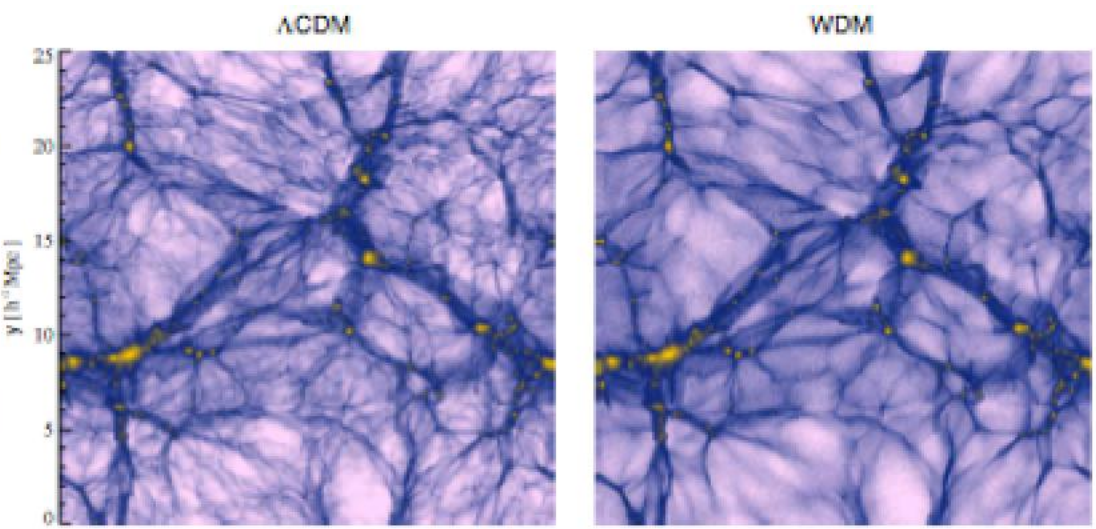
- Cold dark matter is collisionless: zero pressure (thermal velocities).
- Warm dark matter has non zero **thermal velocities** thus non zero pressure (Jeans scale below which perturbations cannot grow).
- Generic prediction is thus a scale and redshift dependent **lack of power** (at non linear level).
- Strong link to **particle physics** and minimal extensions of the standard models: sterile neutrinos?

Non-linear cosmological neutrino background:
characterization of neutrino fluid non-linearities



- Large scale structure simulations > 500 Mpc/h to appreciate neutrino free streaming
- UK facilities have been strongly used (PRACE call) and only partially Zephiro (200 CPU khrs spent on voids/neutrino projects).
- **Requirements: > 200 Gbytes of memory, > 512 cores – 1 M cpu hrs**

Dark Matter at small scales:
physical properties of dark matter and LCDM crisis



- Small scale structure simulations < 20 Mpc/h to appreciate dark matter cutoff scale (WDM, light- axion DM etc.)
- UK facilities have been strongly used (PRACE call) – hydro simulations at high redshift
- **Requirements: >100 Gbytes of memory, > 512 cores – 1 M cpu hrs.**

Computational desiderata

	2018	2019	2020
Mcore-hours	3	4	6

- The proposed trend takes into account a start-up price as well as external resources.
- Requests for permanent storage not exactly quantified, but modest (few Tb range)
- But need ~ Pb for short term/scratch storage
- Fast I/O is not a strict requirement but a plus.

Remarks

- InDark is a project involving theoretical modeling and constraints for cosmological scenarios.
- It has a significant computational side, strongly focusing on HPC (no HTC/grid/@home etc.)
- It draws much of its resources from external service providers, largely free of charge. **This situation is likely not going to last forever.**
- The research activities connected to Indark would greatly benefit from a wider integration into INFN theory connected computing community.
- Computing activities have spawn dedicated research projects (porting efforts, including attempts on GPU, code optimization…)
- These efforts struggle to find dedicated manpower support. Specific financial requests (including to this group) have not been successful in the past.