Smilei

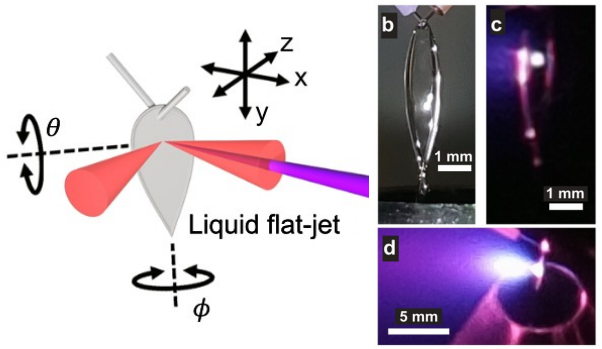
Journées Techniques du LLR
Juillet 2025

Arnaud Beck

The Particle-In-Cell (PIC) simulation of « extreme » plasmas

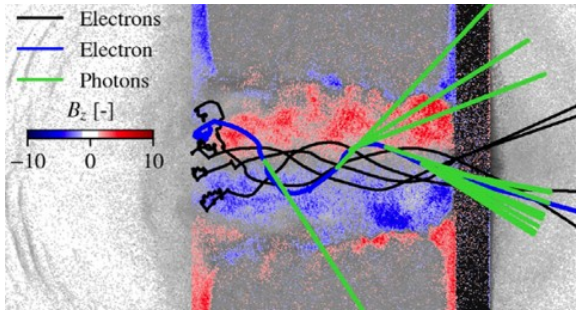
Institute for Basic Science, Gwangju

High-Harmonic Generation



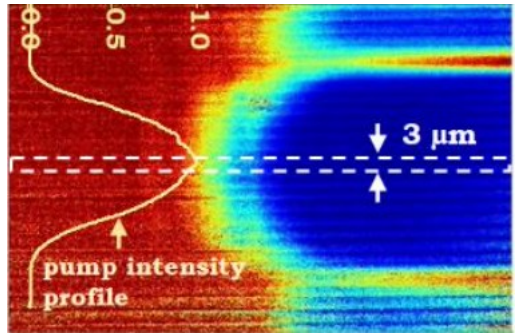
Politecnico, Milano

Radiation sources from DLT

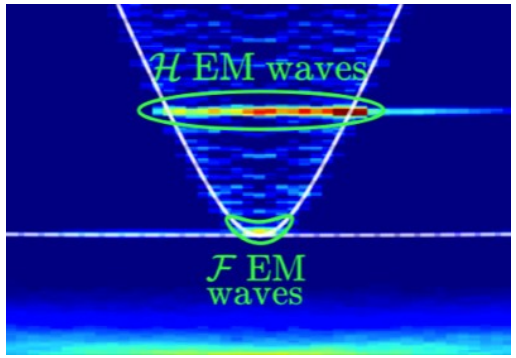


Helmoltz Institute, Jena

Solid to plasma transition

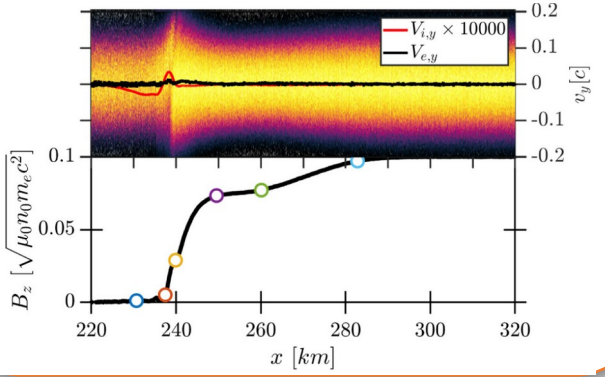


Solar radio-burst



LPP, Ecole polytechnique

Comet environment



Imperial College London

Collisionless shocks & Dark Matter

University of California

Les contributeurs principaux

MAISON DE LA SIMULATION

Smilei)

Project coordinator: Arnaud Beck
Software architect: Charles Prouveur

Community Management Frédéric Perez Francesco Massimo	**Python interface** Frédéric Perez
GPU porting Charles Prouveur Etienne Malaboeuf Olga Abramkina Arnaud Beck Frédéric Perez	**Core performance** Charles Prouveur Arnaud Beck Mathieu Lobet
Documentation Frédéric Perez Charles Prouveur Arnaud Beck Francesco Massimo Mathieu Lobet	**Validation** Arnaud Beck Frédéric Perez Charles Prouveur
Numerical Methods Arnaud Beck Francesco Massimo Guillaume Bouchard	**Additional physics** Frédéric Perez Mathieu Lobet Francesco Massimo

Smilei in a nutshell

2013
Start of the project*

2014
Gitlab
release to co-dev

2016
1st physics studies & large scale simulations
Github

2018
Reference paper

*objective: develop the first open-source PIC code harnessing new paradigms of high-performance computing

Open-source & Community-Oriented

documentation • chat • online tutorials • post processing & visualization
training workshops • summer school & master trainings • issue reporting

Multi-Physics & Multi-Purpose

advanced physics modules: geometries, collisions, ionization, QED
broad range of applications: from laser-plasma interaction to astrophysics

High-performance

C++/Python • MPI/OpenMP/OpenACC/CUDA/HIP • SIMD • HDF5
designed for the latest architectures

MINISTÈRE
DE L'ENSEIGNEMENT
SUPÉRIEUR
ET DE LA RECHERCHE
Liberté
Égalité
Fraternité

Ouvrir la science !

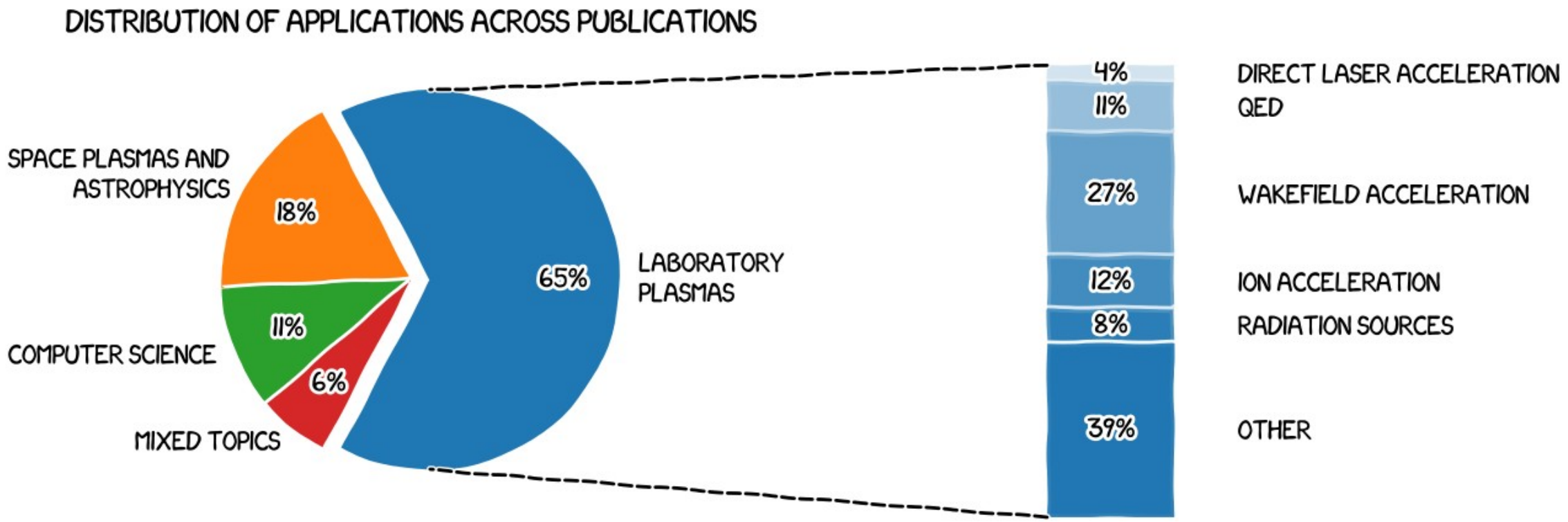
Dedicated to Open-Science !)

PRIX SCIENCE OUVERTE DU LOGICIEL LIBRE DE LA RECHERCHE 2023

CATÉGORIE SCIENTIFIQUE ET TECHNIQUE

Smilei

« Smilers » scientific production



Clearly, our expertise does not cover the range of applications Smilei is used for !

A project anchored in the French & European HPC landscape

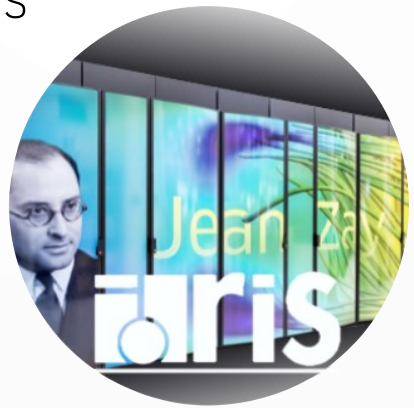
Integration in the French & European HPC landscapes

GENCI
Le calcul intensif au service de la connaissance

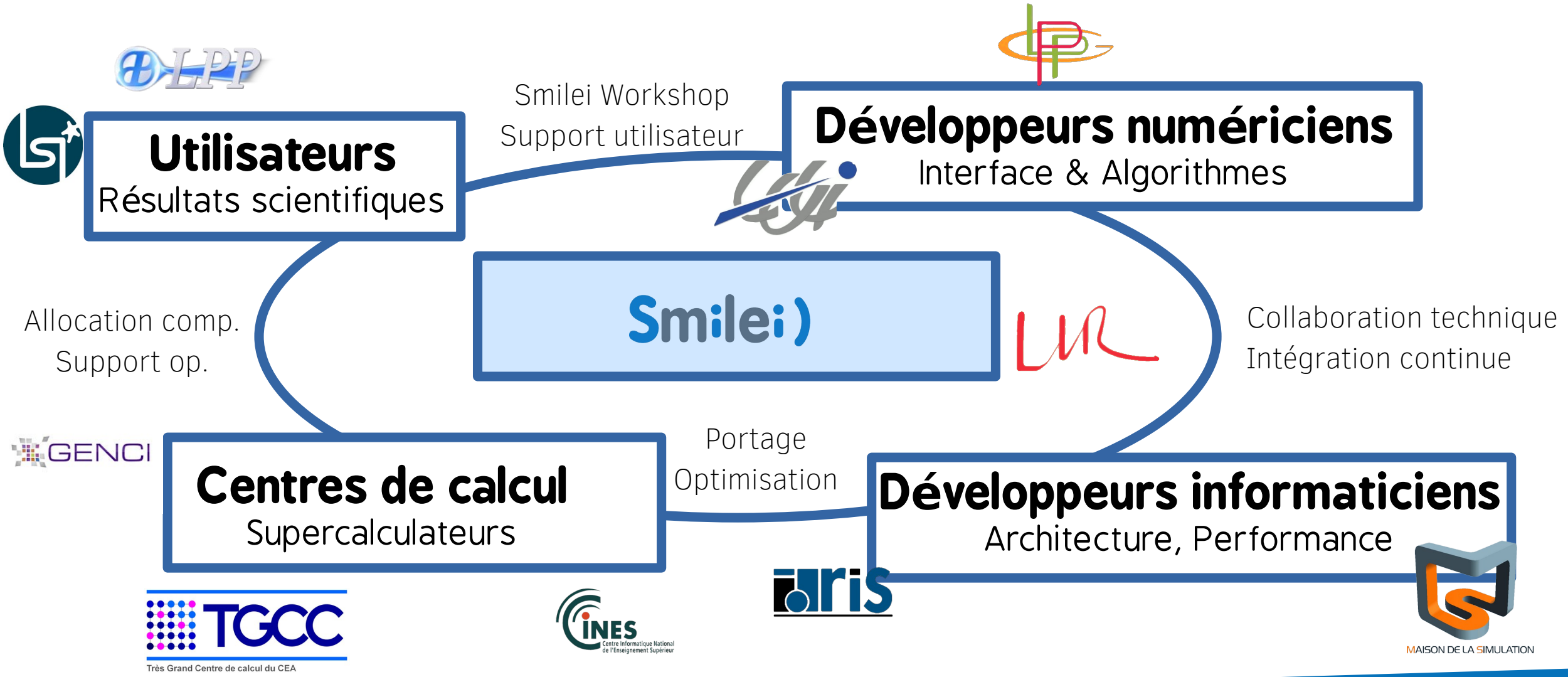
- running on all super-computers in France and many in Europe
- 10s millions computing hours every year via GENCI & PRACE/EuroHPC
- GENCI technological survey
- French Project NumPEX, Exascale project

Special/early access to various machines

2015 IDRIS/Turing BlueGene-Q
2016 CINES/Occigen
2018 TGCC/Irene-Joliot-Curie
2019 IDRIS/Jean Zay
2021 RIKEN/Fugaku
2022 CINES/Adastra (GPU)



L'écosystème de Smilei



What is a PIC code supposed to do?

- Simulate a plasma with kinetic effects (not hydrodynamics)
- Neglect particle-particle interactions (collisions)
- Electromagnetic effects (not electrostatic)

Distribution function

$$f_s(t, \mathbf{x}, \mathbf{p})$$

Vlasov equation

Mean force

Mean distribution

$$\partial_t f_s + \mathbf{v} \cdot \nabla f_s + \mathbf{F} \cdot \nabla_p f_s = (\partial_t f_s)_{\text{collisions}}$$

Maxwell equations

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0} \qquad \partial_t \mathbf{E} = -\frac{1}{\epsilon_0}\mathbf{J} + c^2 \nabla \times \mathbf{B}$$

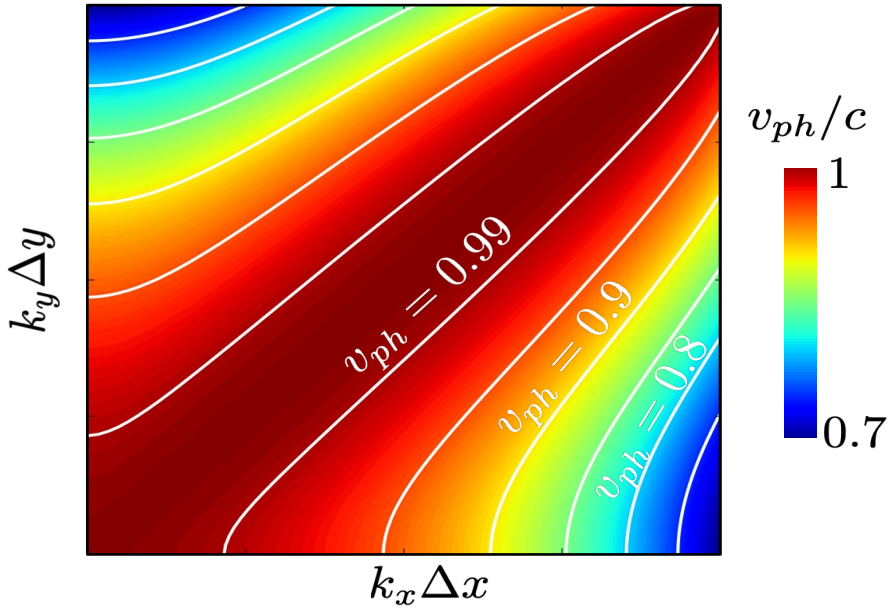
$$\nabla \cdot \mathbf{B} = 0 \qquad \partial_t \mathbf{B} = -\nabla \times \mathbf{E}$$

The numerical vacuum is dispersive and anisotropic !

FDTD equations + search for wave-like solutions

➡ **Dispersion relation**

$$\Delta t^{-2} \sin^2(\omega \Delta t/2) = \sum_{a=x,y,z} \Delta a^{-2} \sin^2(k_a \Delta a/2)$$



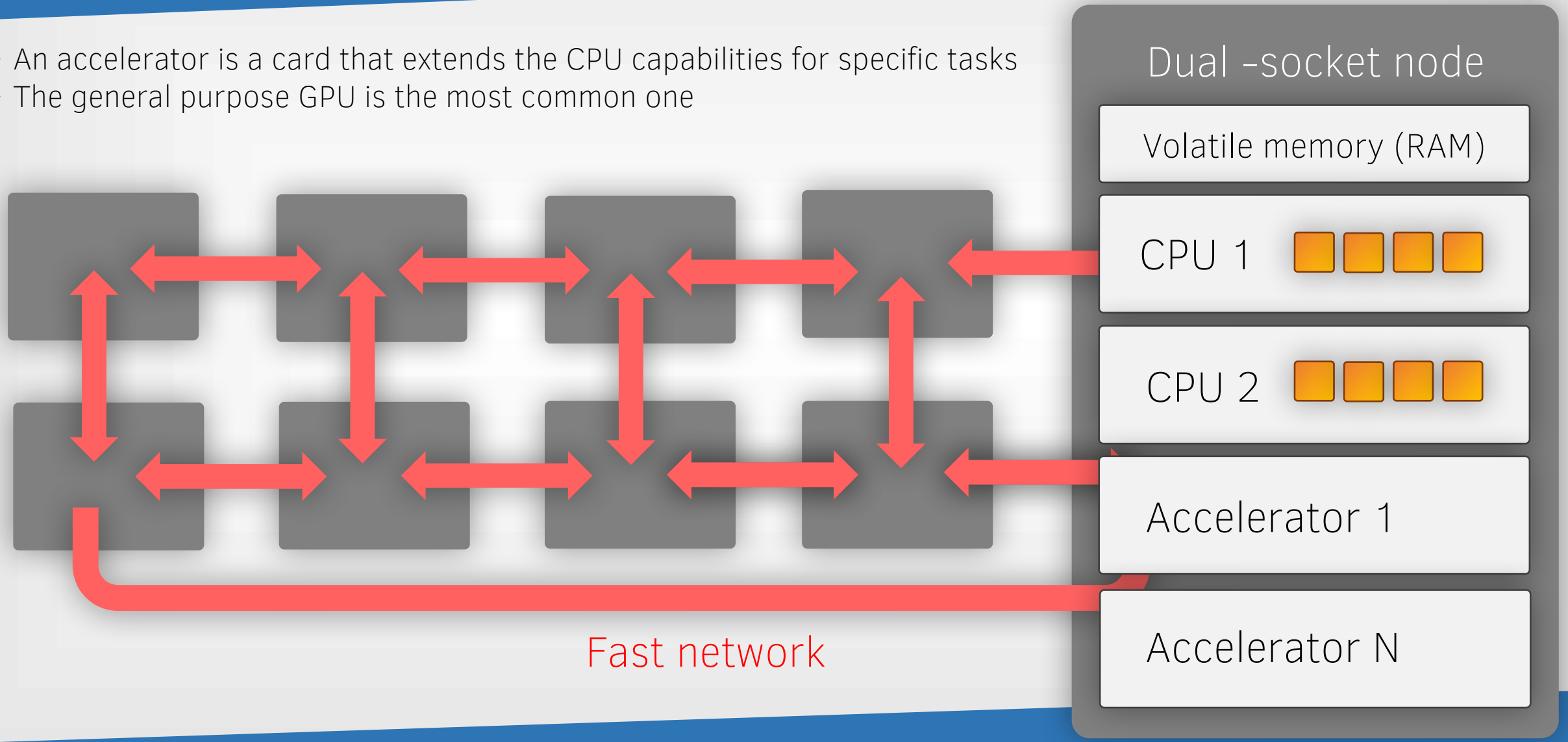
Dispersive

⬇

Numerical Cherenkov radiation

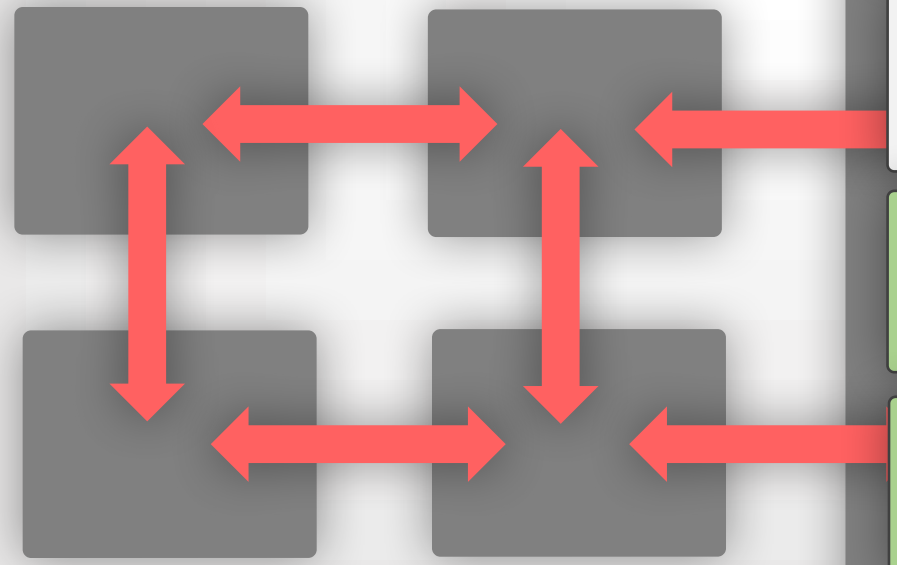
Super computing in a nutshell

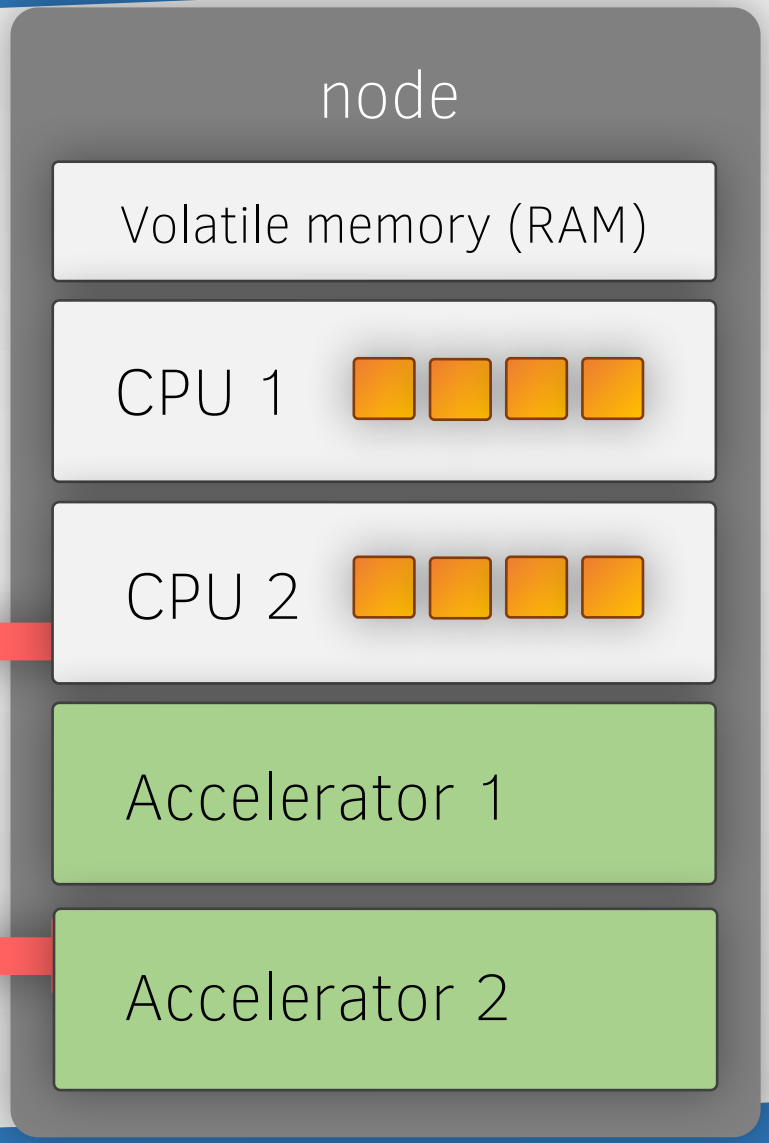
- An accelerator is a card that extends the CPU capabilities for specific tasks
- The general purpose GPU is the most common one



Different parallelism levels to handle

Inter-node parallelism: rely on a very efficient network

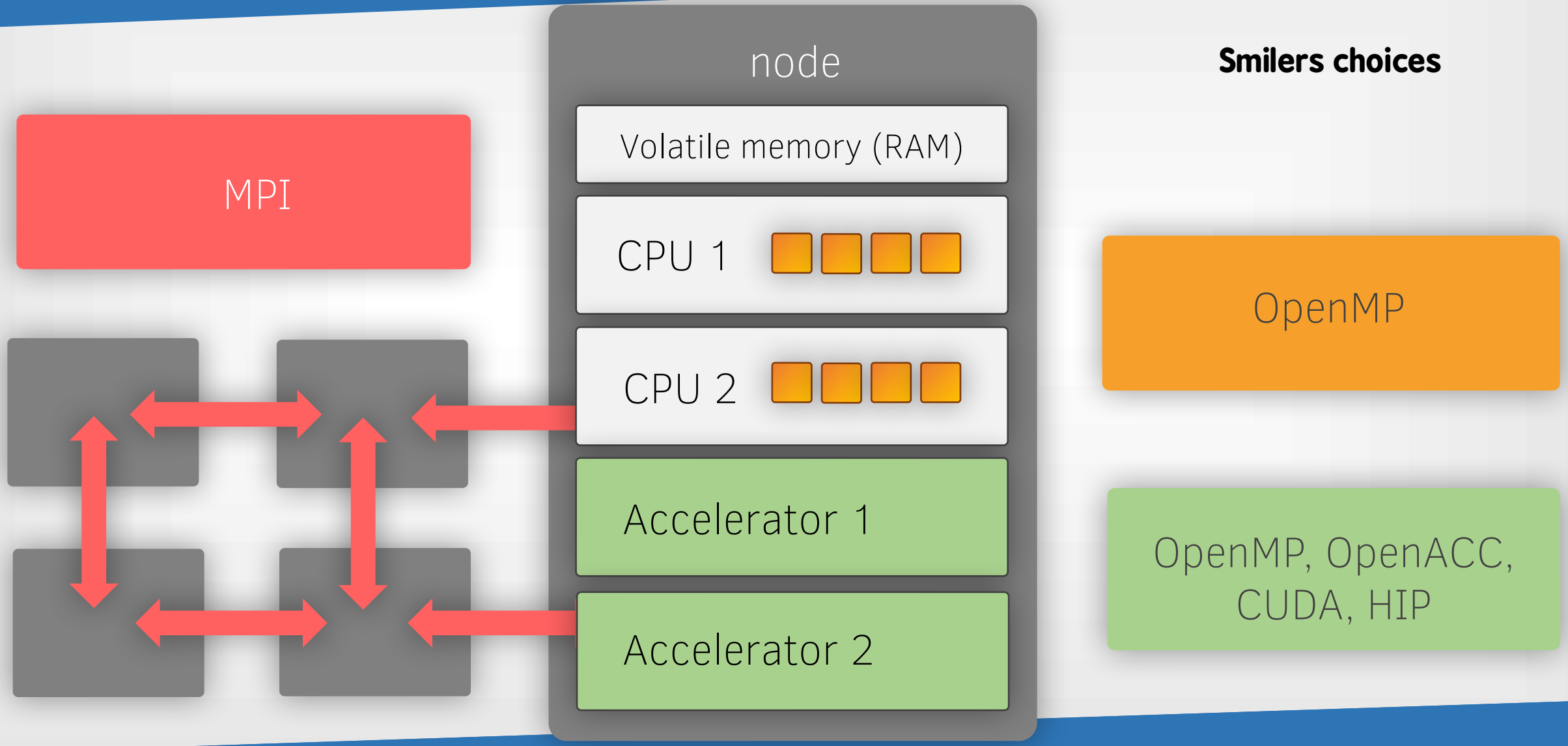




Intra-node parallelism: how to deal with all the cores efficiently

Heterogeneity: nodes with different types of computing units

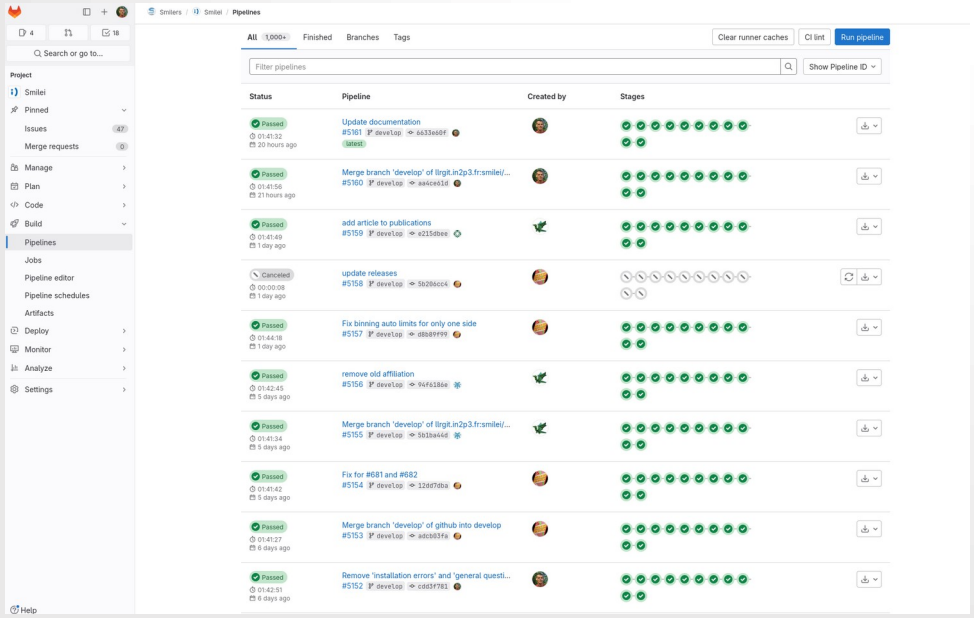
Many software technologies adapted to each level

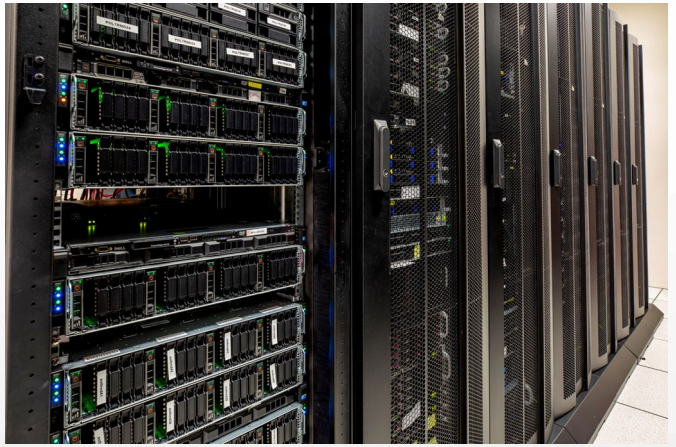


Major contributions from LLR

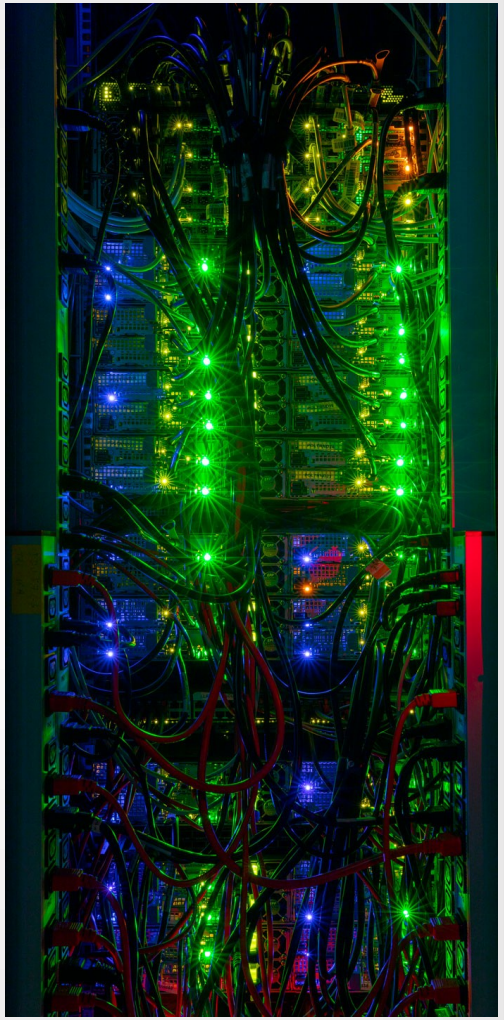
LLR hosts the dev-team meeting ~ 1 per month.

LLR hosts and administrates the development cluster
Tornado, the main git repository and continuous integration
(M. Mellin, A. Garcia)



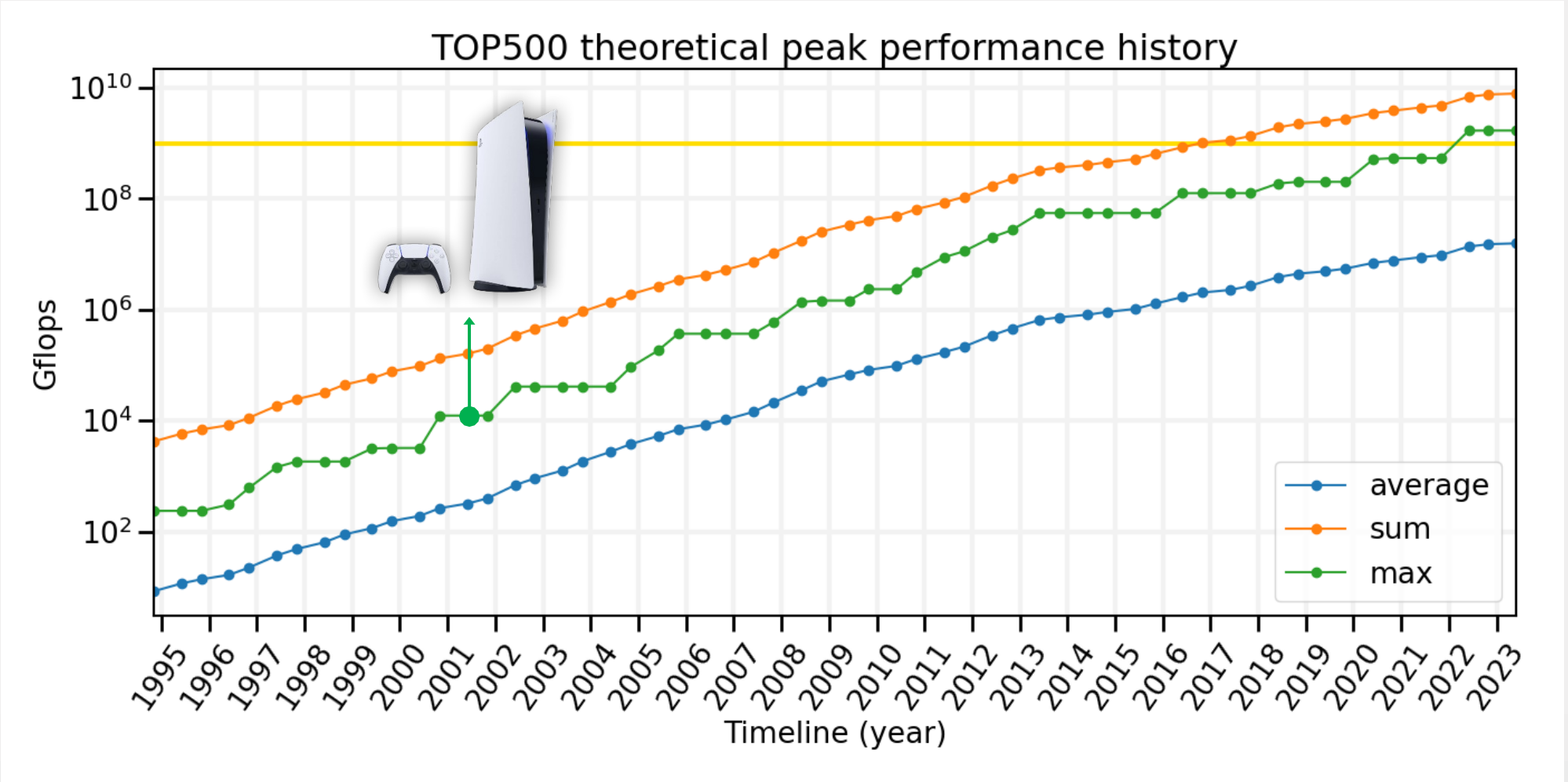


Funded by X, CNRS N&P and LLR

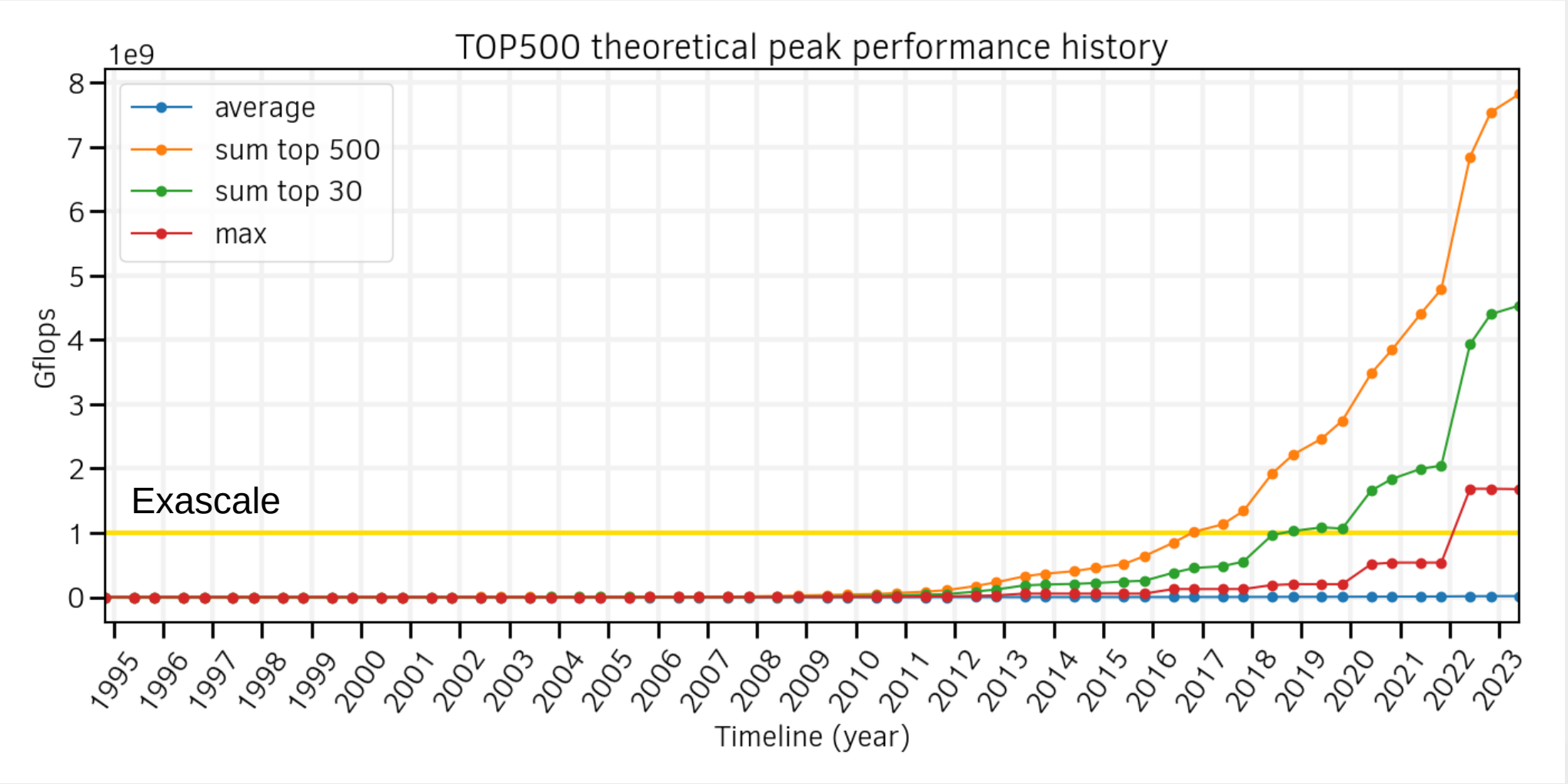


Pictures : S. Pieyre

Evolution of computing power



Evolution of computing power

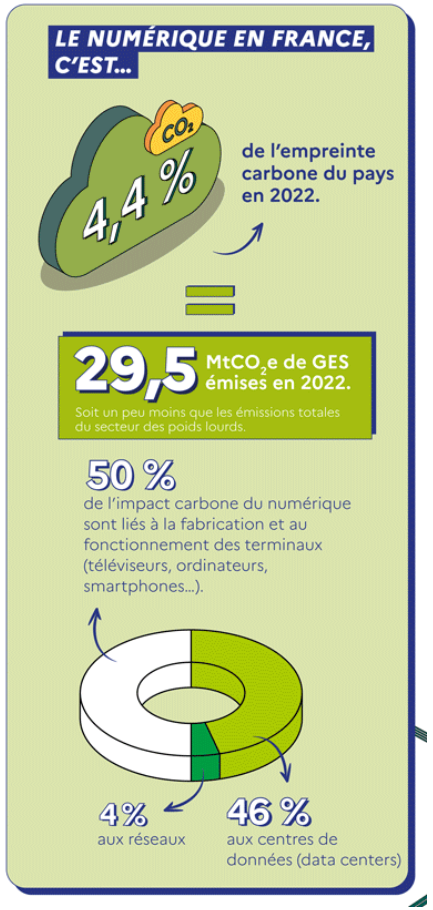


The environmental challenge

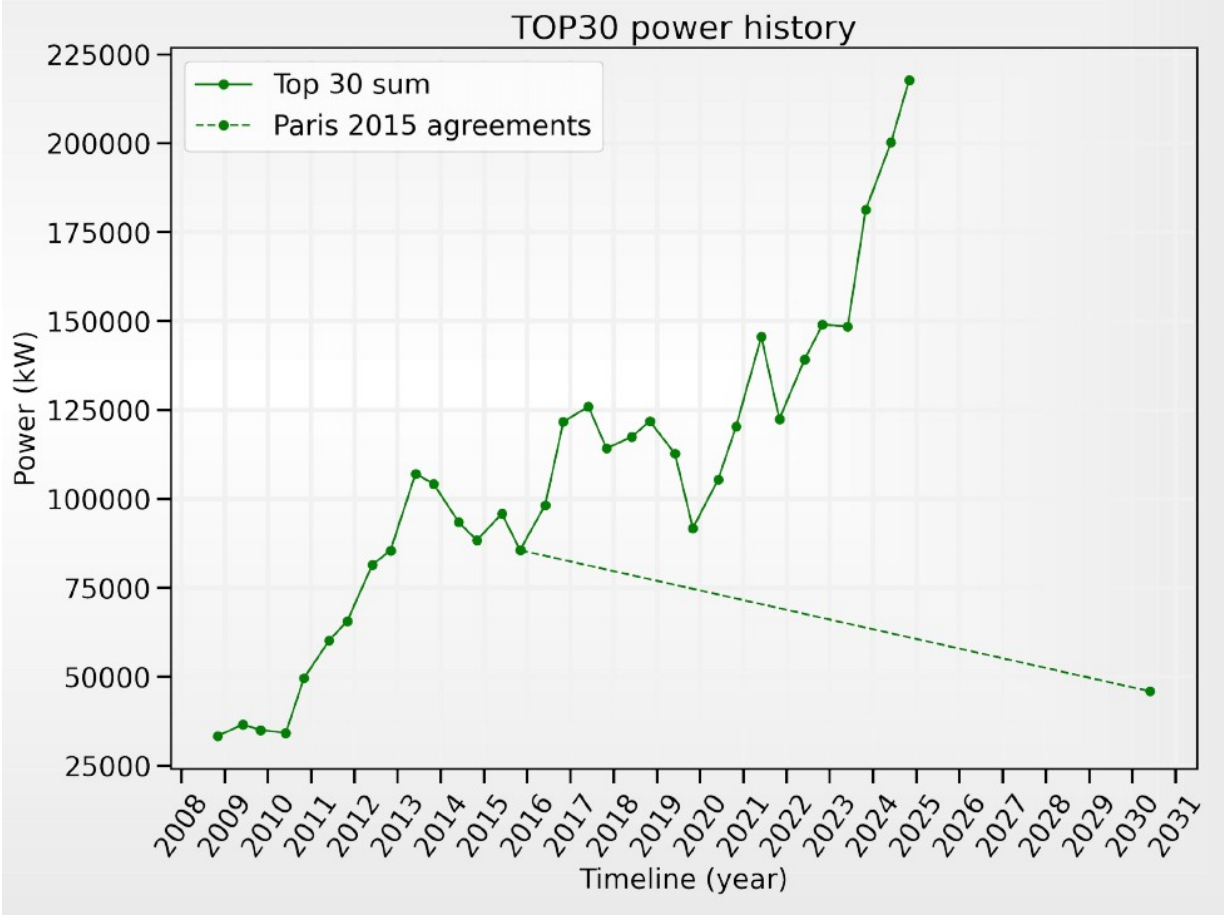
En 16 ans :

- la **performance par W** a été multipliée par **113**
- la **puissance crête** a été multipliée par **905**
- la **consommation** électrique totale a été multipliée par **8**

IDRIS
P.-F. Lavalée

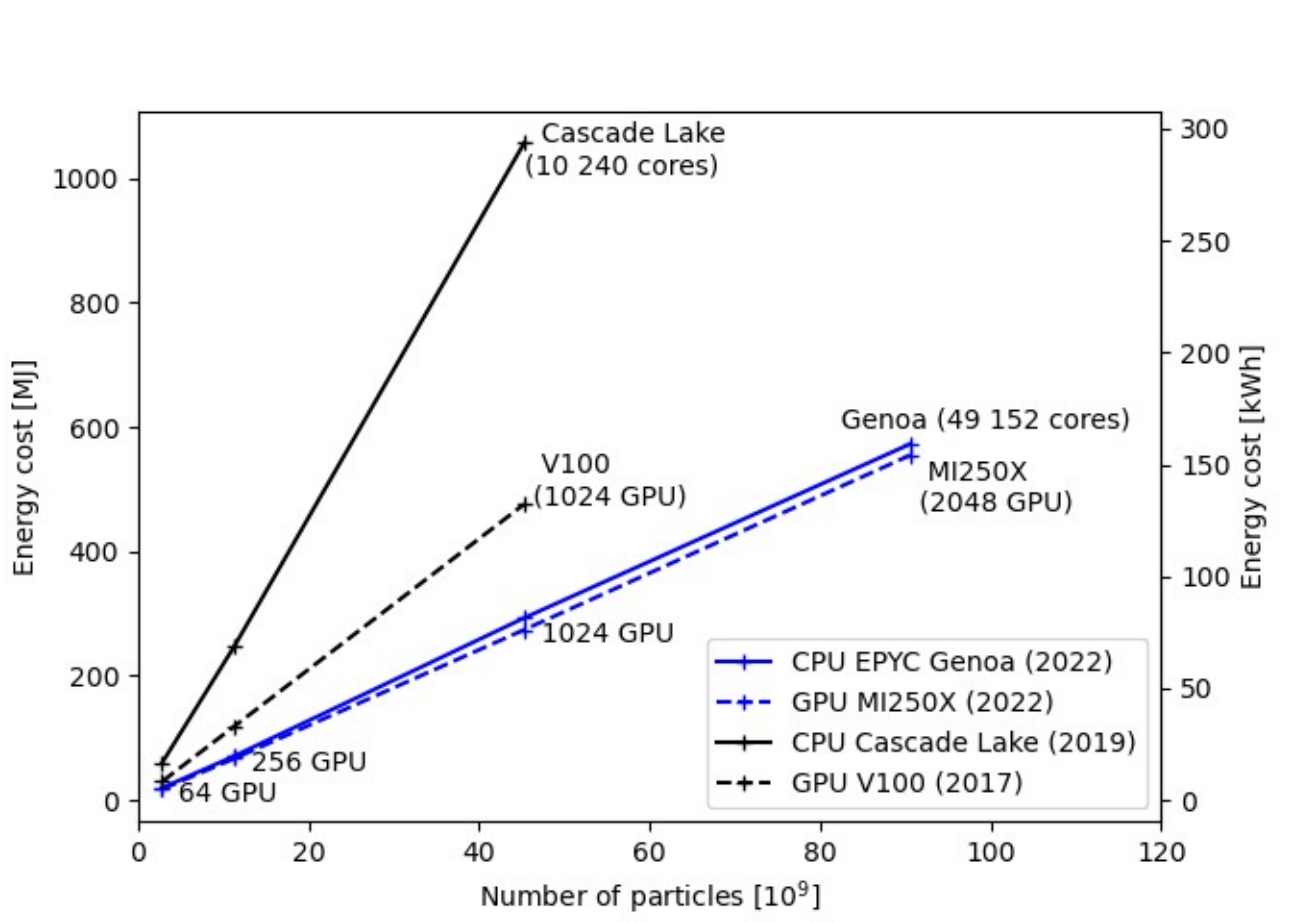


ADEME, Etude impact Environnementale du numérique en France



TOP 500
Power history of the top 30 supercomputers

Energy: the real metric for software performance



- Weak scaling: the resources scale with the problem size.
- The configuration is optimized for each system.
- Results may differ with another physical case.
- The energy cost depends linearly on the size.
- Be aware of the “Rebound effect”.

Thanks & Keep Smileing !

Contributing labs, institutions & funding agencies