FUSION FOR ENERGY

THE ROLE OF HPC IN BROADER APPROACH ACTIVITIES IN FUSION

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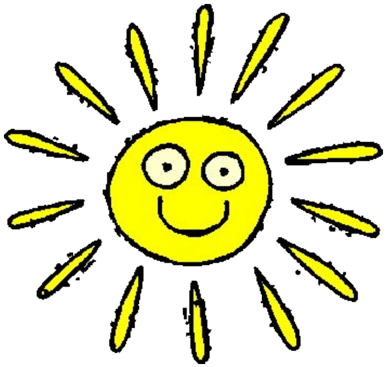
IFERC Project Leader

With particular thanks to François Robin (CEA), and the CEA, EUROfusion and QST teams

Outline



Helios HPC in Broader Approach:

Historical Background

Motivation and goal of the Computational Simulation Center

Phases of procurement and exploitation

- September 2007 - December 2011: Preparation/procurement (phase 1)
- January 2012 - December 2016 : Operation (phase 2)
- January 2017 – 2017-2019: Dismantling and follow-up activities
- 2020 and the future

Scientific Output

Importance of HPC for F4E ITER construction activities

Summary: General Impact for the fusion community and outlook

HPC in Broader Approach

The HPC Helios operated for 5 years between 2012 and 2017 in the International Fusion Energy Research Centre (IFERC) in Rokkasho, Aomori prefecture, in the IFERC Computer Simulation Centre (CSC) as part of the Broader Approach agreement

Why place an HPC in Rokkasho?
Why was F4E involved?
Who were the intended users?

Rokkasho

Historical background

2004: the long ITER Negotiations are blocked by two site proposals

Cadarache **versus** **Rokkasho**

EU, China, Russia

Japan, Korea, US

(India had not joined the ITER negotiations)

To unblock the deal, EU and JA conduct negotiations for a "host / non-host" agreement, where the non-host of the ITER site can chose projects on its territory that contribute to the development of fusion energy

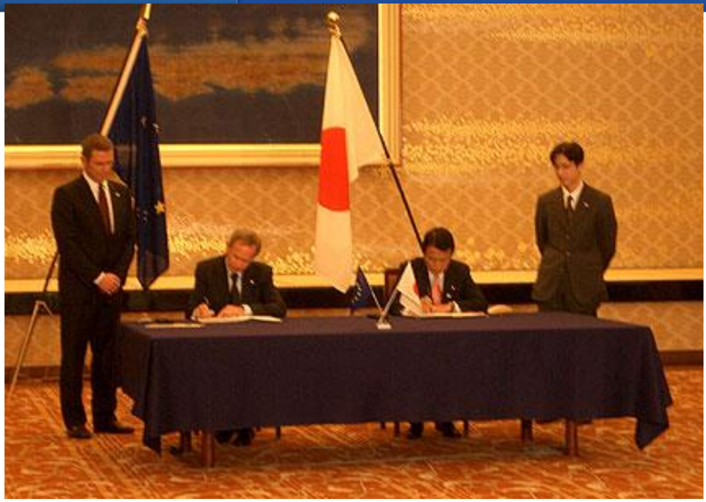
□…Broader Approach to Fusion Energy…

In 2005 an agreement is reached

Broader Approach Agreement

Between EURATOM and Japan

- Equal contribution of 338 M€
- In Europe, France, Italy, Spain, Germany, Switzerland and Belgium make a voluntary contribution for 90% of the total value, and the rest is covered by F4E budget.
- F4E is nominated Implementing Agency for Euratom.



The 3 Projects chosen by Japan:

1) Upgrade of their tokamak JT60U in Naka □ JT-60SA
2) IFMIF-EVEDA: design and prototype construction and testing for a future material irradiation facility: to be sited in Rokkasho, ex ITER site.
3) And IFERC, which had to
   - Fulfill the expectations of an ITER related project on site □ the ITER Remote Experimentation Centre or REC
   - Contribute to the two sides roadmaps to fusion energy □ DEMO Design and R&D in DEMO materials
   - Cover some obvious needs of the EU and JA fusion communities □ An HPC (contributed by France through CEA), to operate in the Computational Simulation Centre CSC

Computer Simulation Centre: Helios HPC

Helios ve LD.wmv

Motivation for IFERC CSC

As in most domains, numerical simulation plays a major role in the field of fusion, complementing theory and experience - it is of critical importance for the design and operation of future experimental devices

The goal of the CSC was: **"the provision and exploitation of a super-computer for large scale simulation activities to analyse experimental data on fusion plasmas, prepare scenarios for ITER operation, predict the performance of the ITER facilities and contribute to DEMO design"**

- The CSC was established in the IFERC Centre in Rokkasho, and provided to the EU and Japan fusion communities a **dedicated state-of the art** supercomputer and support for five years, between 2012 and 2016.
- F4E provided the HPC through CEA (**EU voluntary contributor**) (for a total value of 98.2 kBAUA)
- CEA procured the supercomputer and the peripheral equipment and provided the associated operation and maintenance.
- The High Level Support Team in Garching (under EFDA, and later EUROfusion) contributed to the support of users
- JAEA (later QST) procured the building and the infrastructure equipment and provided electricity and support to the users

energie atomique • energies alternatives

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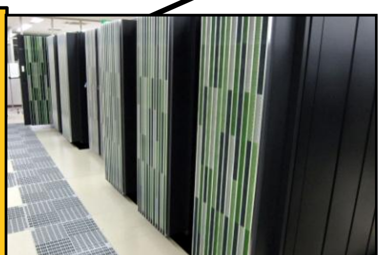
Where were we in 2007? Target spec for Helios

2009 | 2010 | 2011 | 2012

Juelich HPC-FF
8 000 cores
INTEL+IB
100 Tflops (peak)
(BULL)

NIFS
4 000 cores
Power6+IB
77 Tflops (peak)
(Hitachi)



JAEA
17 000 cores
INTEL+IB
200 Tflops (peak)
(Fujitsu)

Rokkasho - CSC
50 000 to 100 000 cores

- **1 Pflops (Linpack)**
- **X10 Juelich computer**
- **X 5 JAEA computer**

IFERC-CSC

Phase 1: Pre-procurement, Procurement
September 2007 -> December 2011

Build a team for the project
Clarify the contribution of each party
Build a plan for the activity
Outline the interfaces

Gather the needs of the fusion community
Perform a market survey
Write the specifications
Define the interfaces

Conduct a competitive procurement (IT equipment and associated services)
Sign a contract with Bull after consulting with the other Parties (JA)

Deliver, Install, Configure the IT equipment (Bull)
Director of the CSC (CEA) moves to Rokkasho

2007	2008				2009				2010				2011			
Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4

Prepare the building

Prepare the infrastructure equipment

September 2007

December 2011 - Ready to run acceptance complete

Helios Pre-procurement phase

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CSC building, completed in March 2012 (JA procurement)

Sept. 2007 – Mid 2009: Preparation activities

- **Clarify the contribution of each party**
- Build a plan for the project
- Outline the interfaces (water / electricity / …)
- Building construction

Mid 2009 – Mid 2010: detailed specifications of the PAs

- **GET INPUT from the users: needs and expectations**
- Market survey
- Select and **adapt benchmark codes (2 fusion codes EU, 2 fusion codes JA)**, and write the specifications
- Agree on a model for the exploitation of CSC: local personnel, role of the EU and JA teams, organisation

Signature of EU PA for the hardware and operation team: 28 April 2010

Procurement phase

Mid 2010 – March 2011: tender

- CEA conducts a competitive procurement for the IT equipment and associated services
- The earthquake on 11 March 2011 caused delays in JA deliveries
- End of March 2011: CEA signs a contract with Bull

March 2011-December 2012: procurement and installation

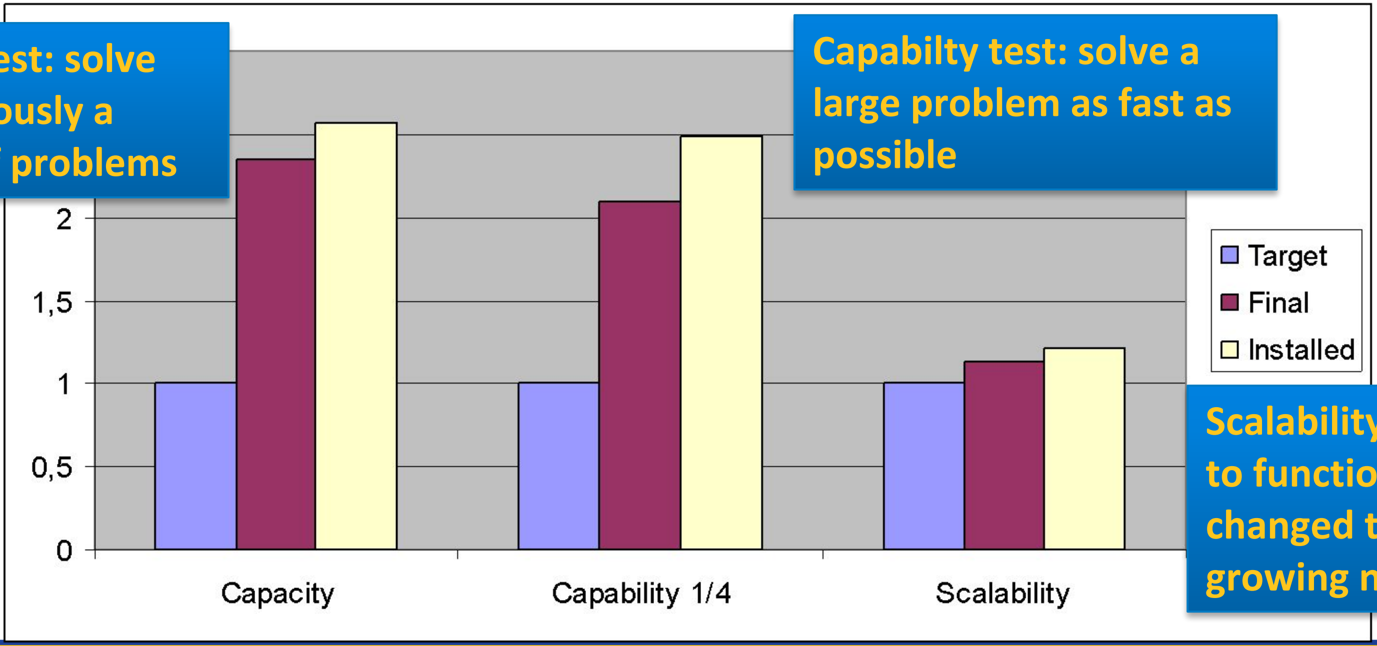
- Preparation of the infrastructure (JAEA)
- Delivery, Installation, Configuration of the IT equipment (Bull)
- Director of the CSC (CEA) moves to Rokkasho
- Acceptance tests week ending 22 December 2011
- **Contract: ready for operation on 1 January 2012**

Chiller system for Helios (JA procurement)

Acceptance tests
Performance of Helios on benchmarks

Capacity test: solve simultaneously a number of problems

Capabilty test: solve a large problem as fast as possible



Scalability test: continue to function well when changed to meet a growing need

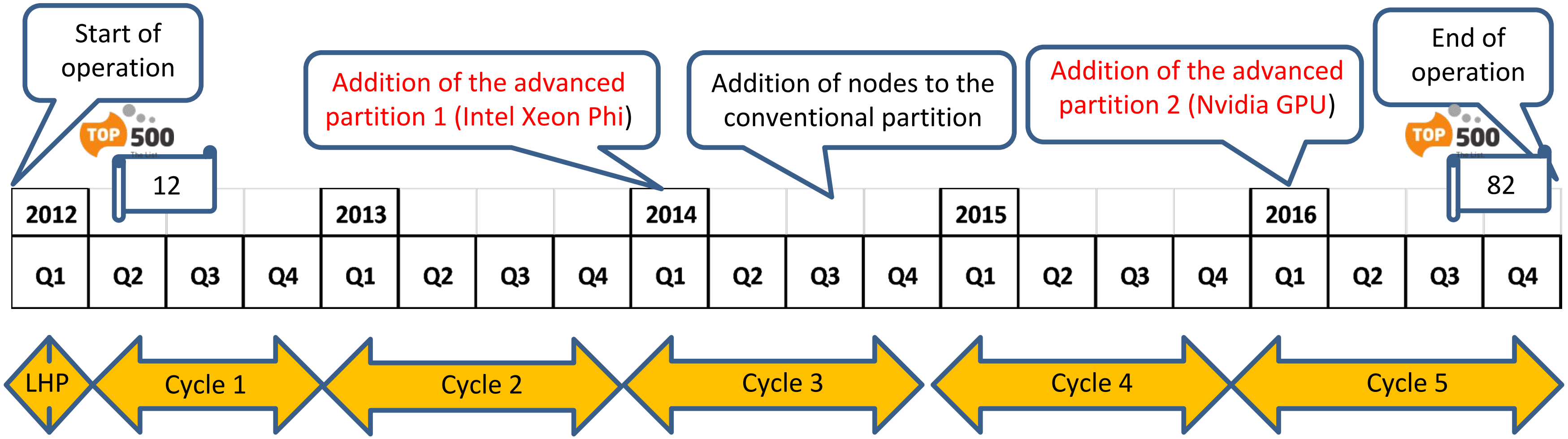
Benchmarking of Helios

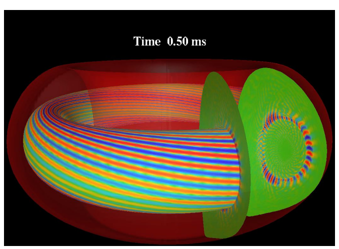
- Choose 4 fusion codes that are representative of those for which the computer will be used
- Give to the tenderers, who commit to a certain extension of their performance
- Test! In addition, the standard Linpack test is performed

Helios achieved Linpack test: 1. 132 Pflop/s (> 1. Pflop/s specified) at 5 in the morning of 22 December 2011…. And a creditable 12^{th} post in the TOP500 supercomputer classification in June 2012

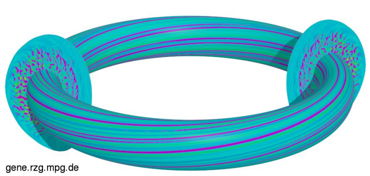
Phase 2: Operation

January 2012 -> December 2016 : Operation



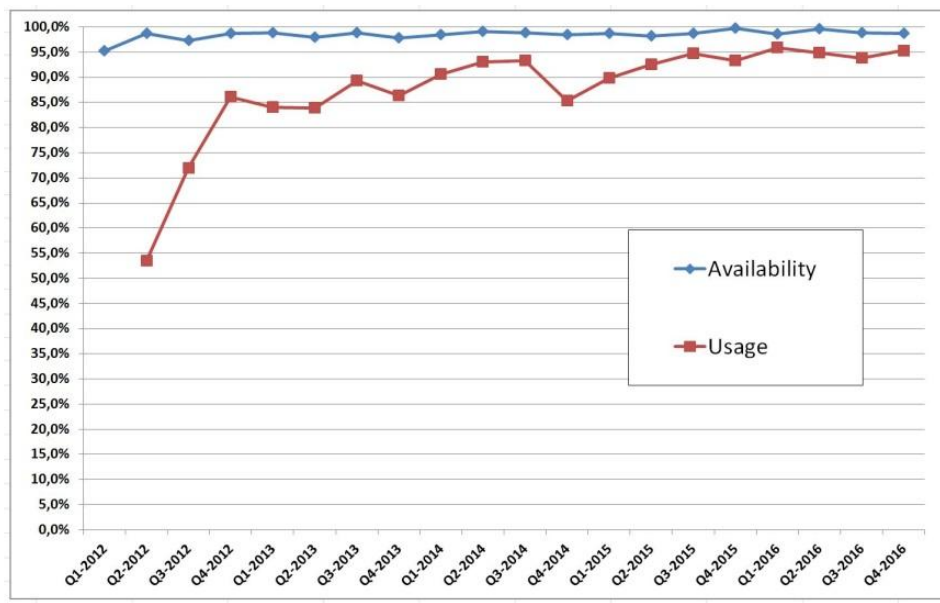


MEGA / Y. Todo



Gene / F. Jenko

Availability and usage of the conventional partition



IFERC-CSC

HPC Helios

Open source software
Commodity components

INTEL
Sandy-Bridge EP
E5-2680 @ 2,7 GHz
8 cores
21,6 Gflop/s per core

8820 processors
70560 cores

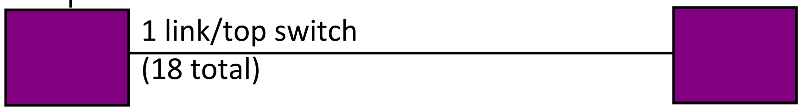
BULL/BullX
<u>Node</u>
2 processors (16 cores)
346 Gflop/s
64 GB memory
120 GB SSD

1 blade=2 nodes

4410 nodes

BULL/BullX
<u>Enclosure</u>
6,2 Tflop/s
18 nodes

1 link/node (18 total)



1 link/top switch
(18 total)

1 bottom switch/enclosure

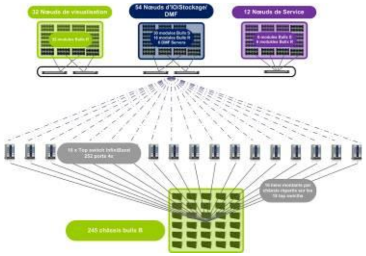
18 top switches
252 ports/switch

245 enclosures

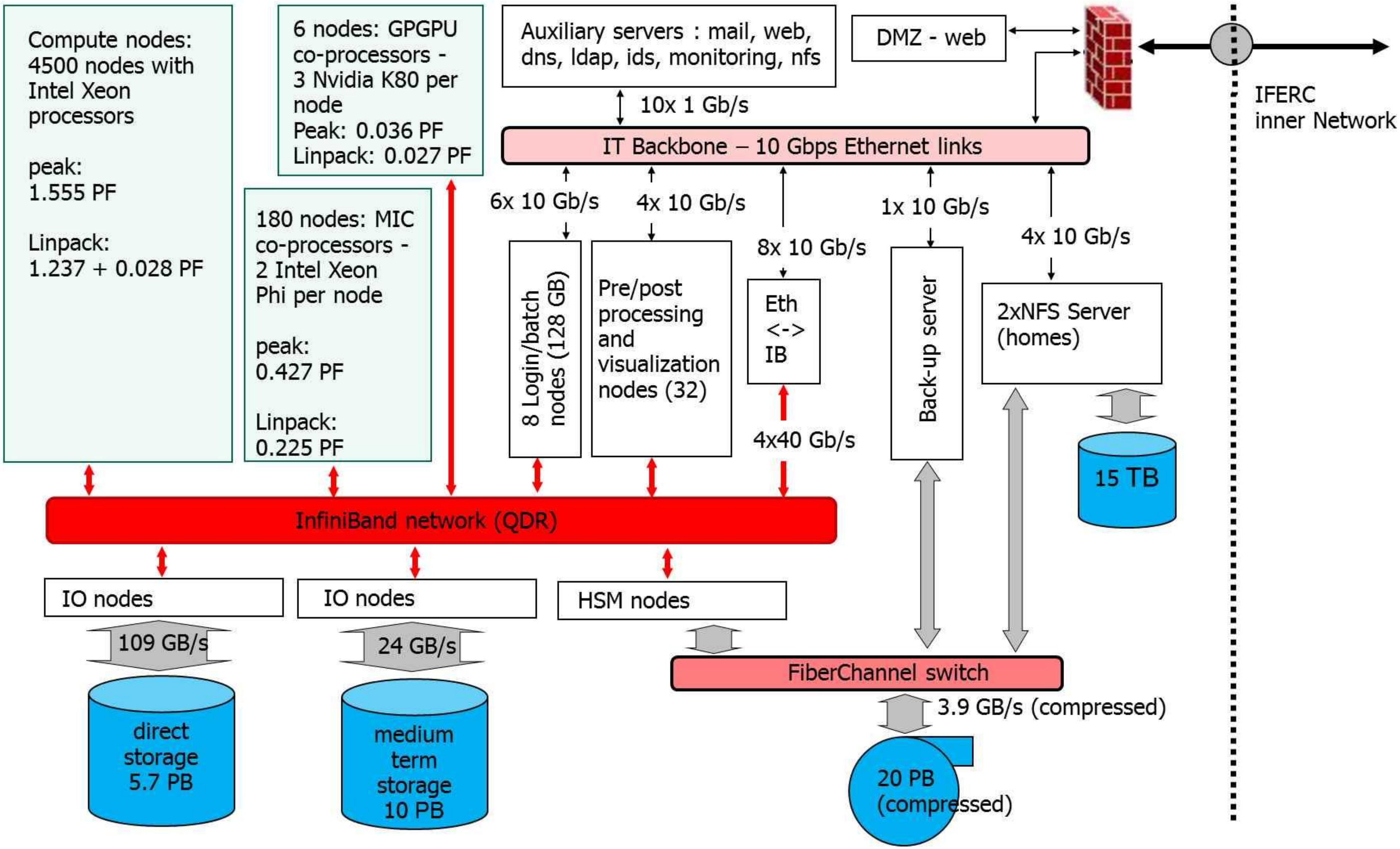
BULL/BullX
<u>Rack</u>
31,1 Tflop/s
5 enclosures
Water cooled door

49 racks

1,524 Pflop/s



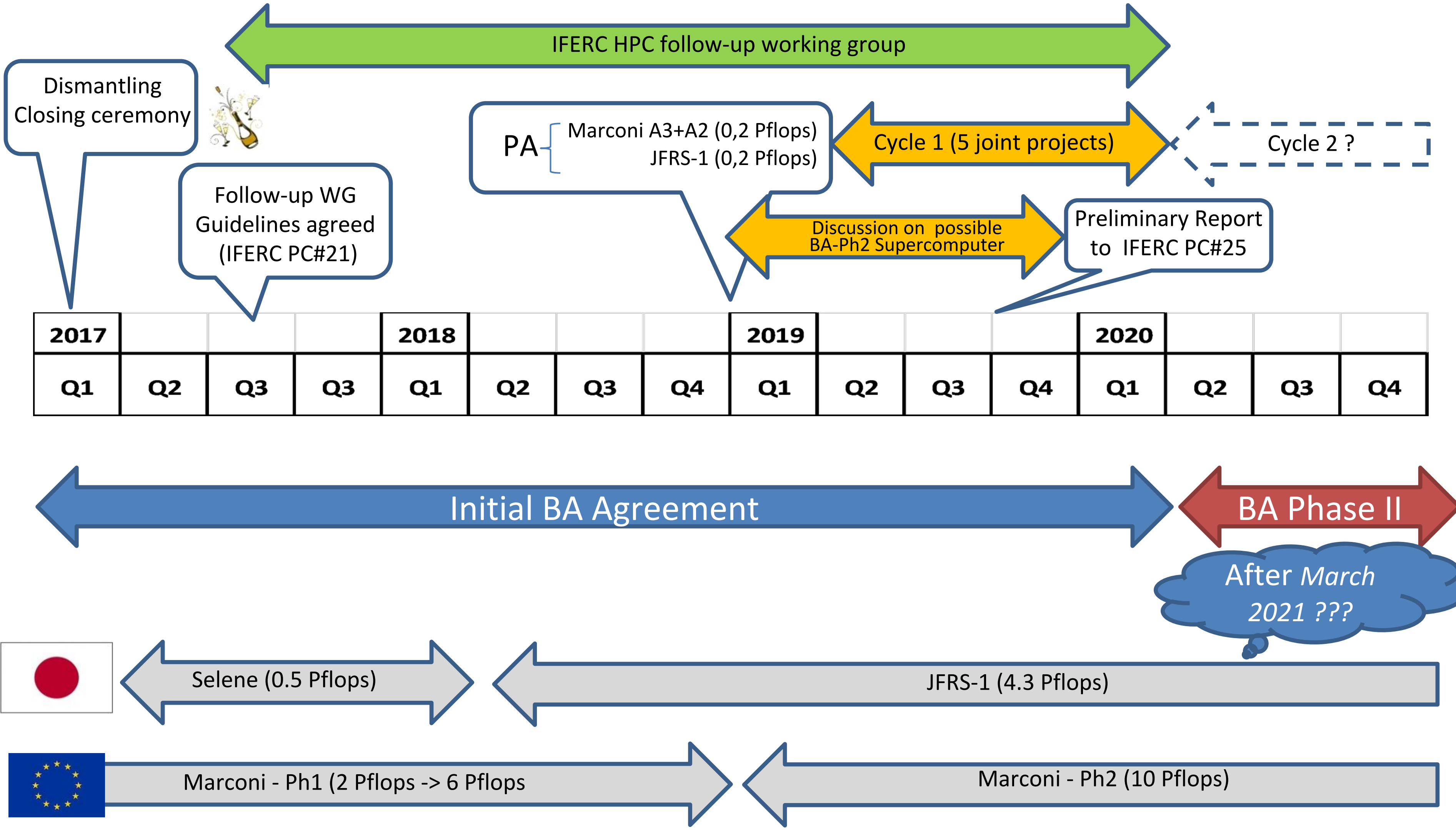
Helios final configuration (ATOS/Bull)



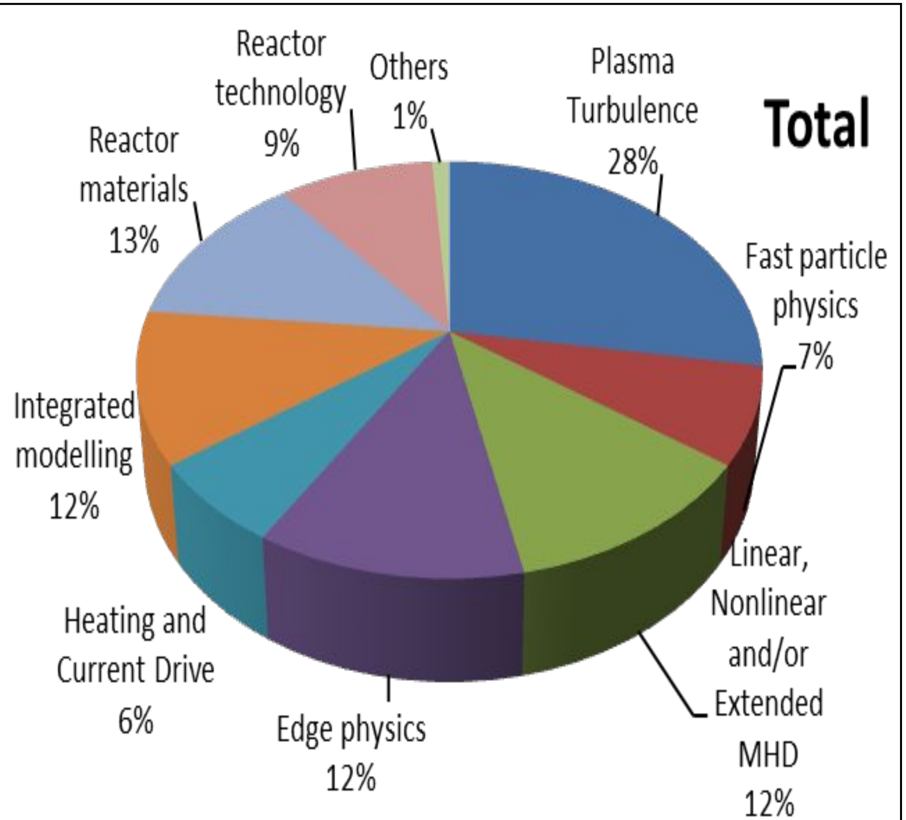
IFERC-CSC

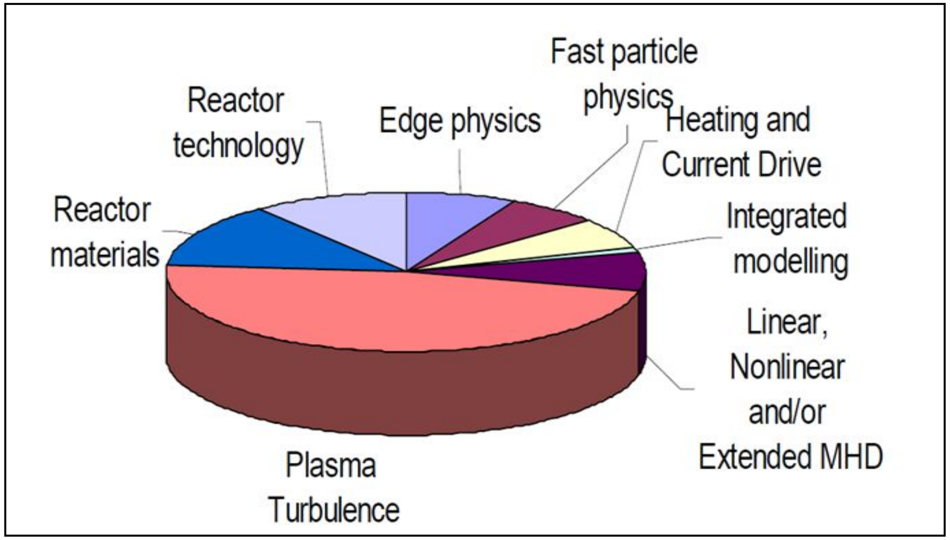
Phase 3

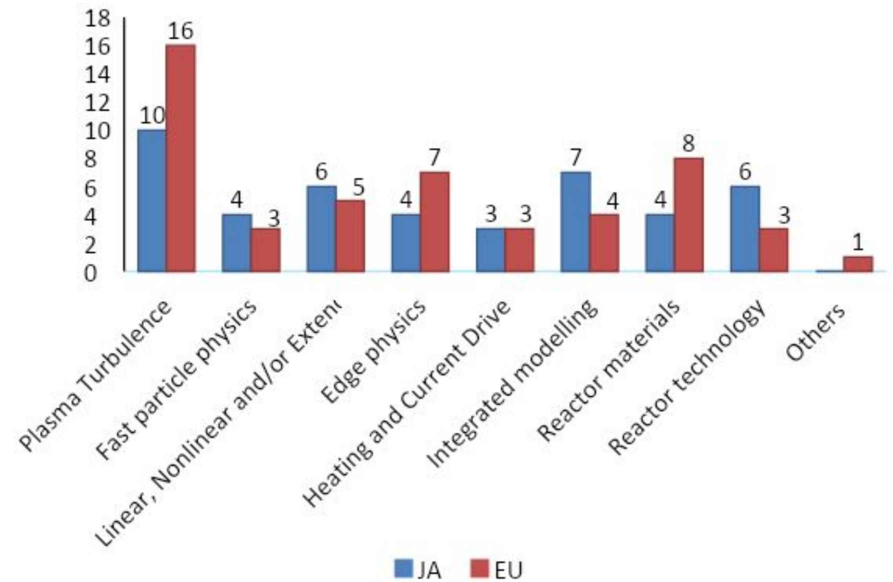
January 2016 -> NOW: Dismantling, follow-up activities



1st Call for projects (April 2012-Nov 2012)



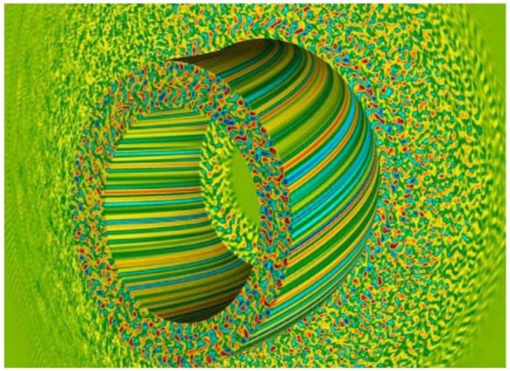




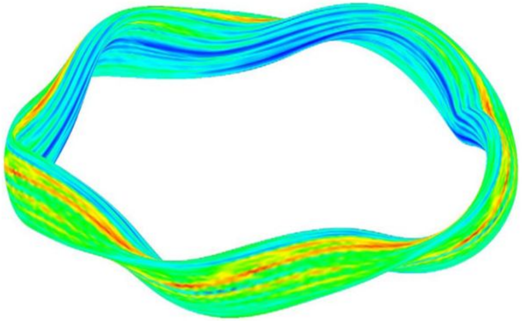
1. The 1st call closed in December 2011, for projects from April to November 2012
2. 94 proposals received (44 JA, 50 EU), 64 projects considered and 58 selected
3. EU and JA get 50% each

Scientific results: Plasma turbulence

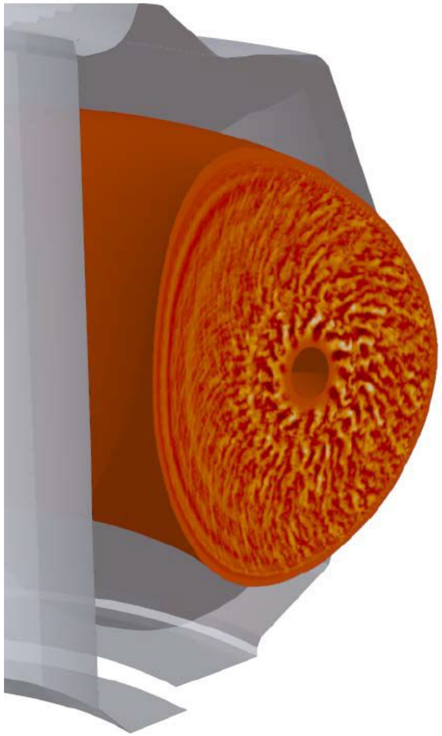
Turbulence Projects are the "superusers" in terms of computer resources



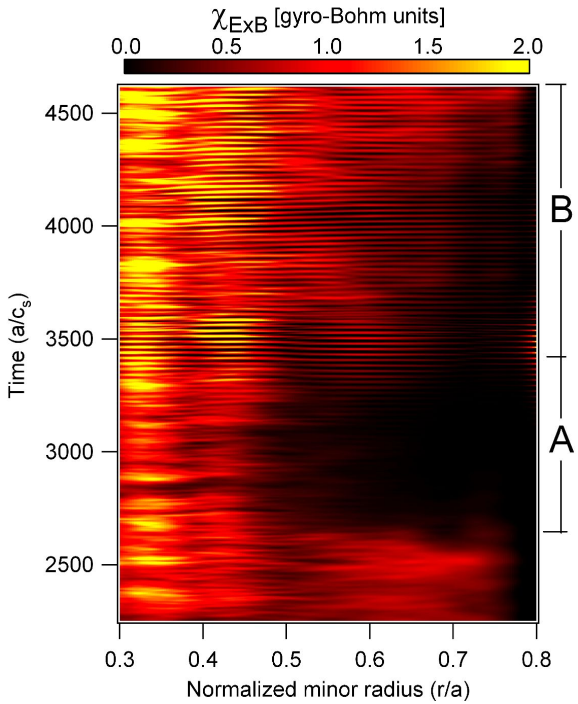
Contours of perturbed density in a global gyrokinetic ITG turbulence simulation of an ITER plasma with the ORB5 code [ORB5ELE, S. Jolliet]



GENE simulation of ITG turbulence for W7-X [GENESTELL P. Xanthopoulos]



Snapshot of ion temperature fluctuations simulated with GENE-global for the DIII-D Lmode discharge. [TOKGYSIM, T. Gorler]



Color plot of the turbulent diffusivity simulated with GYSELA when fast particles excite Energetic Geodesic Acoustic Modes EGAMs. [GYSkinS, R. Dumont]

Scientific results: transport, fast particles….

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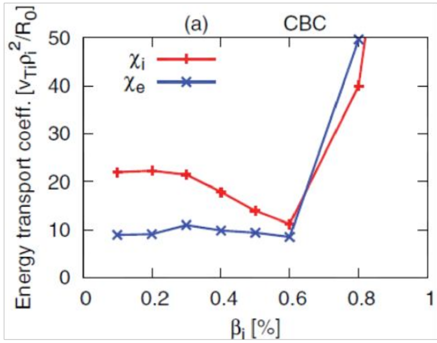
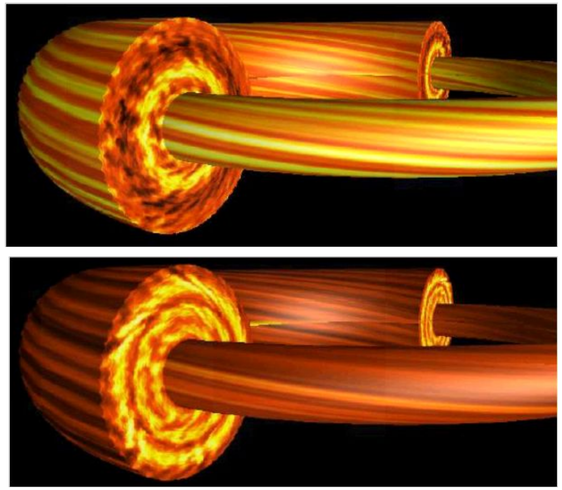
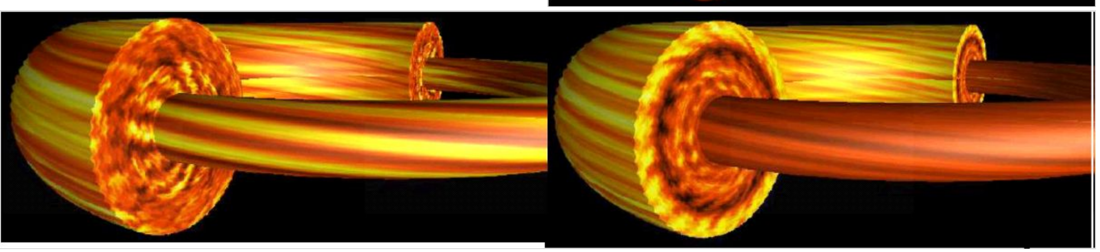
Saturation problem



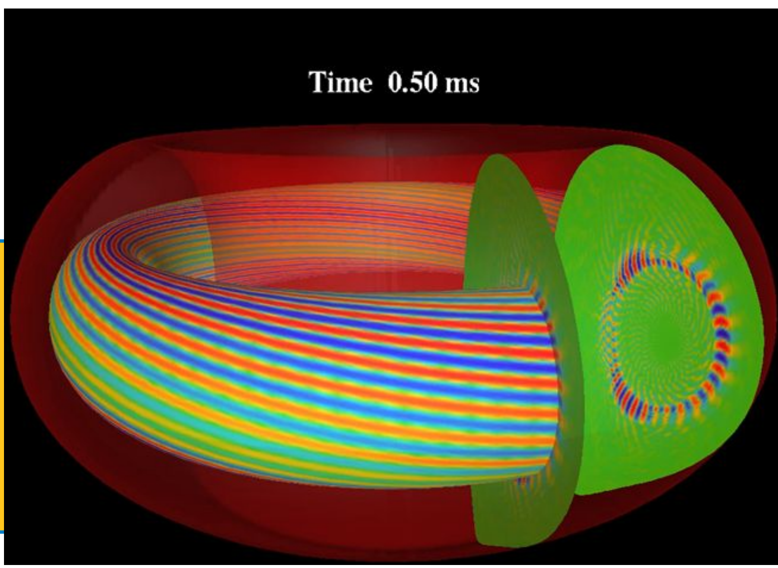




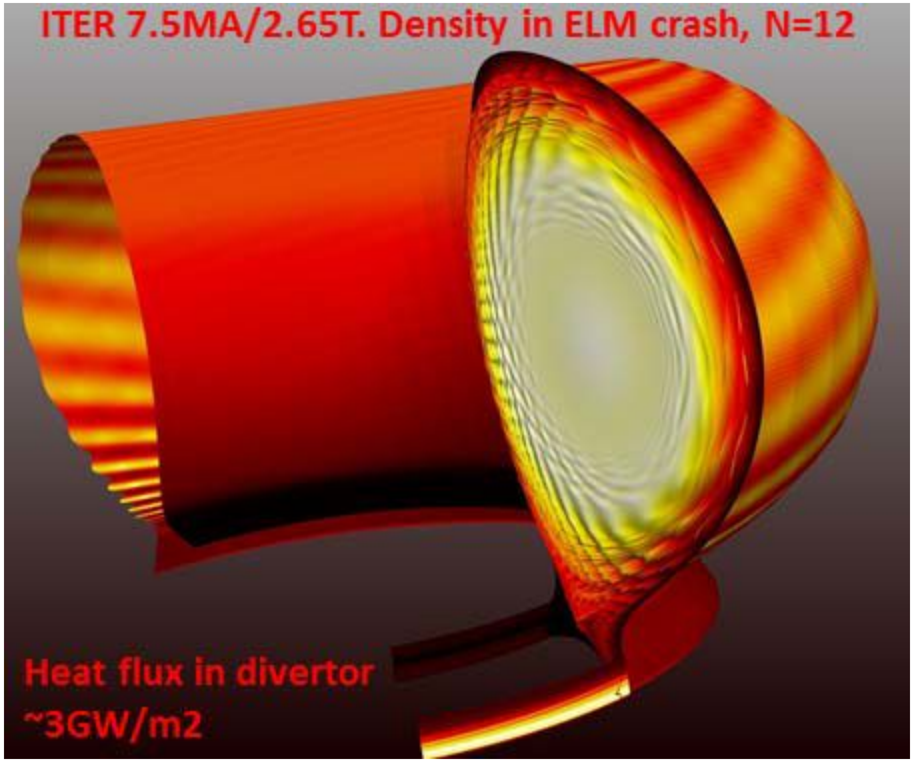
Such as the complicated problem of energy transport in plasmas
(A Ichizawa, electromagnetic gyrokinetic calculations)

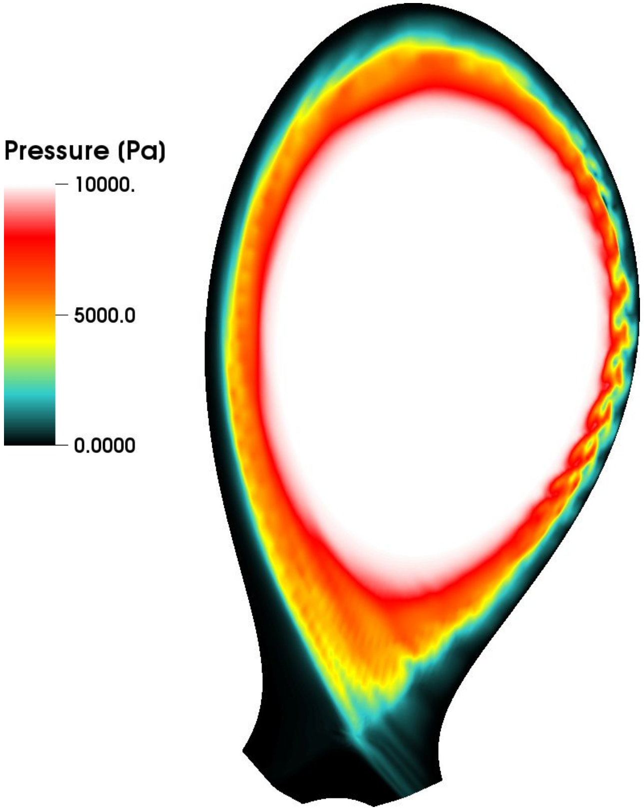
movie4-8fps.mov

Or Instabilities (TAE modes)
Example of transport of energetic particles: TAE modes simulation in ITER Steady State Scenario by using MEGA code (PI: Y. Todo) Fast particles, typically alpha particles in ITER



Scientific results: Edge physics (ITER simulations)





Density filaments and maximum power flux into the divertor in 7.5MA/2.65T ITER scenario in ELM due to n=12 ballooning mode. [JOREK, Marina Becoulet]

Simulations of vertical displacement events in realistic ITER geometry were carried out with the coupled JOREKSTARWALL code [AUGJOR, Matthias Hoelzl]

Scientific results: MHD and materials for DEMO

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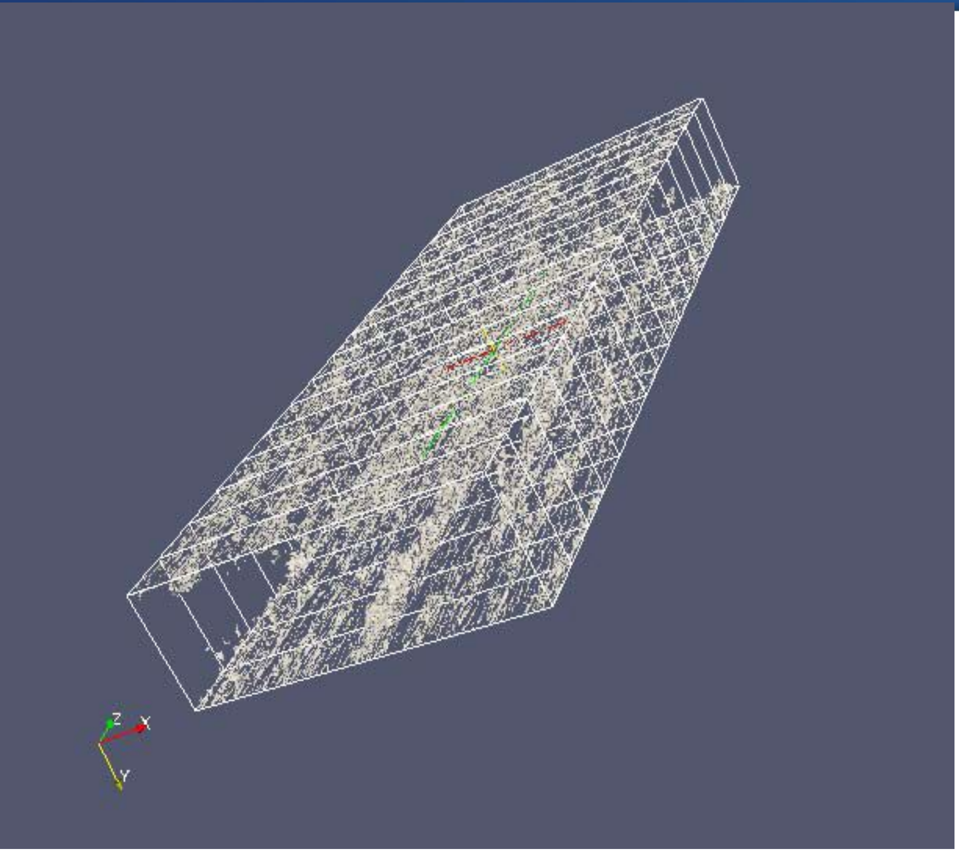
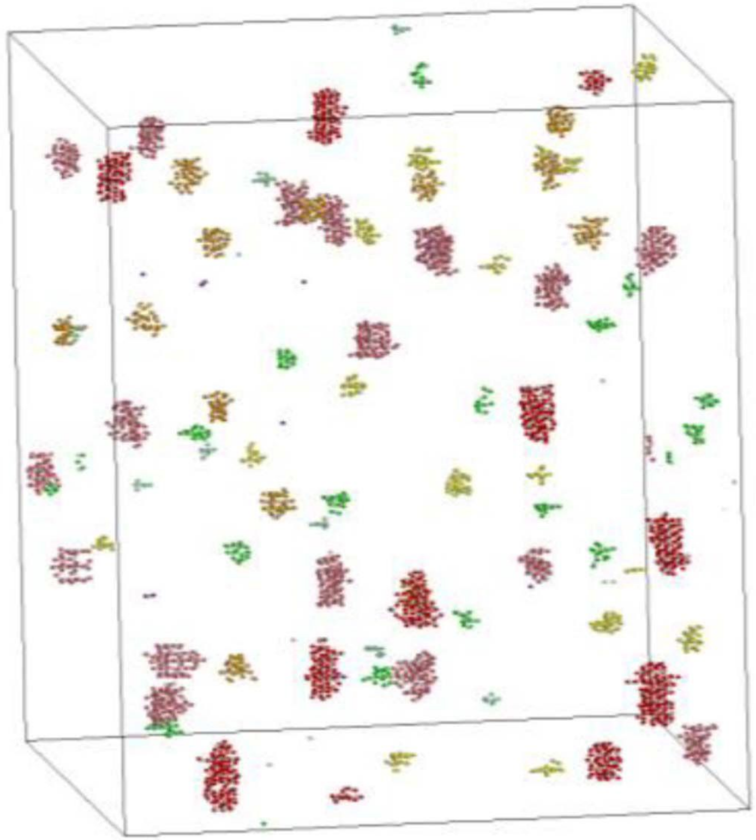


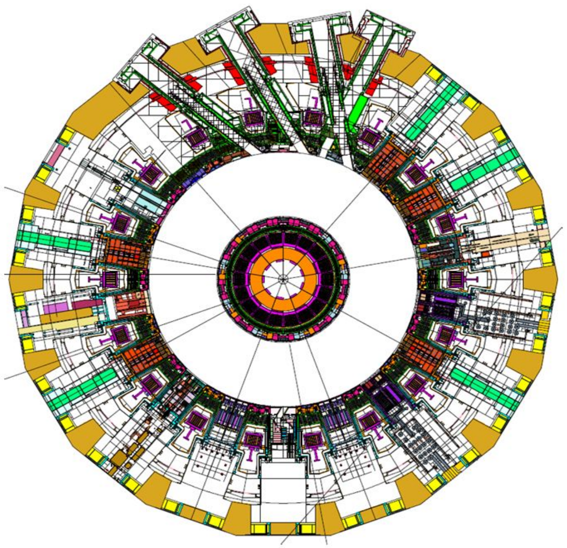
Large-scale MHD simulation of turbulent shear flow [LSMHDTSF,Shin-ichi Satake]



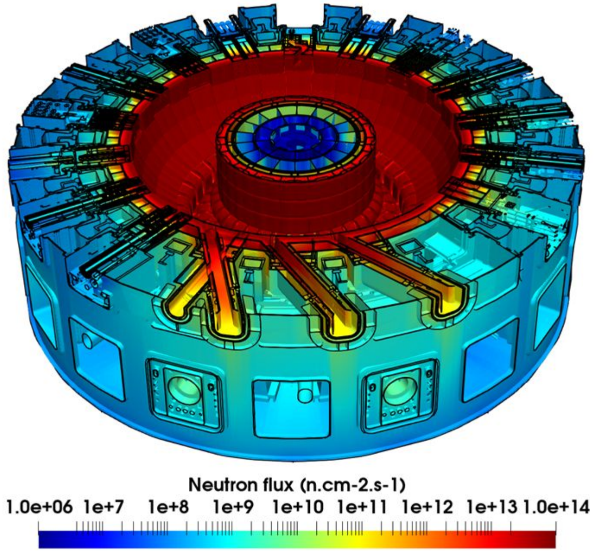
Formation of interstitial clusters from single interstitials in Be, keeping at 1000 K for 1ns [BeFusion, P. Vladimirov]

Direct support to ITER construction: neutronics

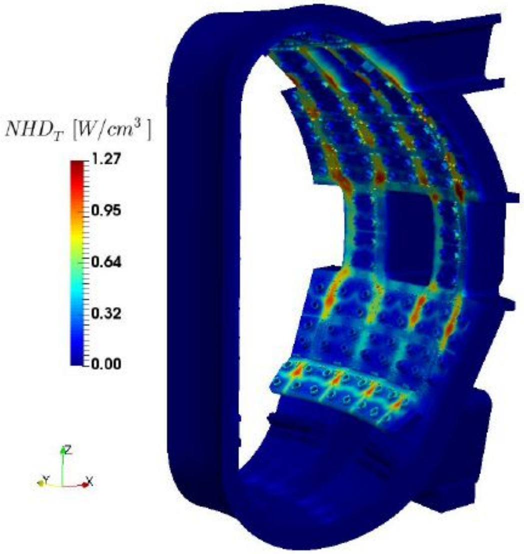
- F4E has had access to Helios (BA programme) and Marconi (EuroFusion) HPC facilities.
- Main user is Analysis and Codes group to perform neutronics and fluid-dynamics simulations.
- ITER neutronics are normally performed with Monte Carlo codes and require the use of very large and complex models for the vast majority of applications.
- It is not possible to obtain statistically meaningful results without the use of HPC, typically ~1,000 CPUs and >4 GB/CPU per simulation; and still calculations are performed overnight… or overweek!



Horizontal cross-section at midplane of ITER tokamak computer model

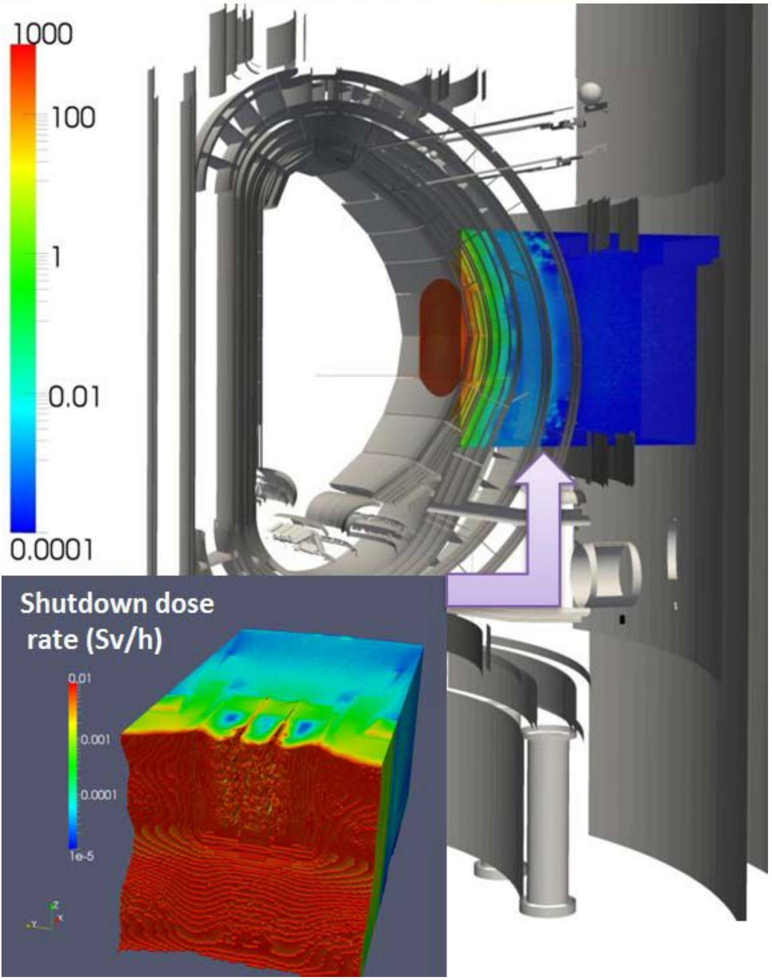


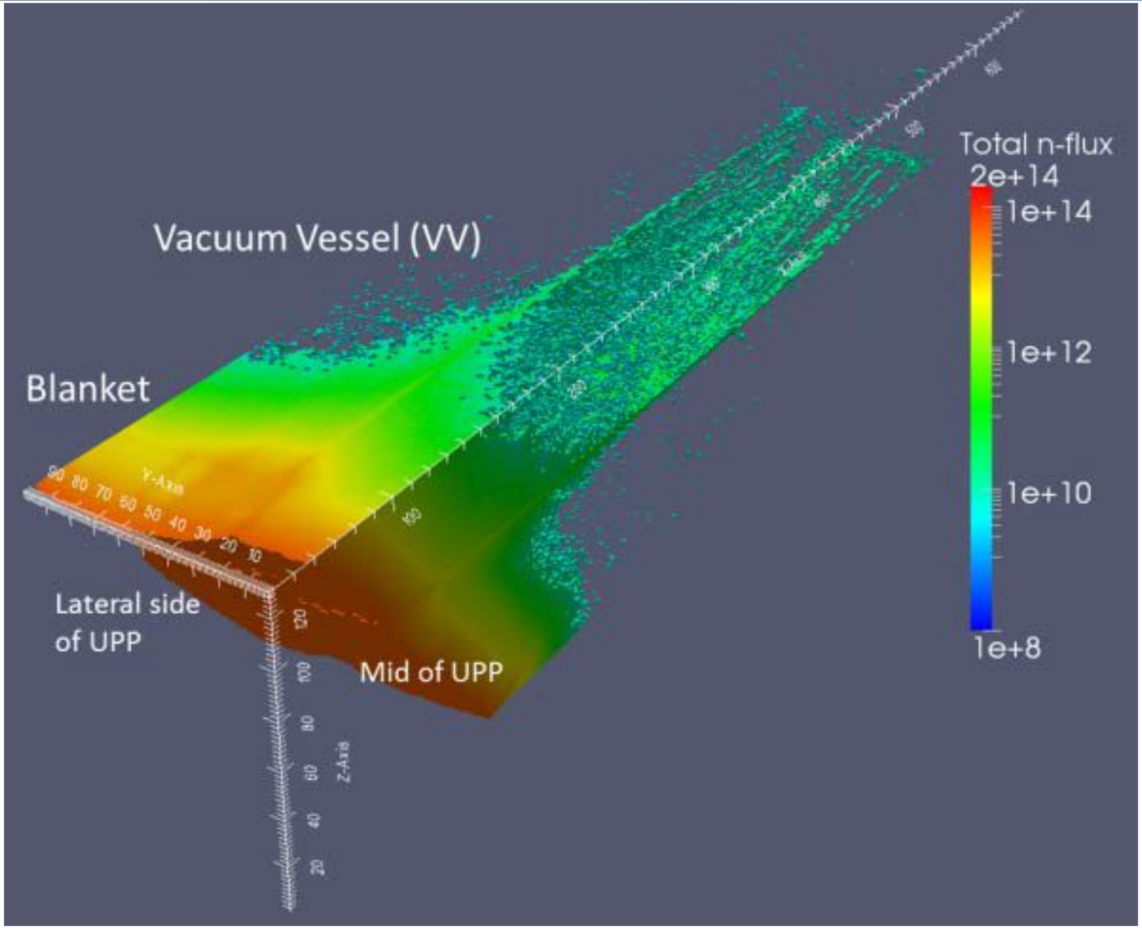
Neutron flux results (R. Juarez, R. Pampin, M. Fabbri et al., to appear in Nature Energy*)*



VV nuclear heat density results (M. Fabbri, R. Pampin et al., Fus. Eng. and Des. *2018)*

Direct support to ITER construction

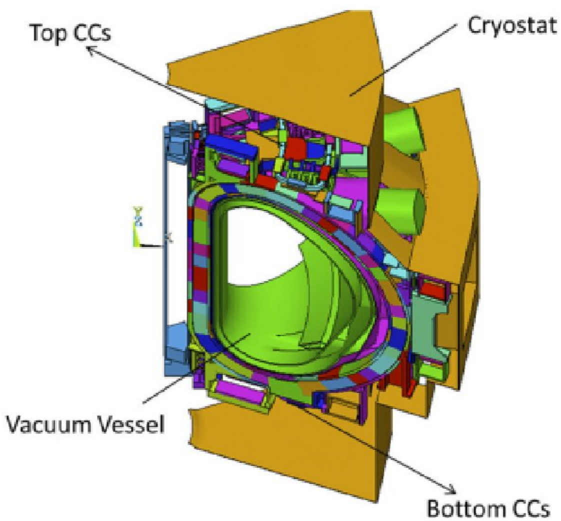


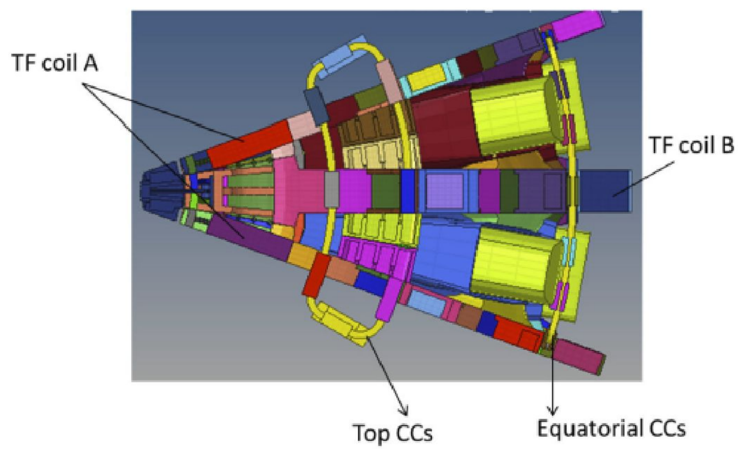


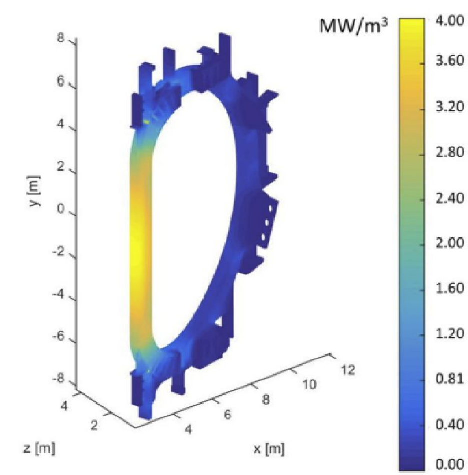
Map of total neutron flux with 3D visualization of excessive neutron streaming for the ITER Diagnostics Generic Upper Port Plug (UPP) on its lateral side, obtained with massively parallel MCNP5 calculations on Helios supercomputer for the MCHIFI and MCHIFI2 project.[MCHIFI and MCHIFI2, Arkady Serikov]

Direct support to ITER construction: Electromagnetics

- For Electromagnetic calculations, F4E has had access to MareNostrum, Helios (BA programme) and Marconi (EuroFusion) HPC facilities.
- A 40 degrees electromagnetic Model of ITER cold structures has been built to compute the eddy currents during a disruption.
- The model consists of around 120 000 elements. The computational cost of the integral formulation used in the CARIDDI code scales with the cube of the degrees of freedom, requiring the use of HPC facilities.
- We used up to 144 cores for maximum 24 hours.



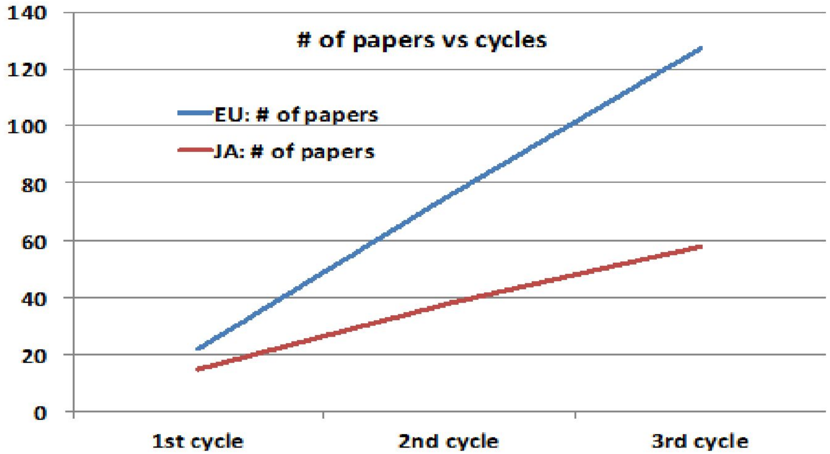


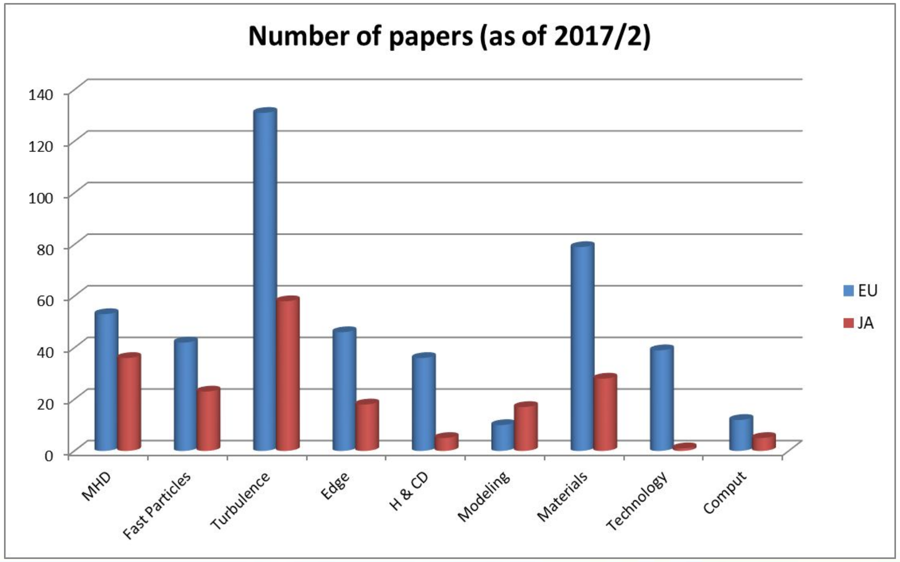


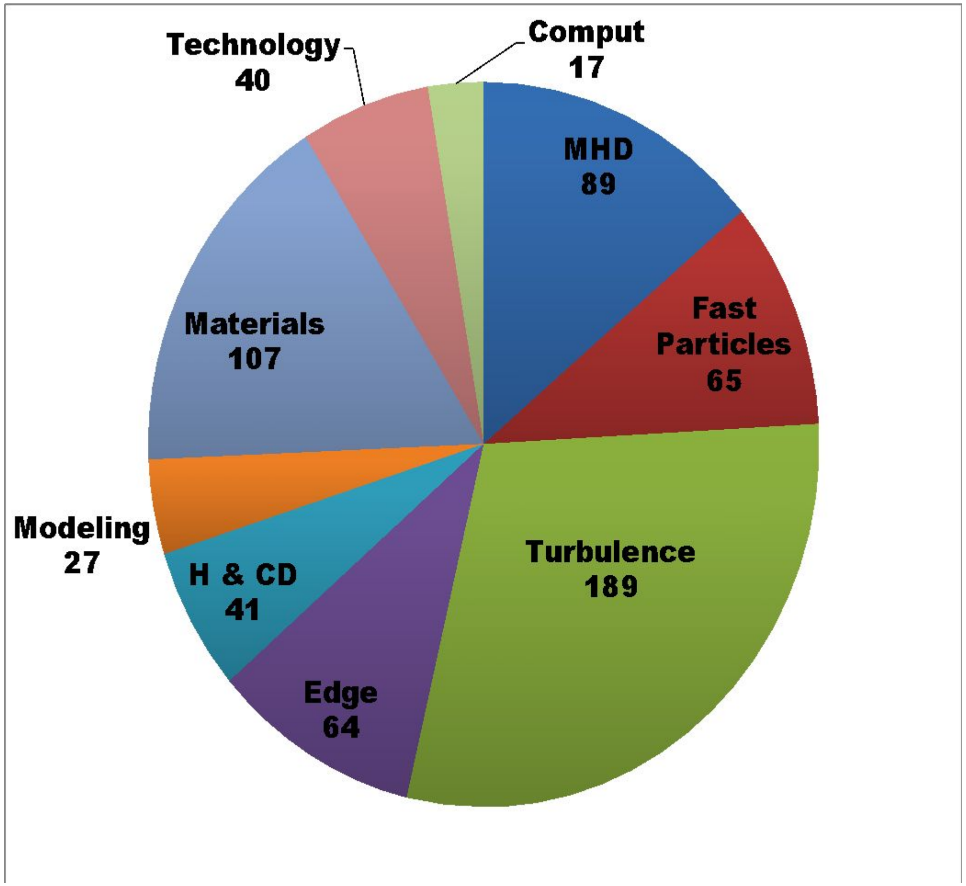
F. Cau et al., "Update of Joule Losses Calculation in the ITER Cold Structures during Fast Plasma Transients", IEEE Transaction on Applied Superc., Volume 30, Issue 4, June 2020

A useful tool for the two fusion communities

The impact of Helios in the scientific field can be seen in total number of refereed publications (639) its progress over time, and the variety of fusion areas involved







Outlook for CSC in BA Phase II

Current activities of CSC

- Sharing experience and best practices in the design and operation of HPC centres for fusion users and in the usage of such centres by fusion users
- Organization and monitoring of the provision of computer resources (JFRS-1 mainly) and related support for fusion research projects.
- **Contribution to the reflections on a possible joint supercomputer to be operated starting in 2022/2023** consistent with the expected life time of current EU and JA supercomputers for fusion:

In Europe, the General Assembly of EUROfusion established an expert group with the mandate (by December 2020) to

- *Establish a clear purpose (in scientific and financial terms) for a joint supercomputer with Japan, including the identification of the added value of such a scheme with respect to an EU only supercomputer solution replacing Marconi-Fusion*
- *Outline a detailed implementation scheme for such a joint supercomputer, including, if relevant, the organization of computing resources for EUROfusion that may not form part of the joint supercomputer*

- In Japan similar discussions are taking place

Thank you for your attention!

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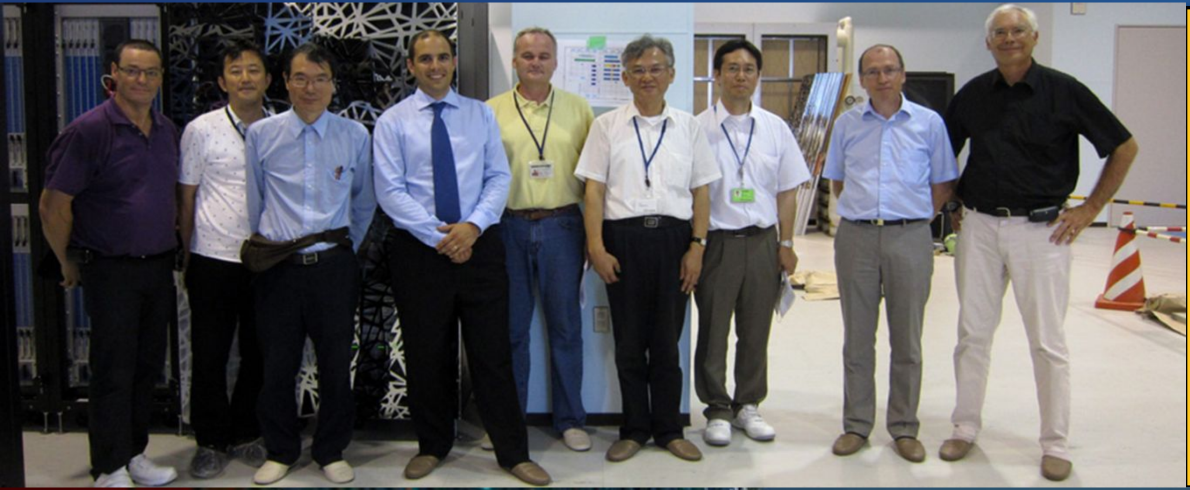

With thanks to CEA, IFERC Project Team, QST, Bull-Atos, and the rest of the CSC teams