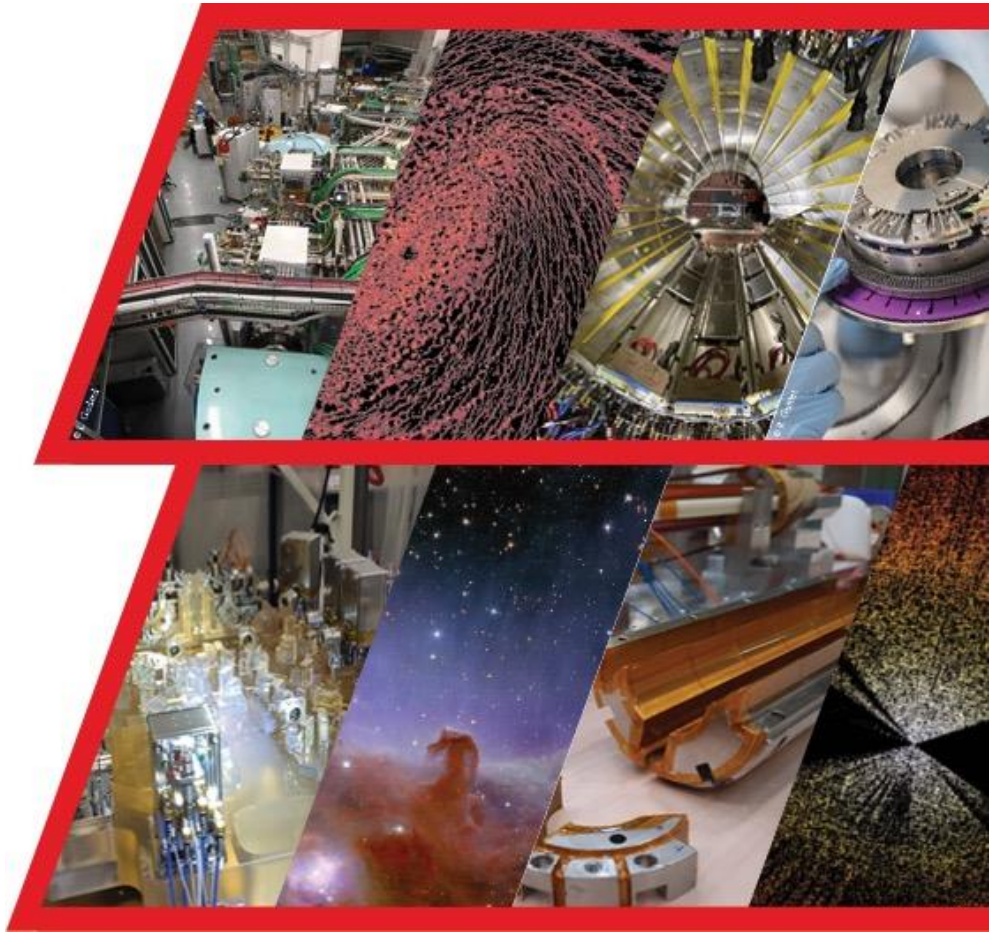
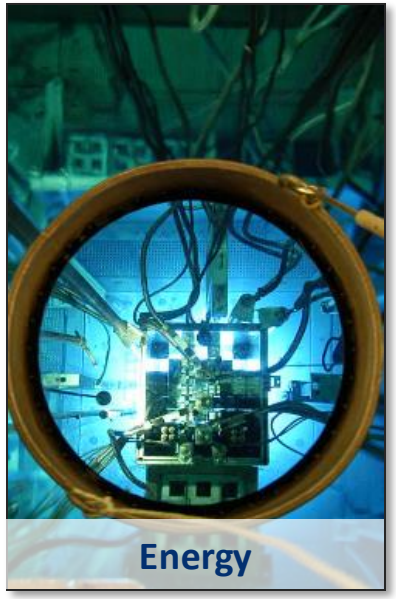
IRFU

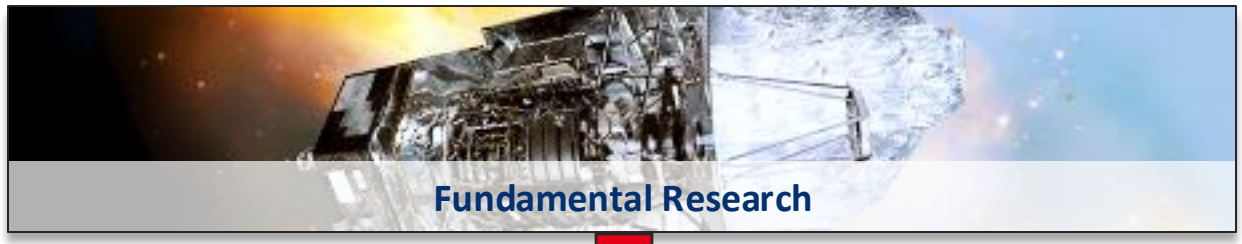
Institute for Research into the Fundamental laws of the Universe

Andrea Formica



CEA – The French Alternative Energies and Atomic Energy Commission





cea irfu Institute for Research into the Fundamental Laws of the Universe

21000 employees

5.8 billion euros

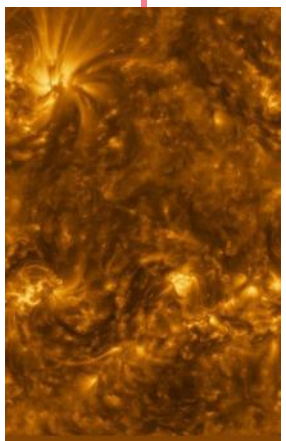
> 5000 publications

> 450 European projets

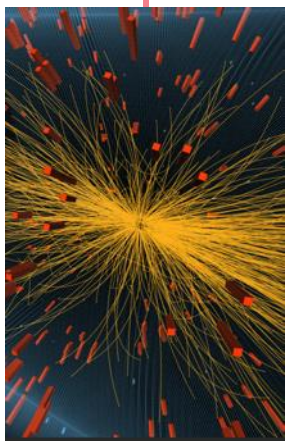
IRFU

cea irfu — Institute for Research into the Fundamental laws of the Universe

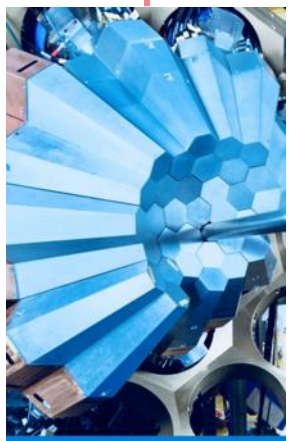
Management Office



DAP
Astrophysics



DPHP
Particle Physics



DPHN
Nuclear Physics

GANIL
Heavy Ion National Accelerator

DEDIP
Detectors
Electronics
Computing

DACM
Accelerators
Cryogenic
Magnets

DIS
System Engineering

1050
- 671 permanent
- 268 fixed-term
- 111 PhD students

1000/an

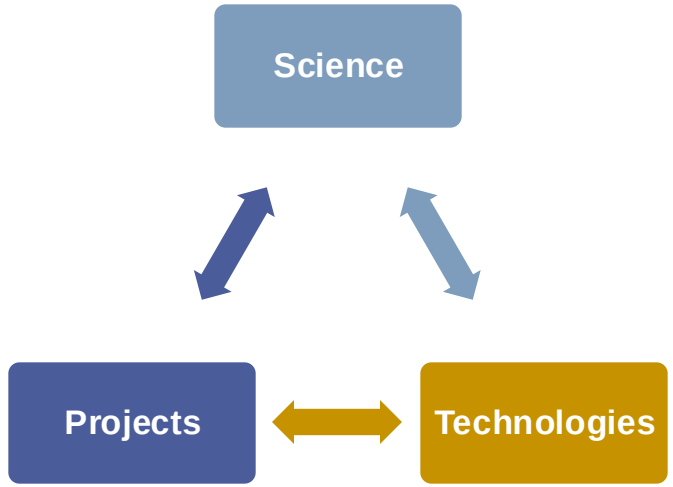
26 ERC
(10 ongoing)

Missions of IRFU

- **Carry out technological and fundamental research** within the framework of CEA's missions, in order to explore the fundamental laws of the universe, from the smallest scales (elementary constituents, nuclear matter) to the largest (energy content and structure of the universe)
- **Apply our technological innovations** to major national or international projects: MRI or fusion magnets, accelerators and neutron sources, medical imaging, etc.

Thanks to its size and the strong integration of its departments, IRFU has the :

- **Ability to cover the entire research chain**
  - Theory, experiment proposal, simulation, design, construction, operation, data analysis, phenomenology and communication
- **Ability to manage large, innovative and complex projects**
  - Accelerators, magnets, detectors

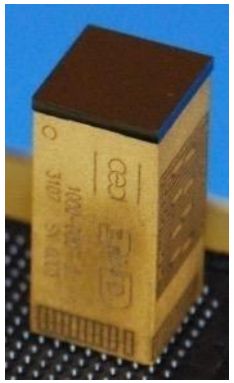


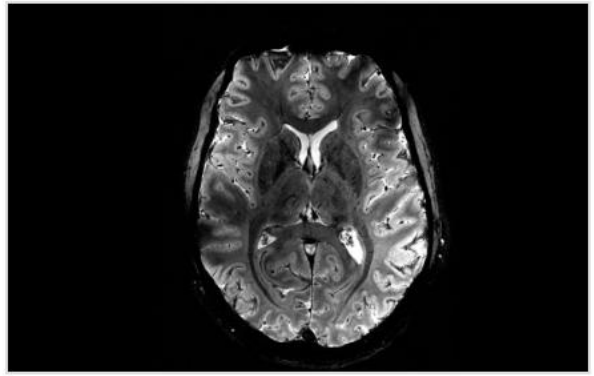
Platforms

COMPUTING	SPACE
3 HPC clusters 13000 cores, 2500 Mh HS06/y **LHC Grid** (tier 2) 9000 cores, 500 Mh HS06/y	**Clean rooms** iso5-8 Instrumentation **Integration** and test halls

MAGNETS ACCELERATORS	DETECTORS
Synergium 25000 m^2 Clean rooms iso4-5 Integration halls and test cryostats	**Clean rooms** incl. Ciclad iso7 130m^2 and iso5 50m^2 **Integration** and test halls

Application of our technologies to large national and international projects



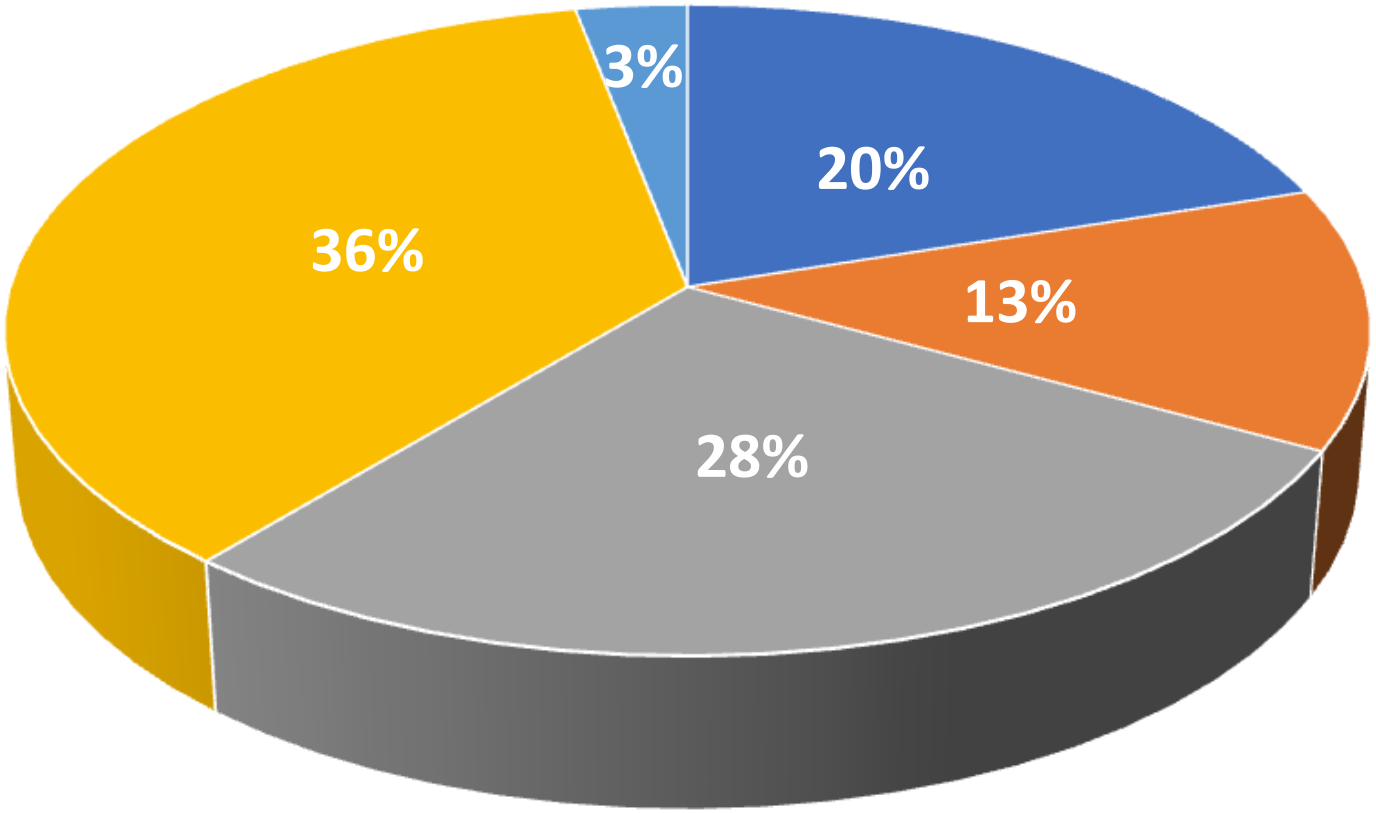


© CEA

2 Avril 2024 -> Le CEA dévoile pour la première fois au monde, une série d'images de cerveau obtenue avec le scanner IRM Iseult, doté d'un champ magnétique inégalé de 11,7 teslas.

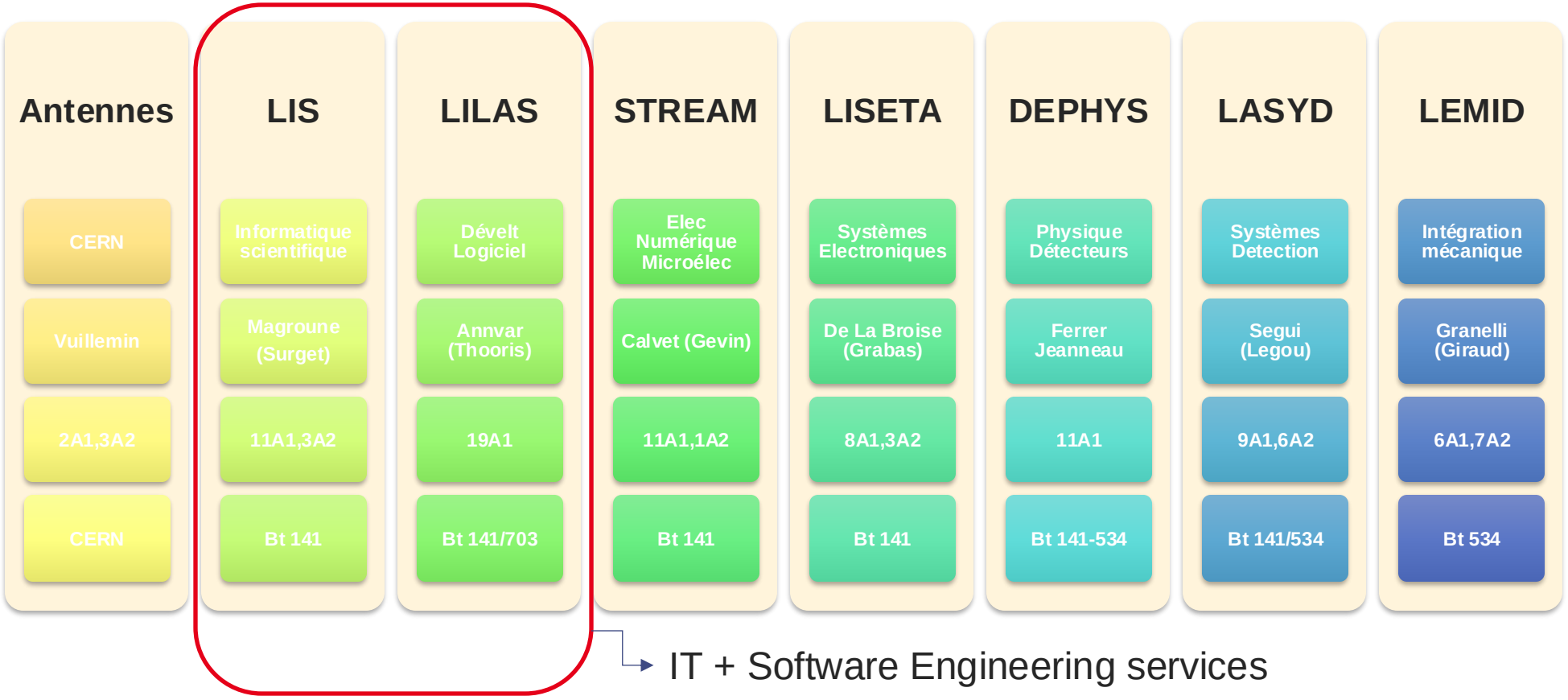
Fusion : IFMIF-EVEDA/DONES, JT60-SA
Light sources: SOLEIL, E-XFEL
Neutrons sources: ESS, SARAF, ICONE
Health : MRI (Iseult 11.7T magnet), TOF-PET

Human Resources per scientific field



2017-2022
(w/o GANIL)

DEDIP: organizational chart



108 Permanents : 81 A1 - Ingénieurs/Chercheurs ; 27 A2 - Techniciens et Administratifs
~ 29 non permanents (Thésards, Postdoc, CDD, Apprentis)

DEDIP: LIS/LILAS

LIS

Team for IT services and operations

Windows/Unix users

Computing clusters for prototyping, data analysis and simulations

CLOUD
DevOps

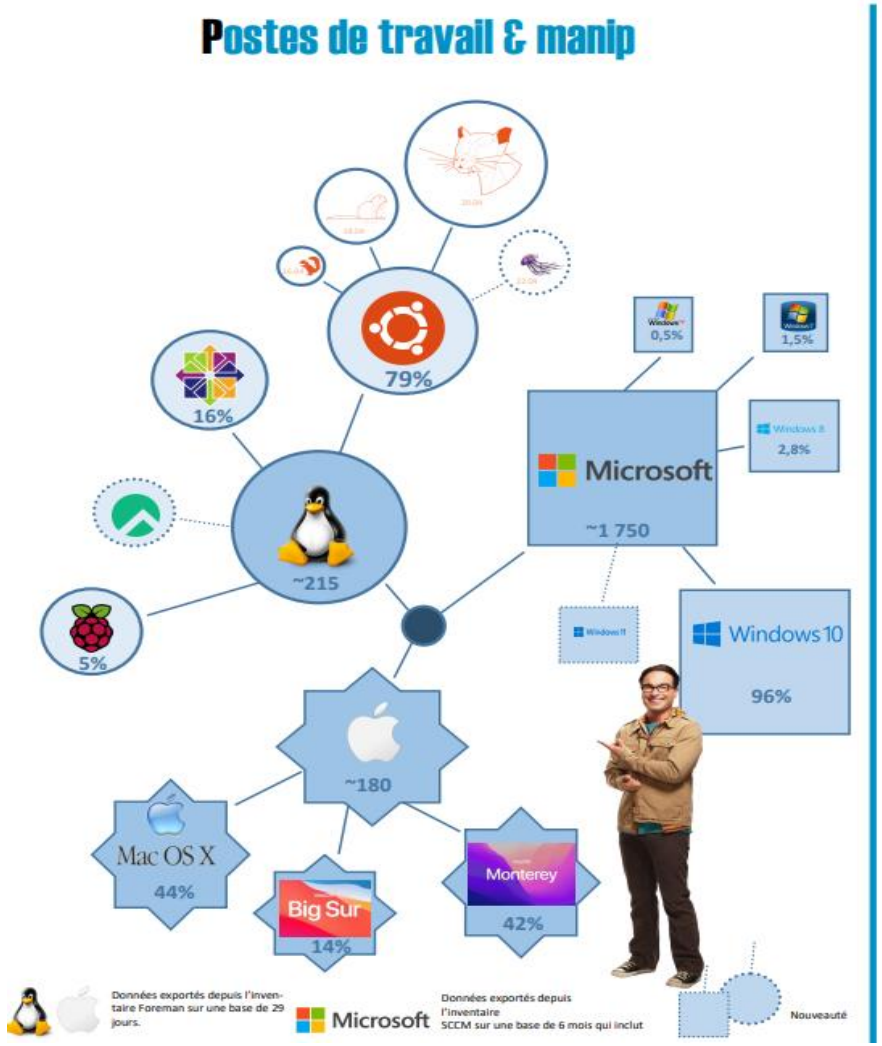
LILAS

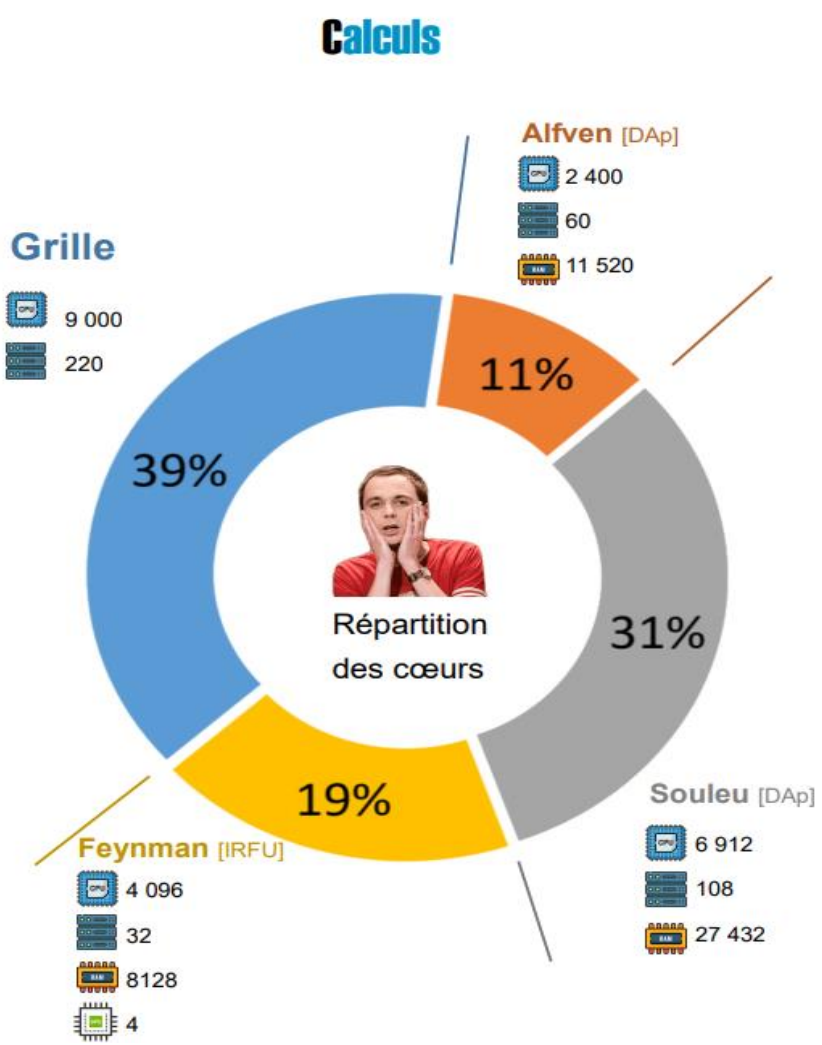
Team for Science related applications developments

Wide range of expertise in many areas (from DAQ to analysis)

IRFU projects : Astrophysics, Particle Physics and Nuclear Physics

IT infrastructure

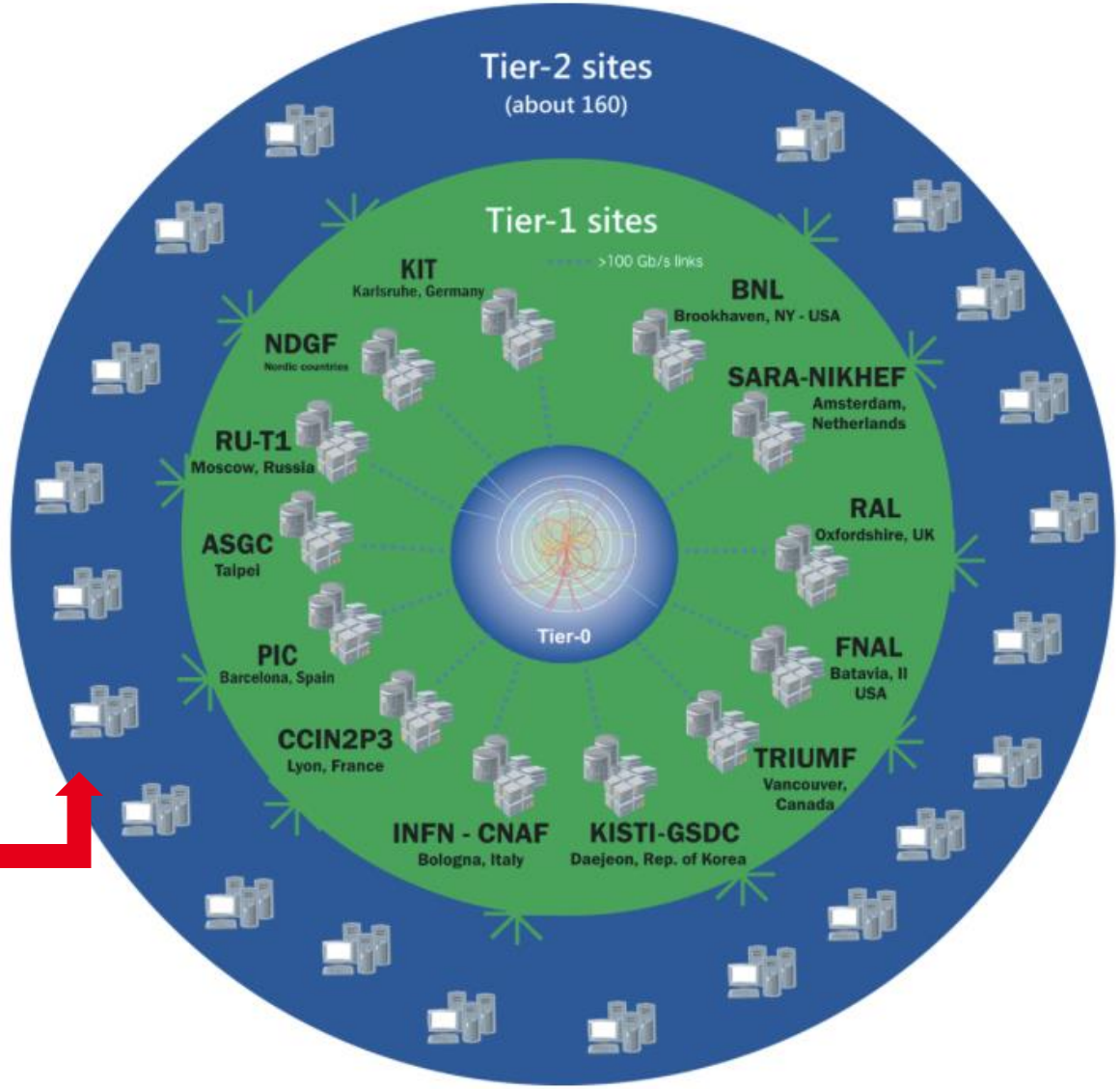




~120 servers, 6 PB data storage, >1000 users

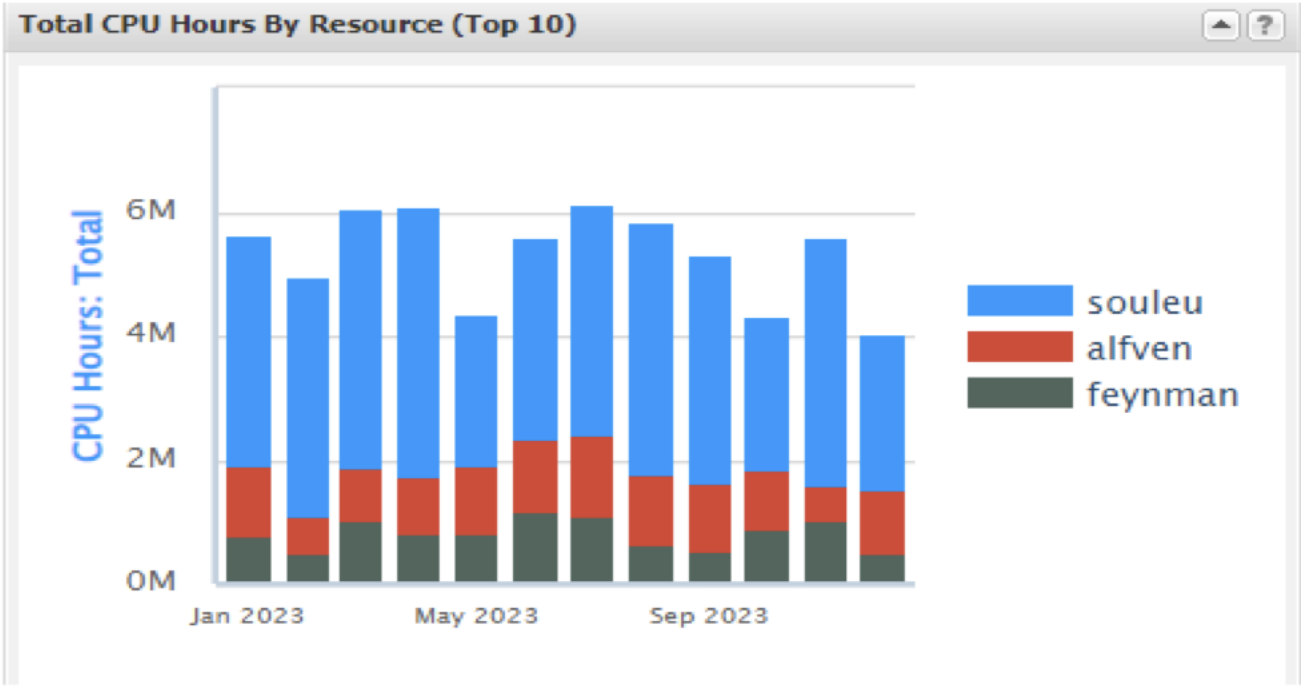
Computing: GRIF

- **Contribution to WLCG**
  - Joint effort **: IJCLab, LPNHE, LRR** and IRFU
- **GRIF pledge for 2024 (IRFU is about 40%)**
  - CPU: 167 kHS23
  - Disk: 15 PB
- Experiments:
  - LHC, CTA, …



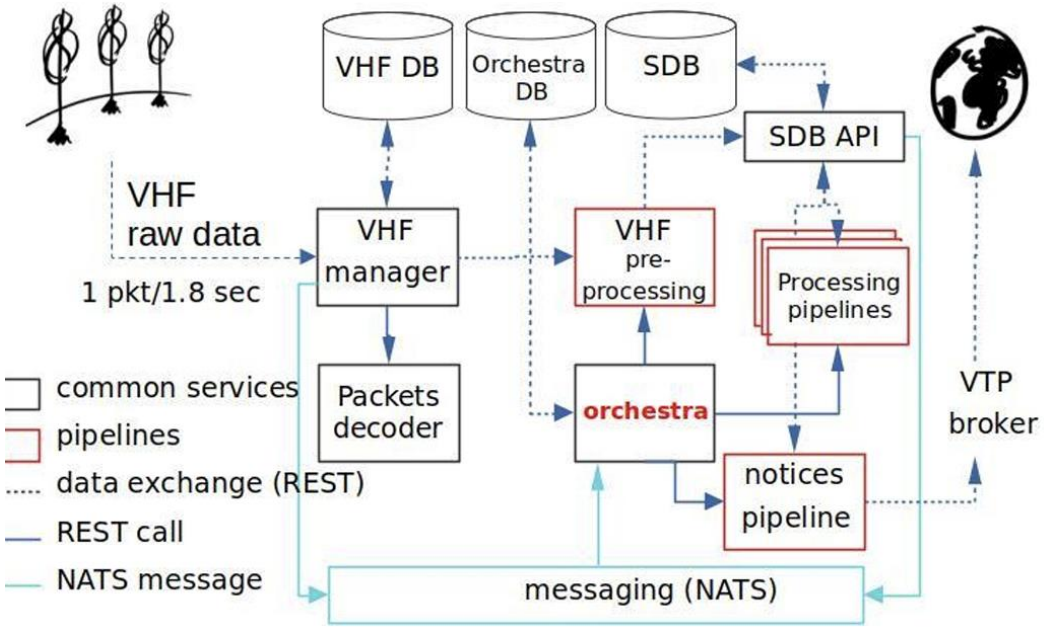
Computing: HPC, HTC, ...

- **computing clusters (souleu, alfven, feynman)**
  - HPC, HTC
    - CentOS7, Rocky8/9, Debian
  - Serving local users (> 150)
- **Storage**
  - DAS [2 PB]
  - NAS [5 PB]
- Main purpose
  - Local analysis
  - Prototyping for larger infrastructures



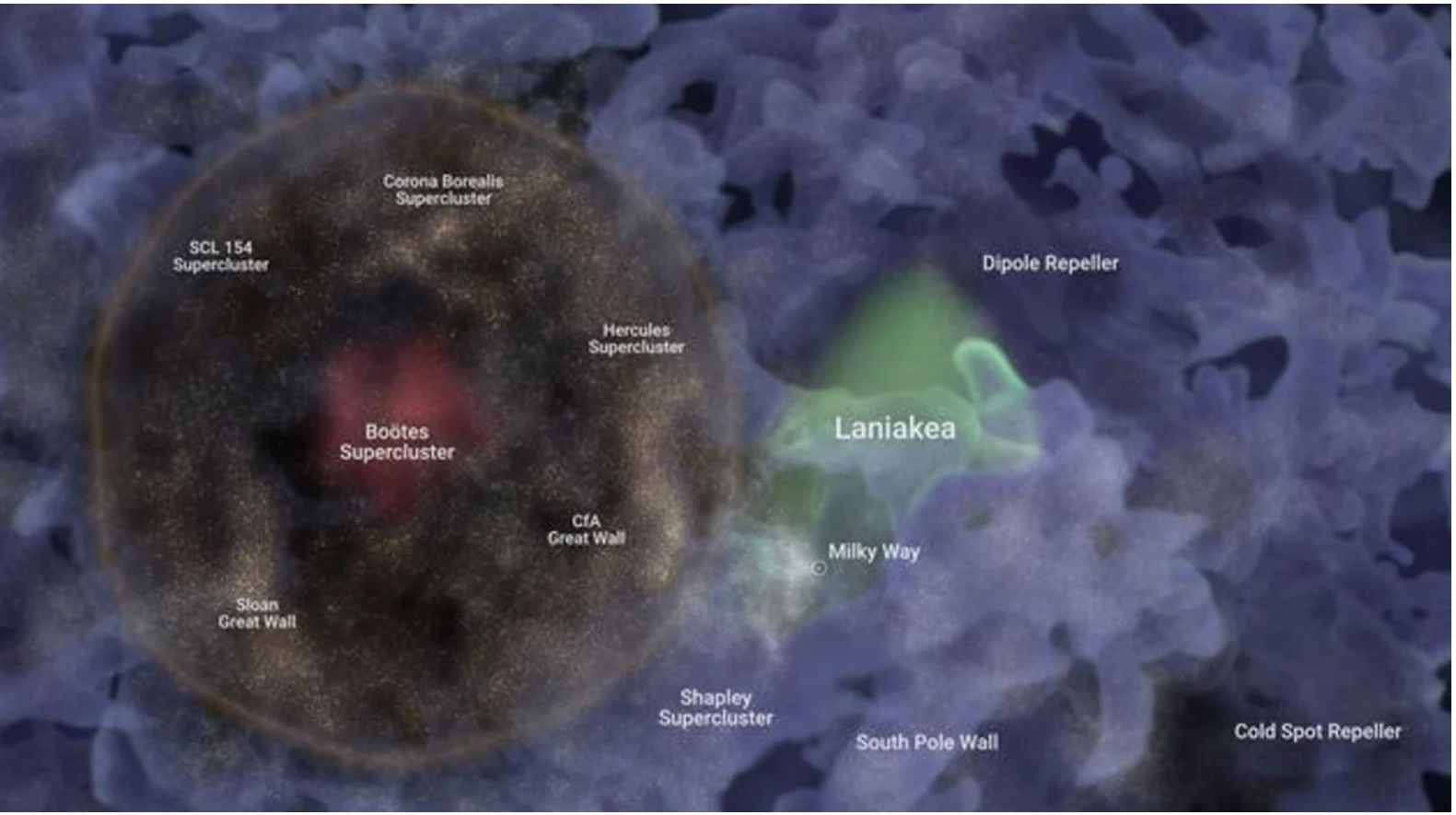
Applications: distributed computing, monitoring

- **Developing architectures for science data processing**
  - Distributed architectures: REST, messaging systems
  - Cloud based deployments
  - Databases
  - Web interfaces
  - Data processing pipelines
- **Application domains in astrophysics and particle physics experiments**
  - SVOM: FSC infrastructure (@ CC-IN2P3 and IJCLab)
  - ATLAS: conditions DB infrastructure for Run4
  - ATLAS: muon spectrometer alignment system
  - CMS: ECAL calibration



Applications: Astrophysics simulations

- **Developments for Astrophysics simulation**
  - Generic toolbox for AMR simulations
  - Distributed applications for post processing and access to simulated data
  - Data visualization
- **Application domains**
  - Dyablo: framework for Computational Fluid Dynamics (CFD) simulations using Adaptive Mesh Refinement (AMR)
  - Galactica: generic platform providing access to computational astrophysics simulation datasets in a wide range of fields (e.g. solar physics, star-planet interactions, star formation, galaxy formation, galaxy mergers, cosmology)
  - **SDVision**: visualization tool for cosmography, using catalogs of galaxy positions and velocity (Cosmicflows Project)



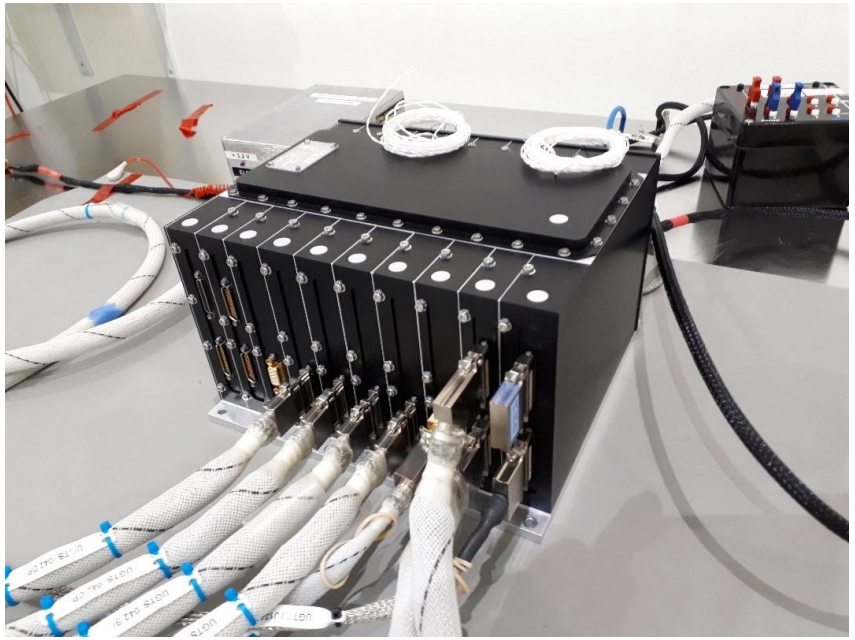
Ho'oleilana, a Billion-Light-Year-Wide Bubble of Galaxies

découverte d'une grande structure cosmologique en forme de coquille sphérique dans la distribution des galaxies. Son diamètre de 1 milliard d'années-lumière suggère qu'elle pourrait être le fossile d'une onde acoustique baryonique, produite dans le plasma primordial de l'univers jeune.

Ref: *Ho'oleilana: An Individual Baryon Acoustic Oscillation?* R.B. Tully, C. Howlett, D. Pomarède, The Astrophysical Journal, **954** (2023) 169

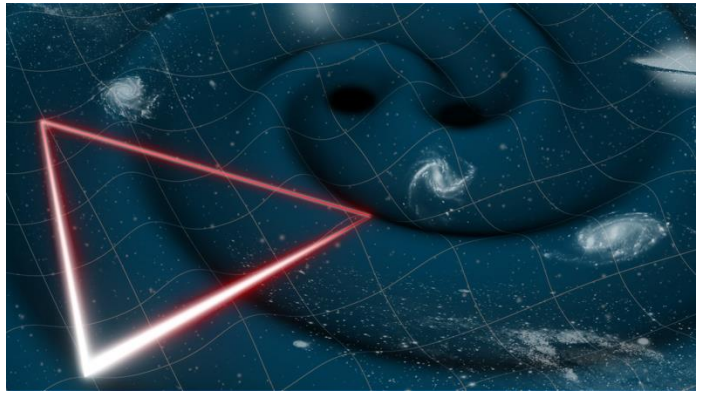
Applications: DAQ and embedded systems

- **Developing architectures for data acquisition**
  - Readout systems
  - Hardware control systems
  - Identify common patterns in DAQ distributed architectures for fast development
- **Application domains**
  - SVOM: UGTS on-board software
  - CTA: NectarCAM camera control & monitoring software (interface)
  - Mordicus: generic toolbox for DAQ systems

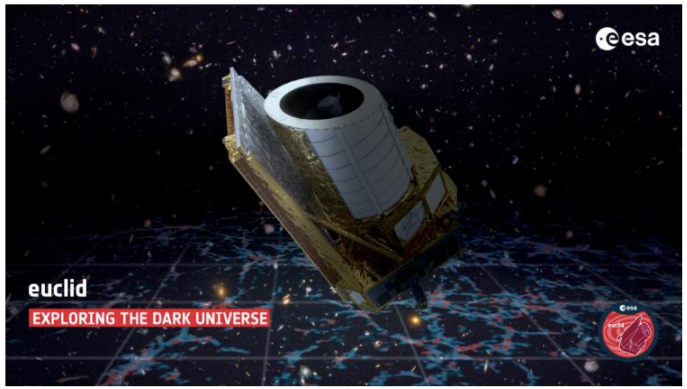


Applications: data pipelines and analysis

LISA :ONDES GRAVITATIONNELLES DANS L'ESPACE



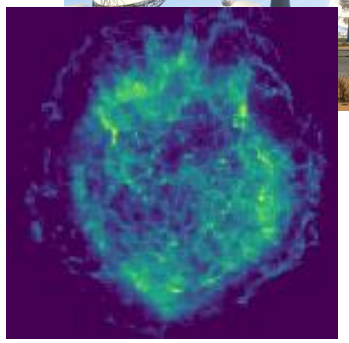
- IRFU responsible of the fast analysis pipeline
- Goal is to detect and characterize GW sources as fast as possible for a EM follow up (MultiMessenger Astronomy)
- Complex analysis: needs gaps and glitches mitigation
- Application of IA is also under study



- R&D on signal processing
- Performant pipelines for Euclid data processing
- Software quality

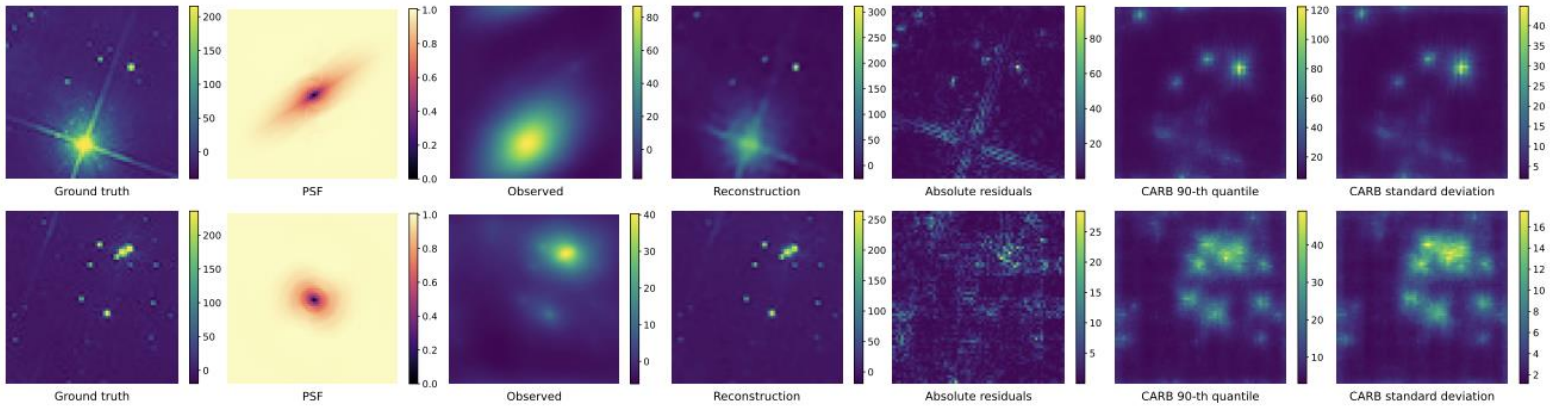
Applications: AI/ML-driven signal processing

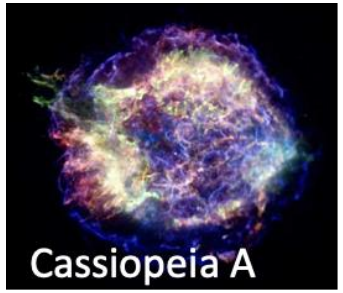
- **Developing cutting-edge signal processing and ML-based methods**
  - Expertise in multi/hyperspectral data analysis
  - ML for signal/image reconstruction, anomaly detection, signal unmixing, …
  - **Uncertainty quantification methods for AI**, avoid using like a black box
  - ML for fast numerical solvers for inference
- **Making AI solutions ready for scientific exploitation**:
  LISA (Laser Interferometry Space array), Athena (X-ray space telescope), SKA (radio-interferometry), nuclear physics (e.g. spectrometry)

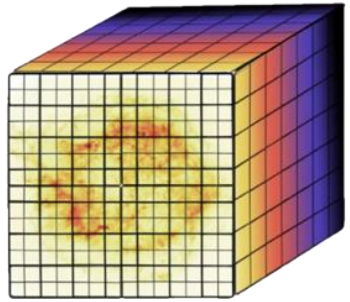


AI for image reconstruction in radio-interferometry

Quantification d'incertitudes pour la reconstruction d'images de radio interférométrie







Hyperspectral image analysis in X-ray spectro imaging

Cloud

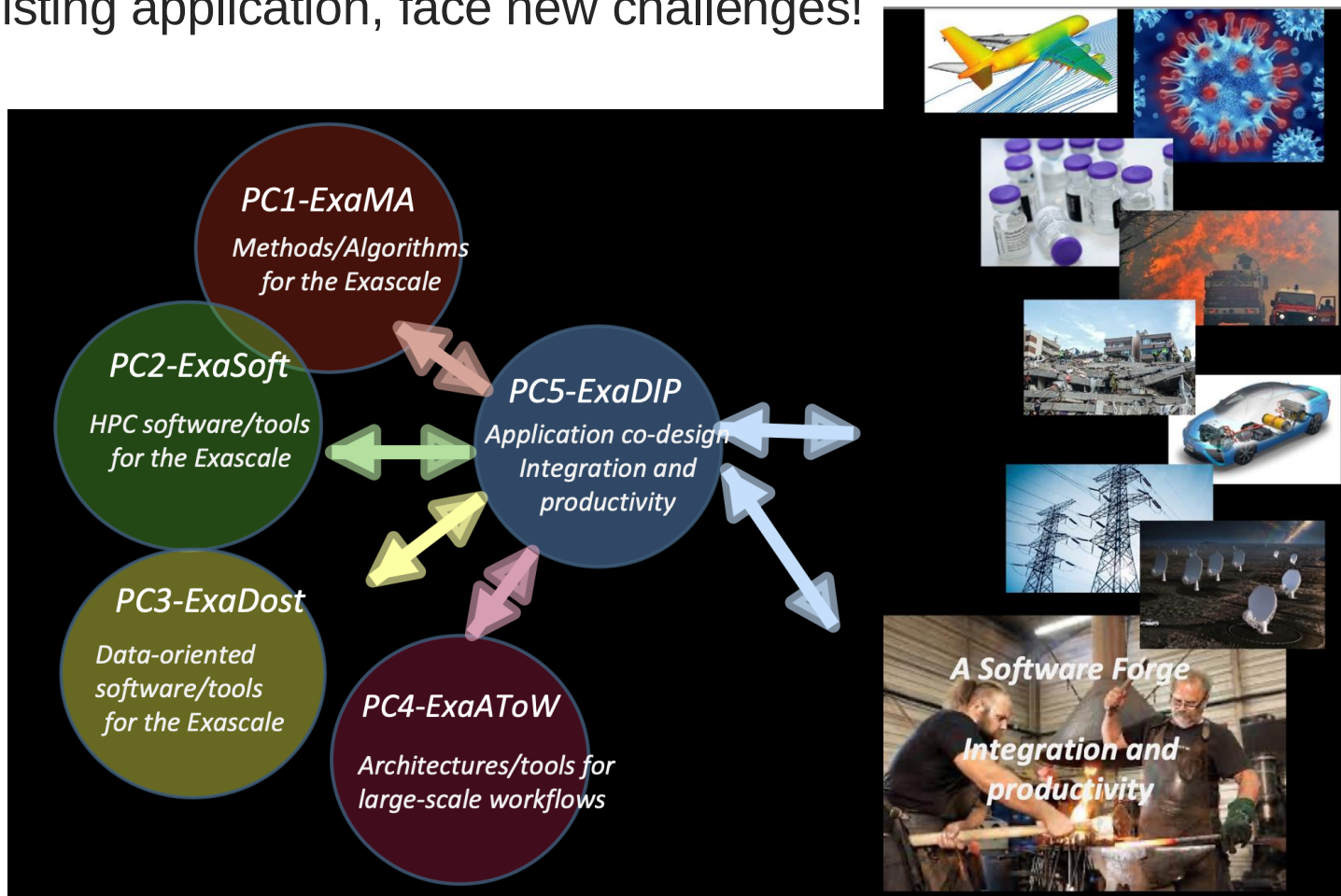
- **DevOps for Computing Infrastructure and Experiments**
  - Joint effort between LIS and LILAS
  - Use the cloud both for internal infrastructure and for physics experiments
    - THE solution for application development cycle and deployment
- **Application for ground segments and others domain**
  - The French Ground Segment of SVOM experiment has been completely designed as a distributed architecture and deployed in a swarm cluster (soon to be migrated to k8s)
  - Computing Centers provide excellent environments for the cloud usage (CC-IN2P3, IJCLab, CERN, …)
  - Many “monitoring” and similar services are becoming more and more consumers of these kind of infrastructures; good practices on the whole development cycle (CI and deployment) are key for a successful application and as well for its maintenance

Numpex : towards hexascale

- **IRFU is a leading partner in the Numpex national project**
  - EuroHPC founds large computing centers for HPC, AI and Big Data
  - Numpex purpose is to be prepared on the software development side
  - Gather community of experts, adapt existing application, face new challenges!

- **Organization**

- **Partners**
  - **CEA, CNRS, INRIA**
  - **15 Universities**
  - **3 Ecoles d'Ingenieurs**
  - **Industry**



Thank you for your attention !

International collaborations

National partners, teaching

Academia

IN2P3
INSU
INP
INSIS

Defense

Industry

- **Integration into the University landscape**
  - DAP is part of the AIM mixed research unit with CEA-CNRS-University Paris-Cité affiliation,
  - IRFU is "*co-tutelle*" of APC mixed research unit in Paris (with CNRS-University Paris-Cité-Paris Observatory),
  - All IRFU departments except GANIL are considered units of the Paris-Saclay University cluster.

- **Teaching duties**
  - Participation at all levels of teaching in Engineering Schools and Universities,
  - Average of 3000 hours/year.