Fundamental Sciences

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Brussels, 4-5.02.25

PRACE is 2025

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What are the main subjects to be addressed?

Within the Fundamental Sciences section, two main areas of research continue to lead the use HPC resources:

- Astrophysics and Cosmology

- Particle and Nuclear Physics

These topics are also the backbones of the document under preparation and reflect the enormous European investments in new **satellites, detectors,** and **accelerators**

What are the burning issues?

Within **Astrophysics and Cosmology** the main topics that have emerged as the focus of recent progress are:

- Space-weather and magnetospheric simulations
- Dynamics of neutron stars and black holes (GWs, X-ray, radio)
- Galaxy formation, large-scale structure, impact of dark matter

Within **Particle and Nuclear Physics** the main topics that have emerged as the focus of recent progress are:

- Lattice QCD and QED simulations
- Muon magnetic moment anomaly
- Simulations of heavy-ion collisions at large/small energies

What is the state-of-the-art?

Within **Astrophysics and Cosmology:**

- Space-weather: PIC simulations and storm predictions
- BH-NS: GW modelling over 100 ms after merger; EM counterparts; multi-messenger astronomy
- Particle-MHD codes to model from megaparsec to kiloparsec

Within **Particle and Nuclear Physics:**

- QCD/QED: controlling impact of discretisation, finite-volume size effects, isospin breaking
- complete QCD calculation of muon anomaly (sub% precision)
- HIC simulations: modelling of resistive/viscous effects; large statistics in initial data

Machine Learning is used but doesn't drive (yet) the science

What are the statistics of typical applications?

Within **Astrophysics and Cosmology:**

- 135 projects awarded
- 3,934 MCPUh
- ~12% of the total awarded

Within **Particle and Nuclear Physics:**

- 172 projects awarded
- 8,6867 MCPUh
- ~25% of the total awarded

When **combined**, Fundamental Sciences account for about **37%** of the awarded resources

How do you see the computational requirements evolving within 5-10 years (post exascale)?

- Already witnessing some radical changes on how HPC facilities are designed and made available to the FS community
- Development of large infrastructures based on GPUs may represent obstacle for large portion of the communities
- Code porting is possible but time-consuming and difficult in terms of man-power and funding
- Development of "community codes" may represent the solution to some of these problems but it has disadvantages (cross-validation) and requires very cohesive communities

Who are the competitors?

- Main competitors remain groups in USA, China, and Japan
- All things considered, Europe provides facilities that are comparable if not better than those of competitors
- Accessing facilities requires significant effort and rightly so; shorter evaluation times can only help
- Would be interesting to learn more how the HPC resources are actually handled elsewhere

How is the domain affected by the political framework?

- Migration to GPU-based systems will have impact on communities dealing with fundamental science
- Small groups may not have resources to adapt; we all lose competitive research (man-power is a commodity)
- Creation of Centres of Excellence (e.g., SPACE) represent effective solutions; funding in this direction should increase
- University HPC training is insufficient; arrives late (MSc, PhD) and needs to be increased ("HPC professors" co/funding?)
- Construction of "community codes" could solve some issues but needs encouragement (funding)

Summary

- Fundamental Sciences are ~ 1/3 of the HPC use in Europe
- State-of-the-art is high: both techniques and science output
- GPU-dominance may represent an obstacle about to emerge
- COE are important solutions for coordinated efforts
- HPC Training part of scientific curriculum (HPC prof?)
- Academic resources seen as part of the HPC investments