Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Use of a High Performance Computing (HPC) and AI for complex phenomena analysis on surface ship design

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Universidad de Vigo

EM3WORKS

UEX

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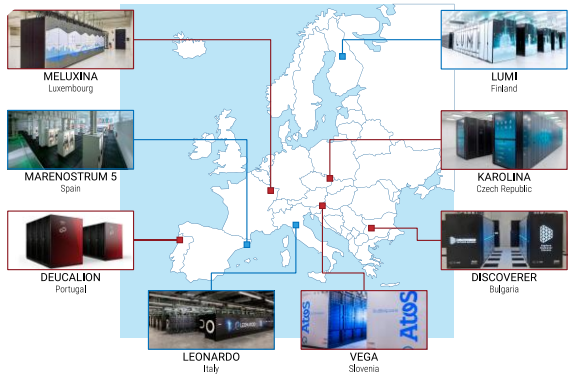
Prof. Dr. Fernando Obelleiro. Full Professor Univeridad de Vigo; obi@com.uvigo.es

NAVY LEADERS | COMBINED NAVAL EVENT

Summary of the presentation

01



High Performance Computing in Europe

02

HPC and AI impact in dual-use technologies. Multiphysics and multi-scale complex phenomena analysis

03

RF and EM

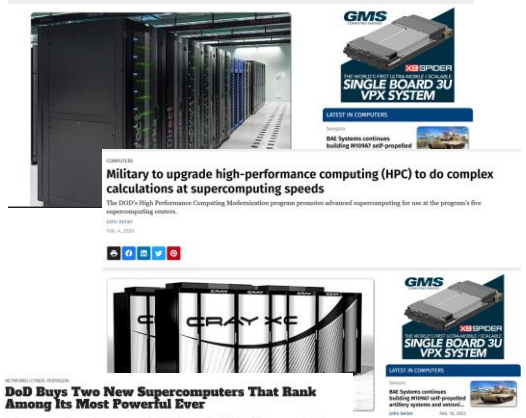
The importance of HPC in dual-use technologies

Pentagon pours another $53.1 million into the five military supercomputer research centers

HUNTSVILLE, Ala., 26 Oct. 2016. U.S. military researchers announced an investment of $53.1 million Wednesday into a U.S. Department of Defense (DOD) program to enhance high-performance computing (HPC) — or supercomputer technology — for advanced research work.

John Keller

Oct. 27, 2016



ACM TECHNEWS

Defense niversity Builds China's Fastest Supercomputer

By Xinhua (China)
October 30, 2009
Comments

VIEW AS: SHARE:

China's fastest super computer "Tianhe," meaning Milky Way, was unveiled Thursday (Oct. 29). The supercomputer is theoretically able to execute one petaflop at peak speed.

Credit: He Shuyuan / Xinhua

China's National University of Defense Technology (NUDT) has unveiled the Tianhe supercomputer, the fastest supercomputer in China. Tianhe runs at 563.1 teraflops on the Linpack benchmark and is theoretically capable of petaflop performance. NUDT president Zhang Yulin says the system is expected to be used to process seismic data for oil exploration, perform bio-medical computing, and help design aerospace vehicles.

If Tianhe had been operational for the most recent Top 500 list, it would have ranked as the world's fourth-most powerful supercomputer. NUDT says that approximately 200 computer scientists worked on Tianhe over two years. The supercomputer was housed at the NUDT campus in Changsha, and is scheduled to be moved to the National Supercomputing Center in Tianjin at the end of this year.

Tianhe features 6,144 Intel CPUs and 5,120 AMD GPUs. "As far as I know, a combination of CPU and GPU is something new used to make a petaflop computer," says NUDT professor Zhou Xingming. "After it's installed in Tianjin, we plan to add hundreds or thousands of China-made CPUs to the machine, and improve its Linpack performance to over 800 teraflops

From Xinhua

View Full Art

The Washington Post

China builds advanced weapons systems using American chip technology

By Ellen Nakashima and Gerry Shih

April 9, 2021 at 8:52 p.m. EDT

Abstracts Cog

THE ECONOMIC TIMES | News

US President Joe Biden makes surprise visit to Ukraine

US adds Chinese supercomputer centers to export blacklist

NIKKEI Asia

World Trending Business Markets Tech Politics Economy Features Opinion Life & Arts

TECHNOLOGY

Japan's Riken plans quantum link to supercomputer Fugaku

Institute aims to launch hybrid computing in 2025, helping boost competitiveness

Fugaku, located in the Japanese city of Kobe, was the 2022. (Photo obtained by Nikkei)

AKIRA OKAWA, Nikkei staff writer
January 3, 2023 03:07 JST

EE. UU., Japón y Corea del Sur realizan maniobras tras lanzamiento de misil de Pyongyang

Japan Ministry of Defense/Self-Defense Forces
@ModJapan_en · Follow

#JMOD will formally join NATO Cooperative Cyber Defence Centre of Excellence's (#CCDCOE) activities, following the completion of participation procedures. JMOD will continue to collaborate with international partners to respond to threats in cyber domain.

CCDCOE
NATO COOPERATIVE CYBER DEFENCE CENTRE OF EXCELLENCE

10:43 AM · Nov 4, 2022

53 Reply Copy link

The EuroHPC Joint Undertaking

The European High Performance Computing Joint Undertaking was est
by Council Regulation (EU) 2018/1488, and is currently regulated by Co
Drawing together countries, industry and public bodies to lead the way in European supercomputing, the EuroHPC JU has a combined budget of EUR 7 billion, drawn from the Digital Europe Programme, Horizon Europe, and Connecting Europe Facility 2.0 as well as contributions from participating countries and private members.

Supercomputers are vital tools needed to meet Europe's climate, energy and transport goals. They are also essential for national security, defence and sovereignty. The EuroHPC JU complements the aims of the European Chips Act to boost Europe's competitiveness and resilience in semiconductor technologies and applications, as chips are critical components of a supercomputer.

A central objective of the EuroHPC JU is to promote green and sustainable technologies as part of the EU's goals of carbon neutrality laid out in the European Green Deal. It is building some of the world's greenest supercomputers, drawing on technologies such as water cooling, waste heat recycling and next-generation energy-efficient microprocessors.

The EuroHPC JU contributes to the EC priority A Europe fit for the digital age, digital transition work for people and businesses.

Expansión

El Barcelona Supercomputing Center albergará un ordenador cuántico

Barcelona desarrollará el chip de los superordenadores europeos

La CE financia una tecnología clave para la soberanía informática del continente

El proyecto del chip europeo estará liderado por Barcelona

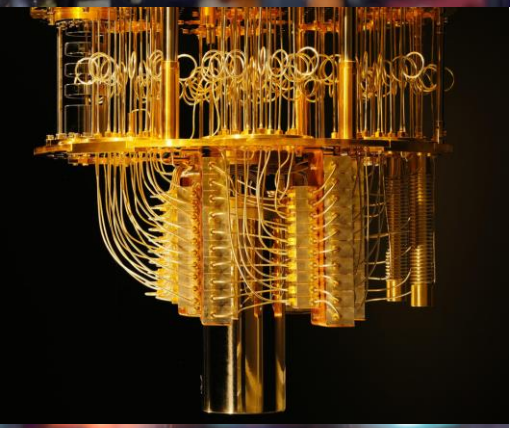
Barcelona desarrolla el chip de los futuros superordenadores europeos

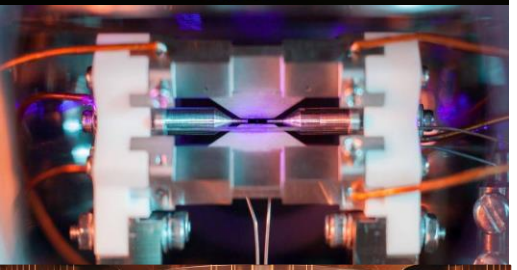
El superordenador MareNostrum 5 se lanzará a la conquista de procesadores y chips 'made in Europe'

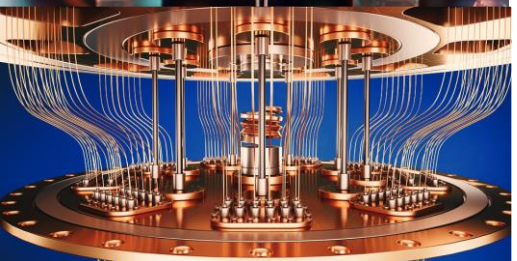
El MareNostrum 5 incluirá una plataforma para crear chips europeos

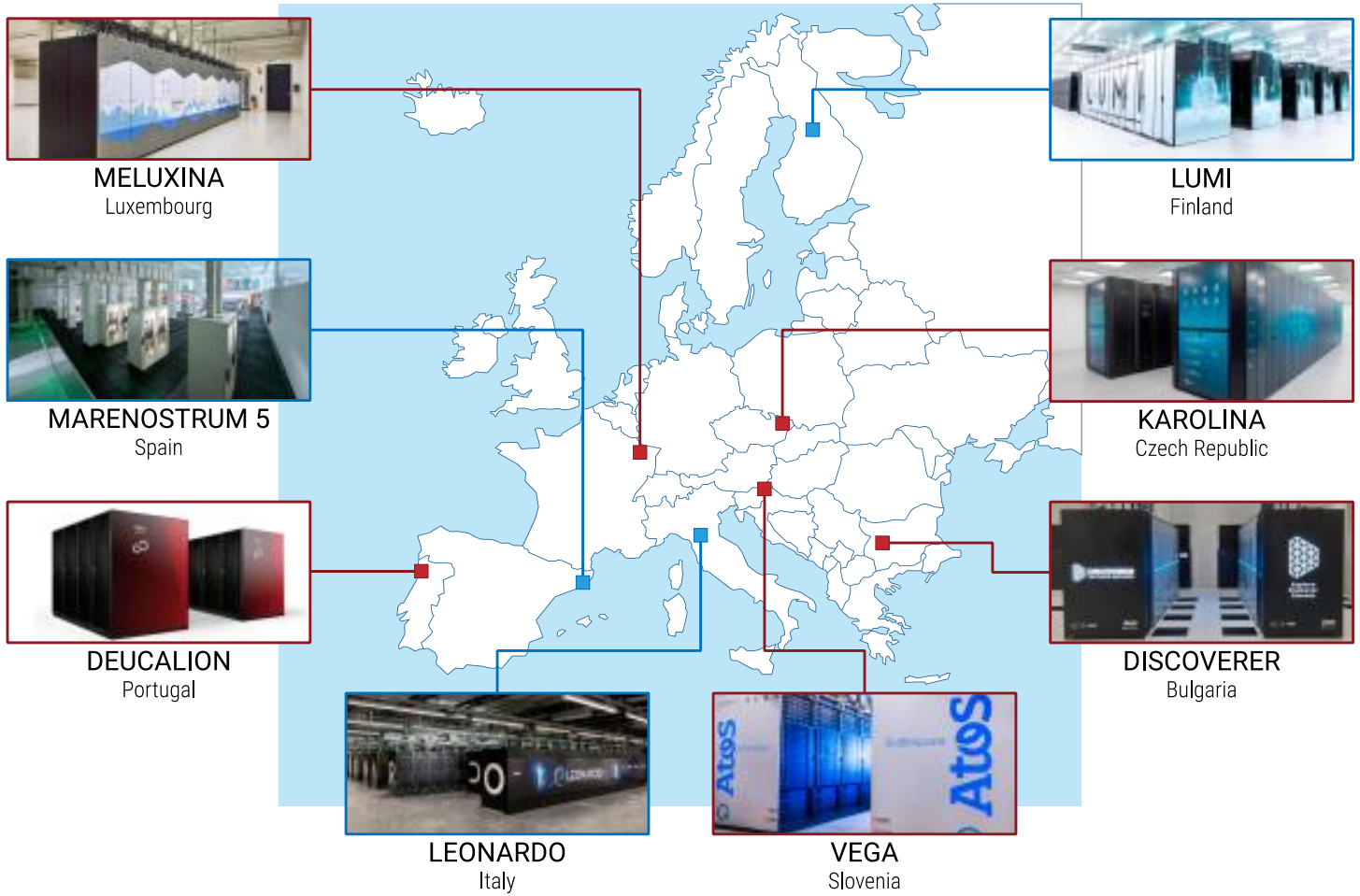
El súperordenador presentará batalla en la fabricación de chips y procesadores europeos

High Performance Computing (and quantum) in Europe. A long term vision towards exascale



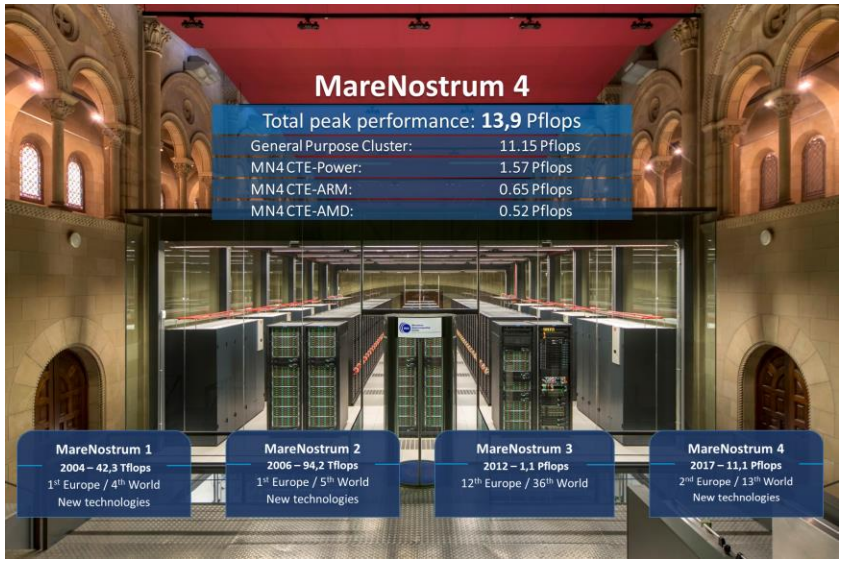






Barcelona Supercomputing Center-Centro Nacional de Supercomputación (BSC-CNS)

- **Spanish National Supercomputing Center**
- Located at Polytechnic University of Catalonia - Barcelona Tech
- Around >**1000 people** from several disciplines (>55 nationalities)
- >350 on-going R&D Projects (May 2024)
- Four main departments**: Engineering (CASE)**, **Computer Sciences**, Life Science, Earth Sciences.
- BSC hosts and manages **Marenostrum 5**: A European pre-exascale supercomputer (EuroHPC JU) (>317 Pflops peak; >223 M€) **(#8 World**; **#3 in Europe** 2023)



325 Articles in peer-reviewed journals — 244 in Q1

23 Doctoral theses

214 Open-access publications

57 Papers in conference proceedings — 25 In A and A* conferences

1 Book published

8 Chapters in published books

European Commission

Hosting Consortium:

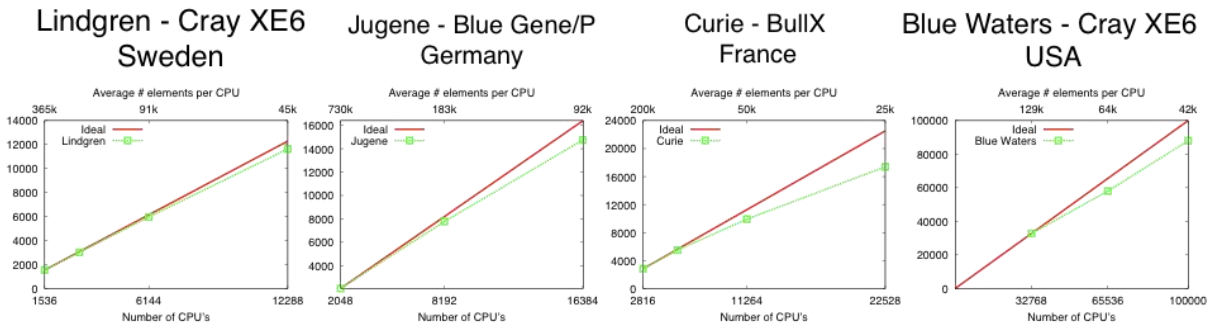
Spain | Portugal | Turkey | Croatia

RES Red Española de Supercomputación · PRACE · ETP 4 HPC · BDV

Main software for BSC-CNS multi-physics: Alya

- Multiphysics code Alya

- **FEM-based** Computational Mechanics code
- Language: **Fortran 2008**
- **Parallelization** model:
  - MPI (130K CPU-cores) + OpenMP
  - Accelerators: OpenACC-CUDA
  - Co-execution on heterogeneous systems
- Fully **parallel workflow** - **dynamic load balance** - **mesh adaptivity**
- Parallel **multi-physics/multi-code** coupling
- Alya is regularly run on **PRACE Tier 0 systems** and is part of the European Applications Benchmark Suite (EUABS) of PRACE

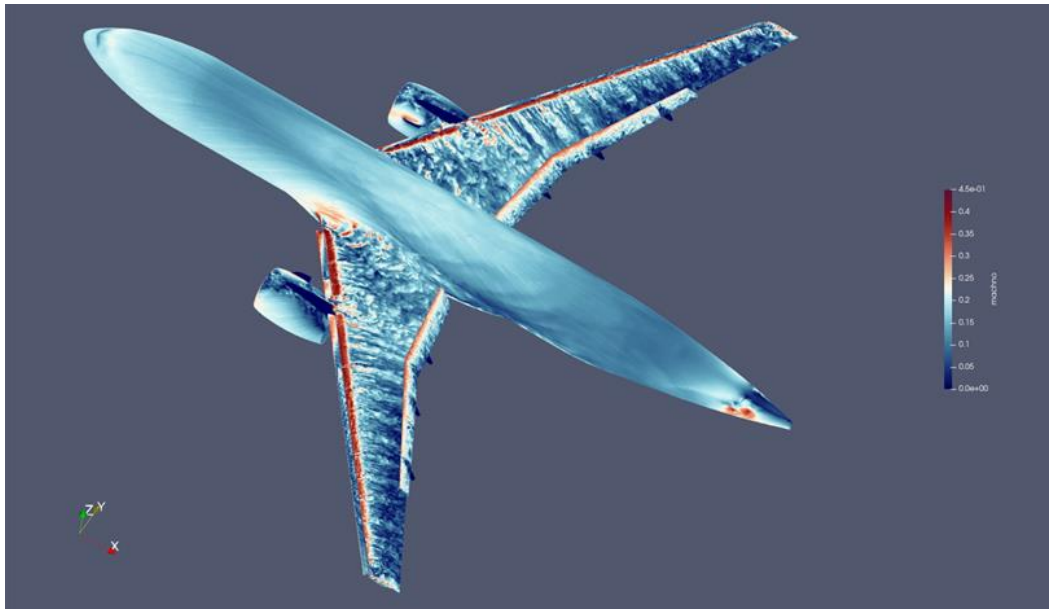


EXCELLERAT P2 · CEEC Centre of Excellence in Exascale CFD · oec Center of Excellence in Combustion · Energy Oriented Center of Excellence: toward exascale for energy E·C·E

Main software for CFD in LS/CFD team

SOD2D

- Language: **Fortran**
- GPU port path: **OpenACC**
- Required libs: **HDF5, MPI**
- **Compressible and incompressible flows**
- Git repo: https://gitlab.com/bsc_sod2d/sod2d_gitlab/
- … and btw, the code is **3D!**

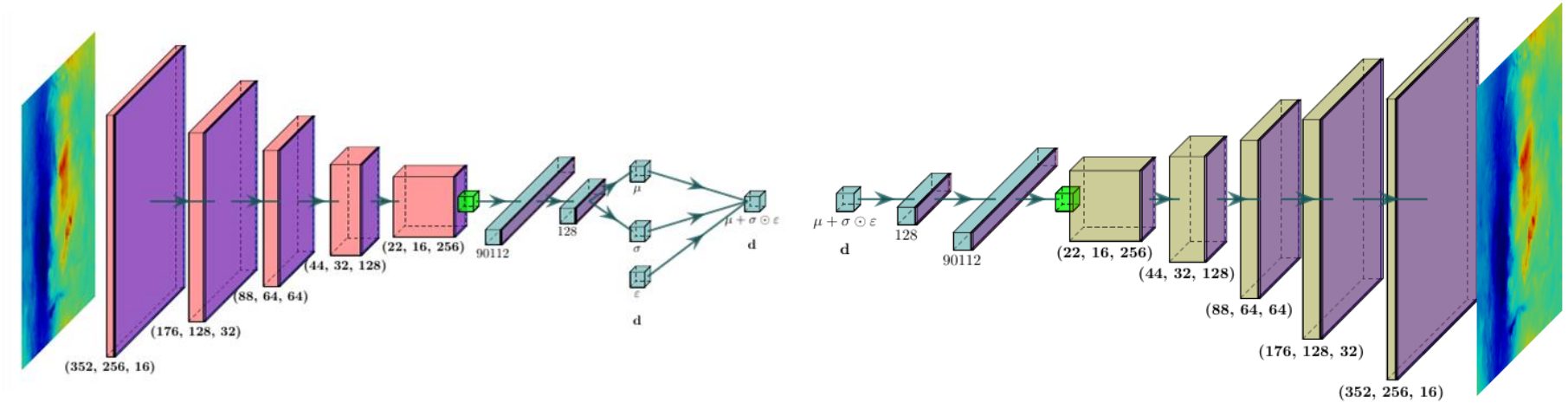


SOD2D: **S**pectral high-**O**rder co**D**e **2** solve partial **D**ifferential equations

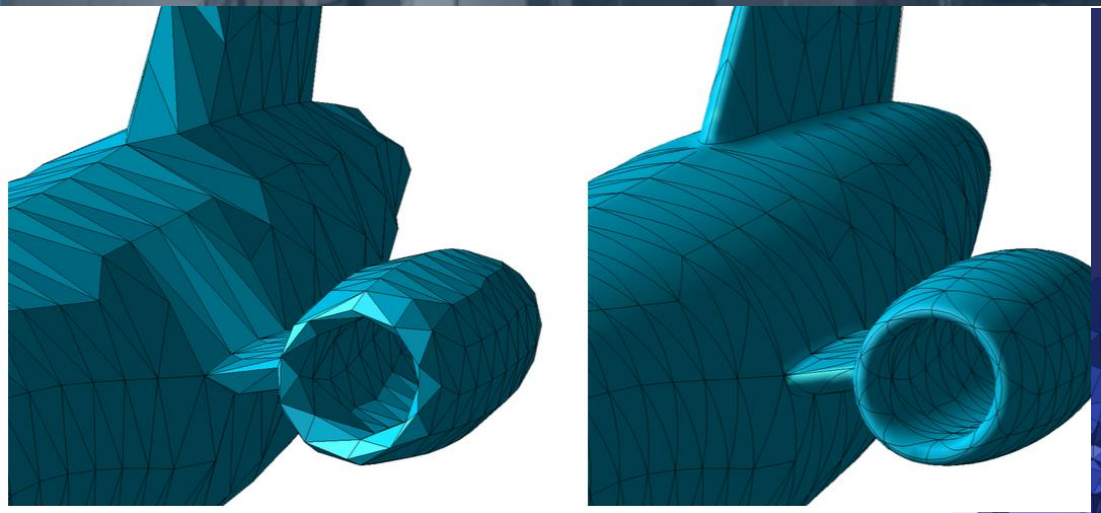
Paper: https://doi.org/10.1016/j.cpc.2023.109067

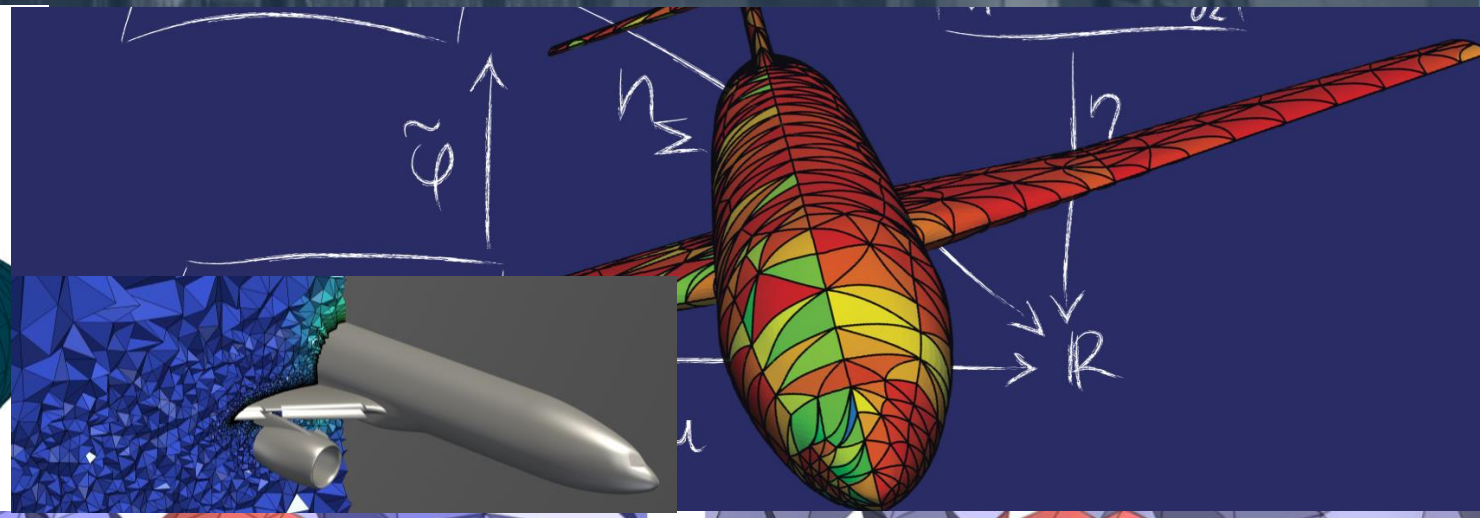
pyLOM: integration of VAE-beta autoencoders

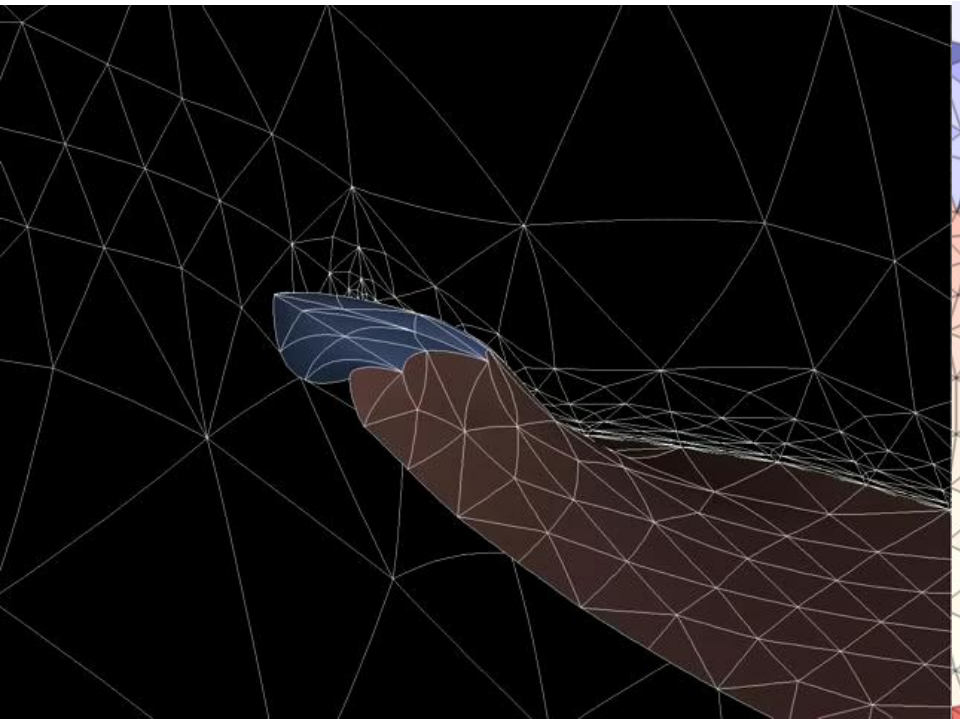
- Integration of VAE-Beta autoencoders inside the pyLOM
- Tested in a simplified at yaw angles of 2.5º, 5º and 10º
- 660 snapshots have been generated with WMLES at yaw angles of 2.5º, 5º and 10º
- A CNN variational autoencoder has been trained with the back-pressure
- The training and validation datasets have been splitted to have the same number of snapshots of each angle
- A latent space of size 2 was enough to recover the original dataset

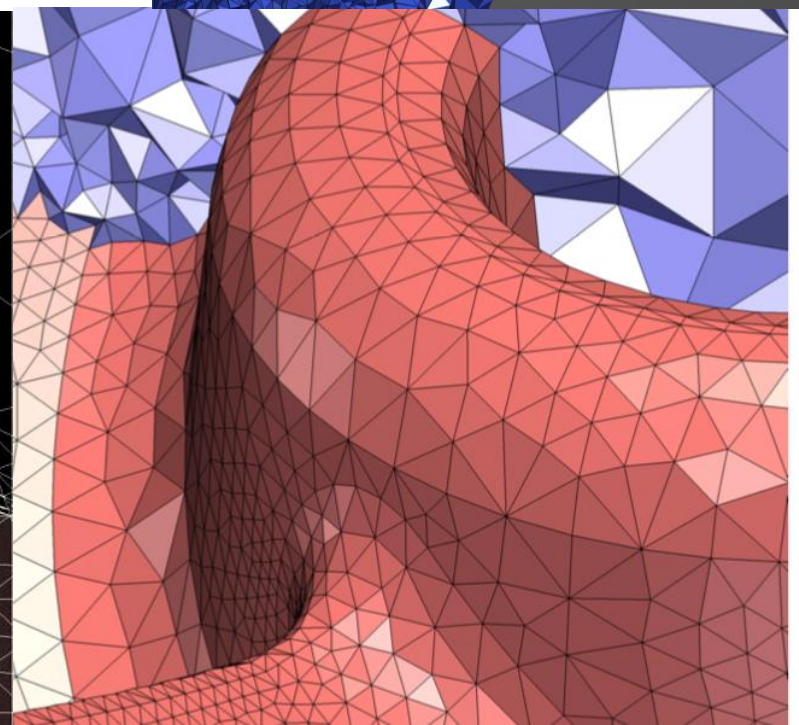


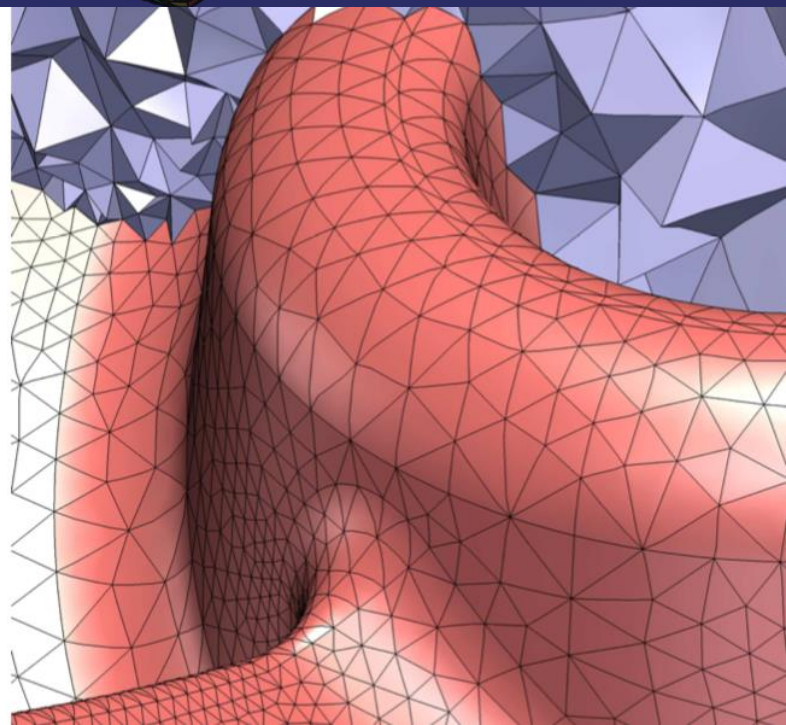
Meshing for high-fidelity simulation











Parallel mesh refinement using High Performance Computing

Source: https://en.wikipedia.org/wiki/Visby-class_corvette

Visby class corvette
Operator: Swedish Navy

General Characteristics
Type: corvette
Displacement: 640 tonnes
Length 72.7 m
Beam 10.4 m
Draught: 2.4 m
Speed: 40 mph
Range: 2.400 nmi at 17 mph

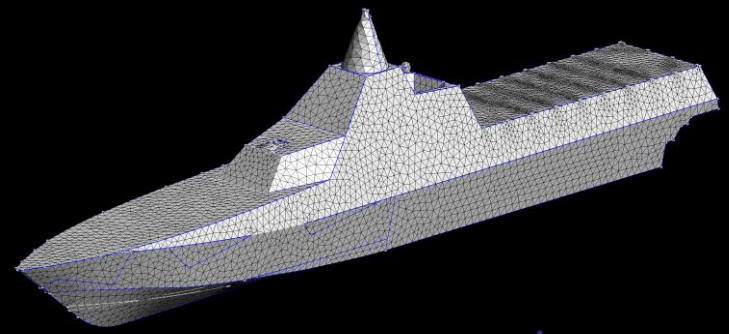
Mesh partitioning & refinement

Software: Alya Multyphysics
Machine: MareNostrum5
Architecture: GPP:

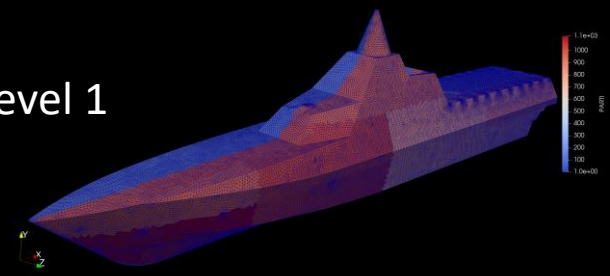
- 2x Intel Sapphire Rapids 8480+ at 2Ghz and 56c each (112 cores per node)
- 256 GB of Main memory, using DDR5 (with 216 nodes with 1024GB)
- 960GB on NVMe storage
- 1x NDR200 shared by 2 nodes (SharedIO)

No. of CPUs used: 1120

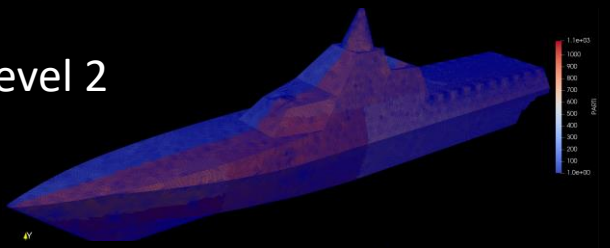
	Level 0	Level 1	Level 2	Level 3
No. of cells	288K	2.3M	18.4M	147M
Total CPU time [s]	-	0.01	0.04	0.4



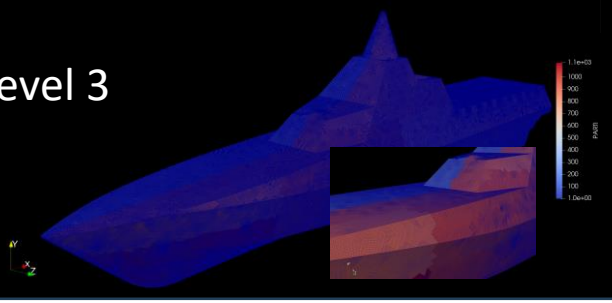
Level 1



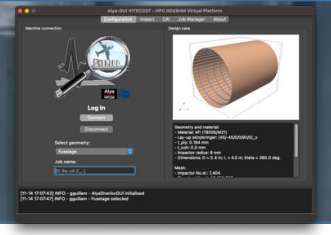
Level 2



Level 3



Structural mechanics HPC virtual platform to asses the fuselatge and complex geometries design

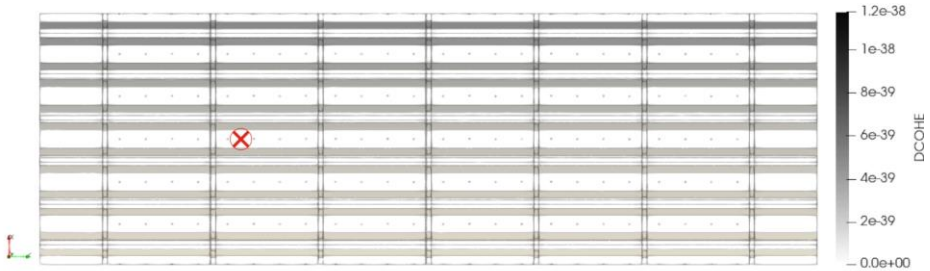


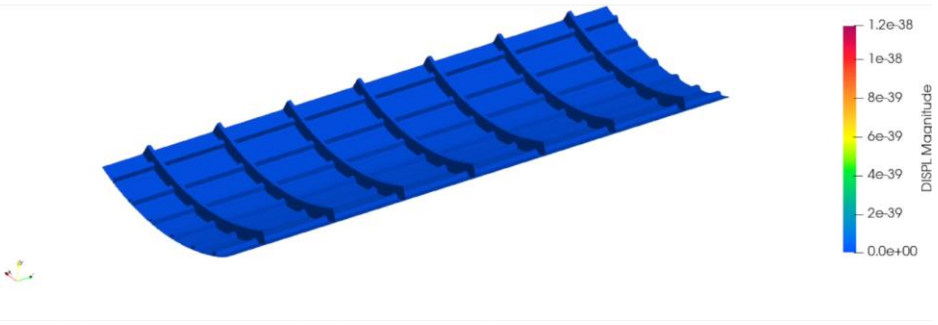
Imperial College London

POLITÉCNICA

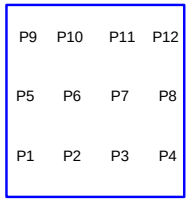
SHERLOC: Structural Health monitoring, manufacturing and Repair tecnologies for Life management Of Composite fuselage

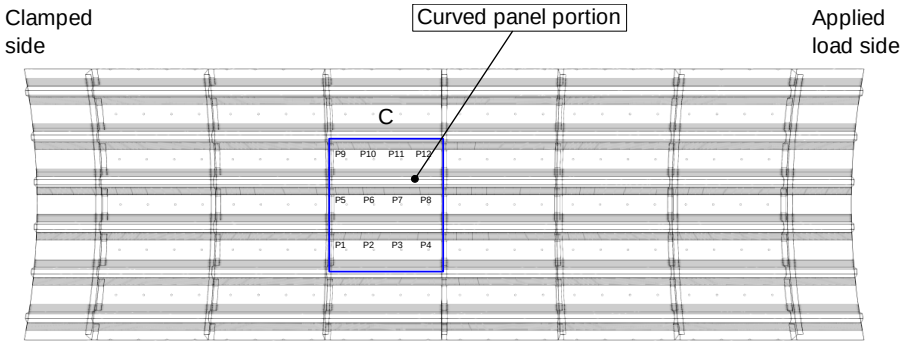
● Sensor ⊗ Impact from inside (skin/stringer's foot 23~31J) ⊙ Impact from fuselage-skin side 20~25J

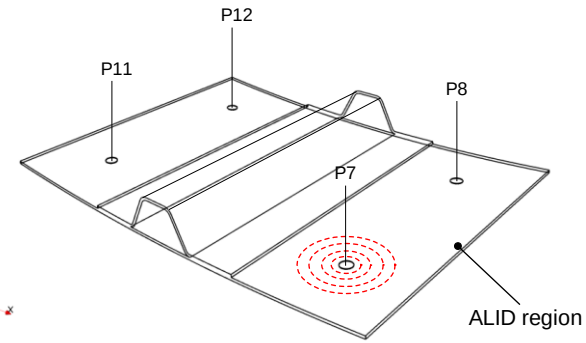


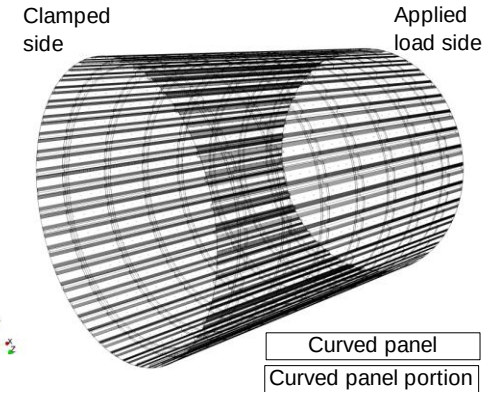


17 impact simulations on a 5-m curved panel using 2400 CPUs with average cpu-time of 4h for each impact

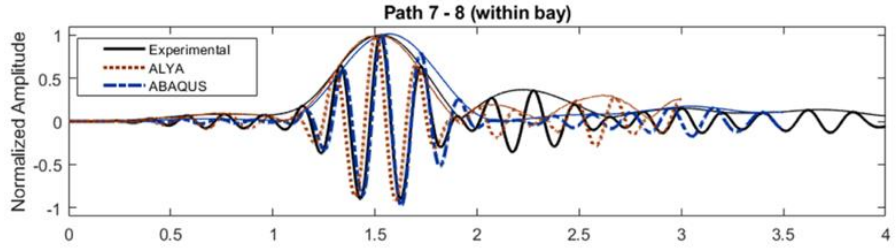








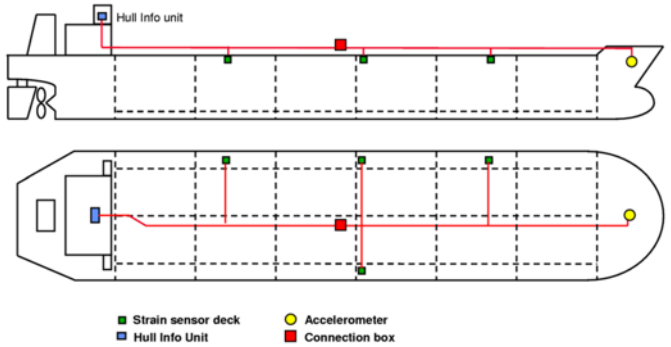
SHM Curved portion (15M dof)	Impact + SHM Curved panel (22M doF)	SHM Fuselage (160M dof)
768	1200	2400
~10 min	~4h impact + ~13 min SHM	~35 min



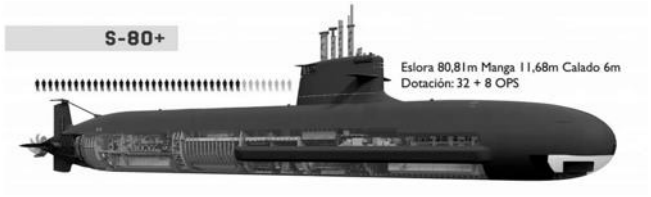
BSC has developed an HPC virtual platform to assist the design of a smart fuselage by damage tolerance (multi-impact) and SHM

Potential Applications of SHM systems in Naval Engineering

Structural Health Monitoring



Source: G. Sagvolden and K. Pran



Source: G. Sagvolden and K. Pran

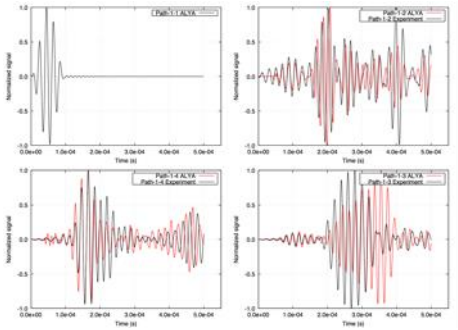
Fiber Optic SHM systems have been in operation in Naval vessels for 20 years
Passive sensing (no electrical power)
Surface-mounted & in some cases embedded (in case of composites)

Critical problems

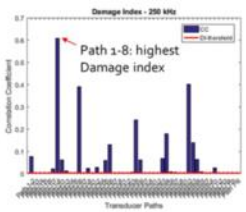
- Localized corrosions (long-period hull thickness)
- Short term overload detection
- Long term fatigue analysis (induced by periodic solicitations and hydrodynamic motion)
- Critical deformation values

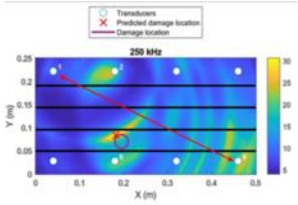
Aim of monitoring

Increase safety & reduce costs by conditionent-based maintenance



Leverage various sets of expertise and tools available at BSC for (i) modeling and (ii) AI application





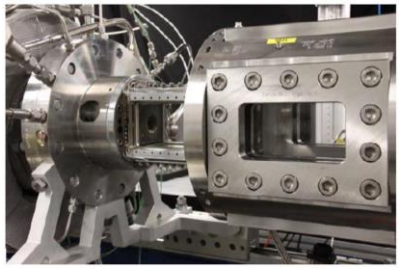
Digital technologies for power and propulsion

- Research activities

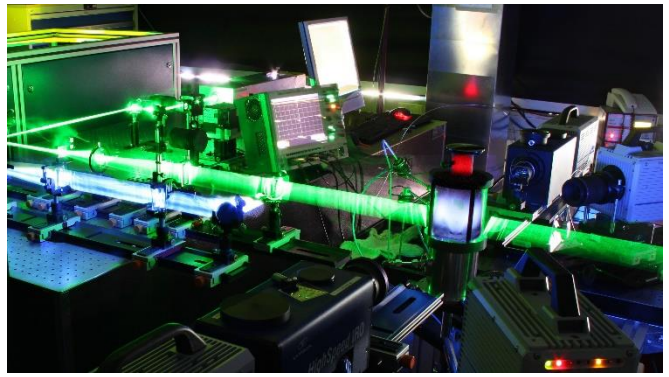
EU *decarbonization strategy* in power generation and transportation

- High-fidelity simulations of multiphysics systems
- HPC- and Exascale-enabling methodologies
- Data-driven methods and Artificial Intelligence
- *Applications*: Propulsion & Power generation, and Electromobility

Hydrogen combustion (propulsion and power)



Aeroengine combustion



Electromobility and P2X

Study of primary breakup and fuel atomization

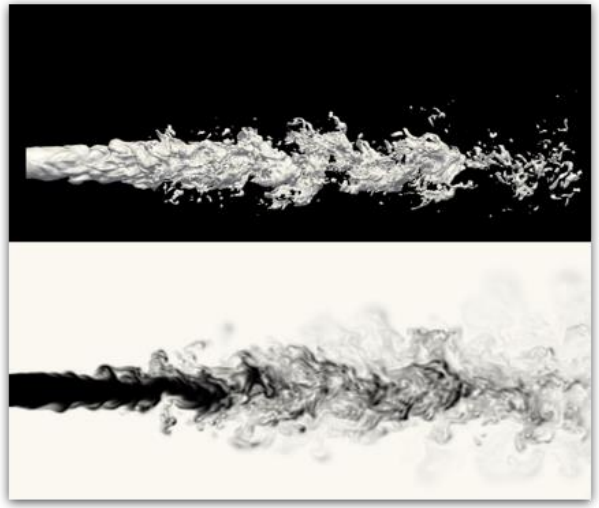
From dense to dilute sprays

Fuel atomization has large impact on:

- ✓ Spray length and spreading
- ✓ Fuel/air mixing
- ➢ Unburnt hydrocarbons
- ➢ Formation of pollutants

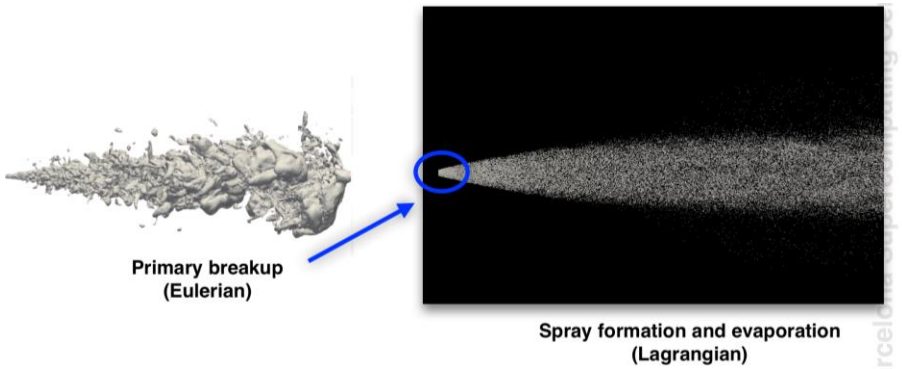
Engine overall efficiency

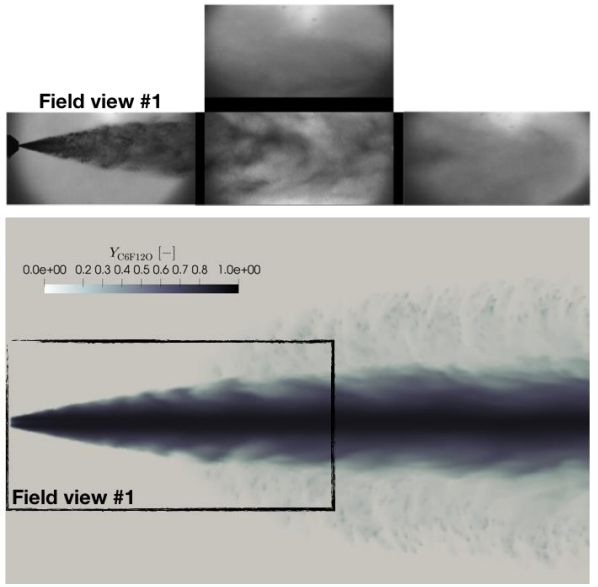
- ➢ Fuel consumption
- ➢ Power and thrust
- ➢ Emissions

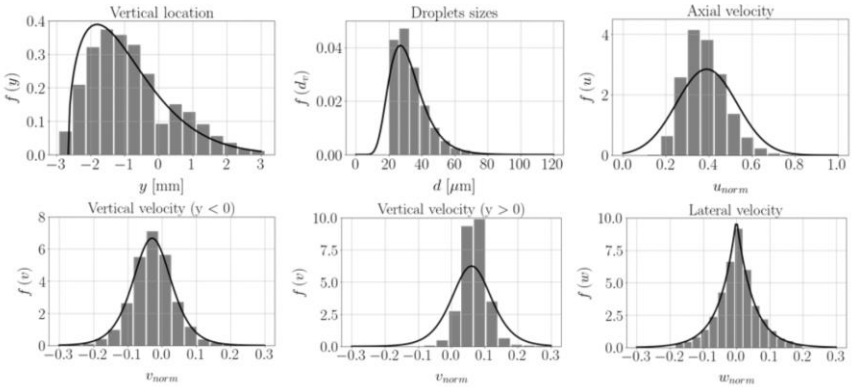


Round jet injector n-dodecane

Development of primary breakup models





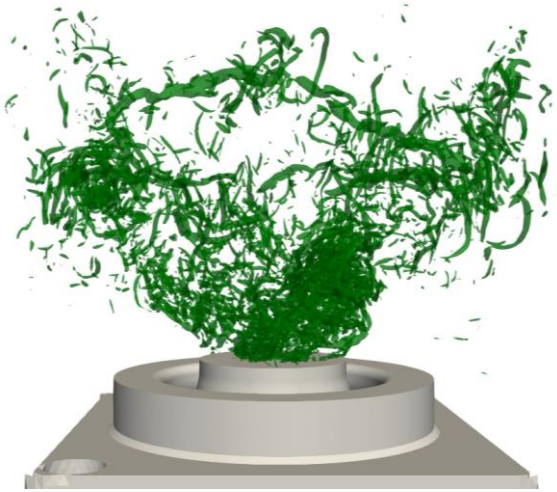


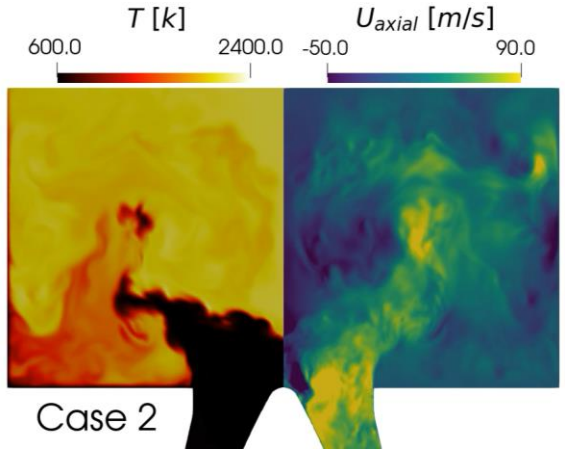
Applications of hydrogen combustion
(e.g. Generation of high-fidelity synthetic data for IRST)

H2/NH3 combustion for propulsion applications

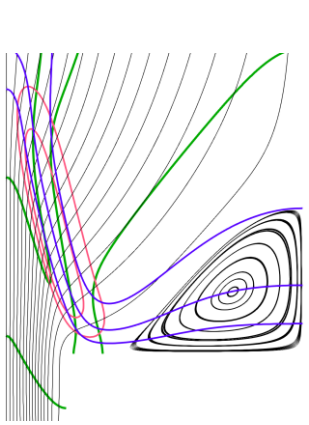
Motivation and scientific questions

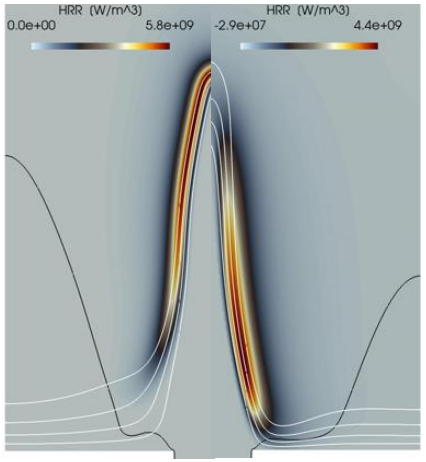
1) Flame stabilization in gas turbines and aircraft engines
2) H2-enrichment in natural gas and high-pressure
3) Flashback, instabilities and NOx formation

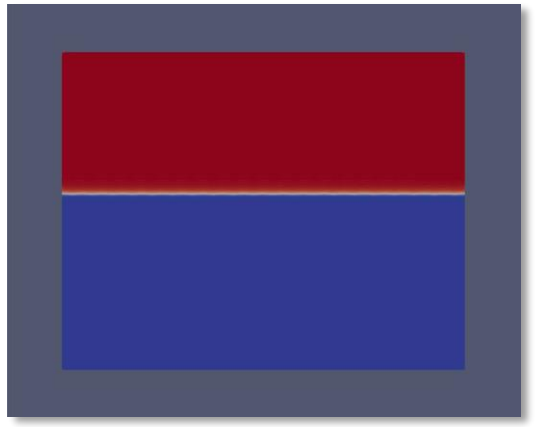




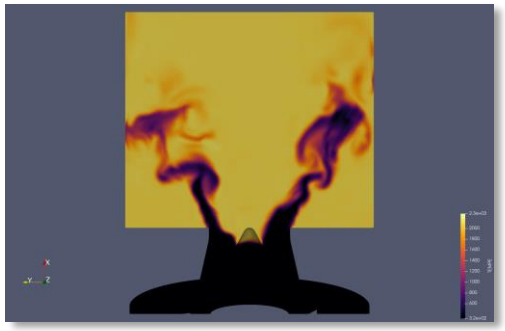
High-pressure H2-enriched natural gas flames

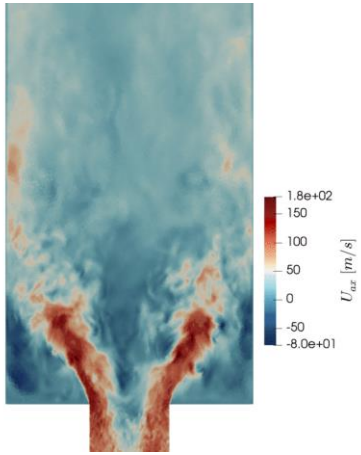


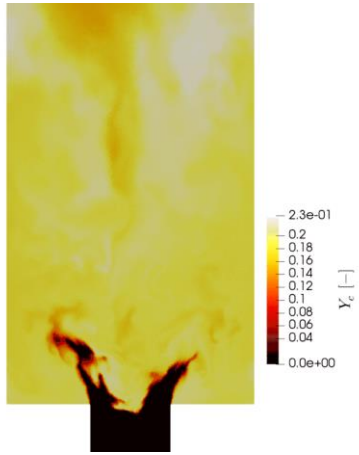




Thermodiffusive instabilities and acoustics in H2 flames







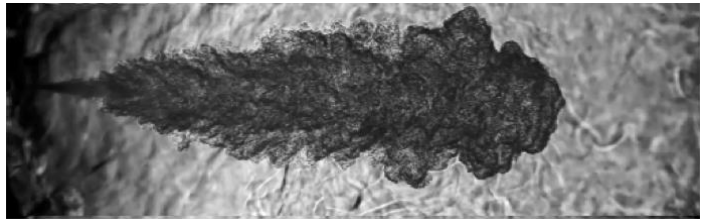
H2 combustion near flashback conditions in GTs

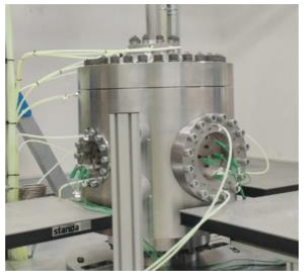
Combustion of liquid e-fuels

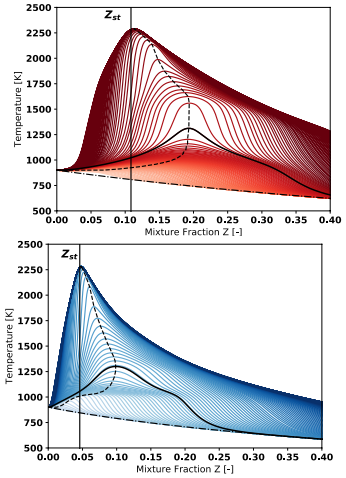
High-pressure spray flames of renewable fuels in RCE

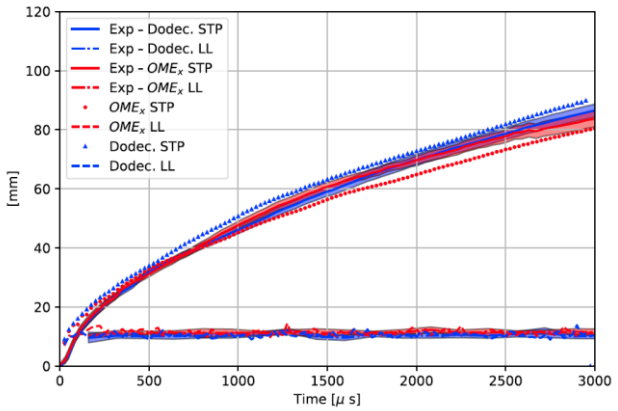
Motivation and scientific questions

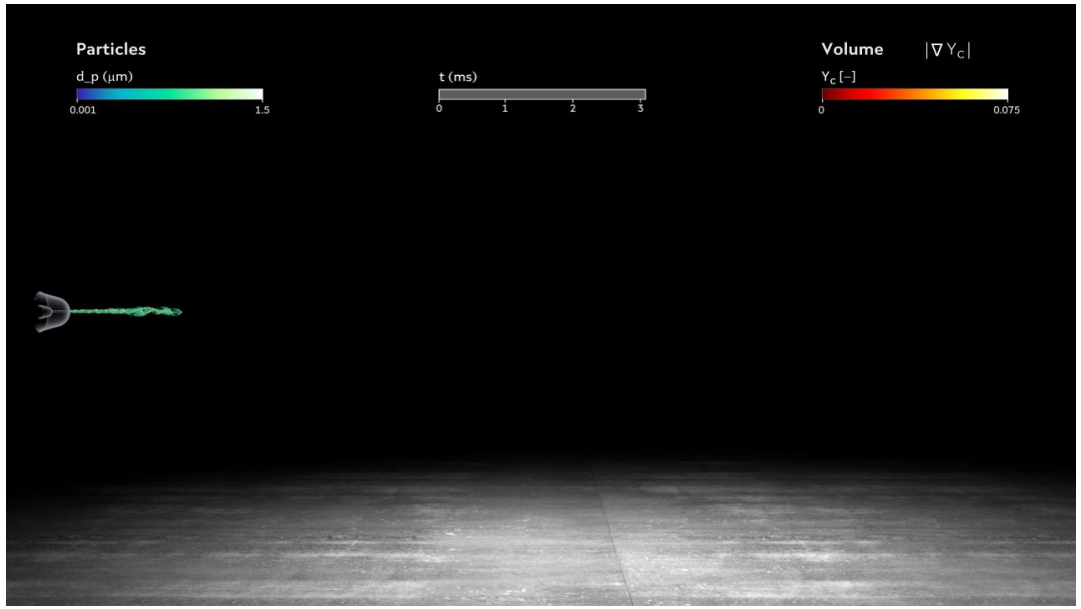
1) Virtual platform development
2) Prediction ID, LOL and spray flame parameters
3) IC-engine like conditions (60 bar)











EXCELLERAT

Center of Excellence in Combustion

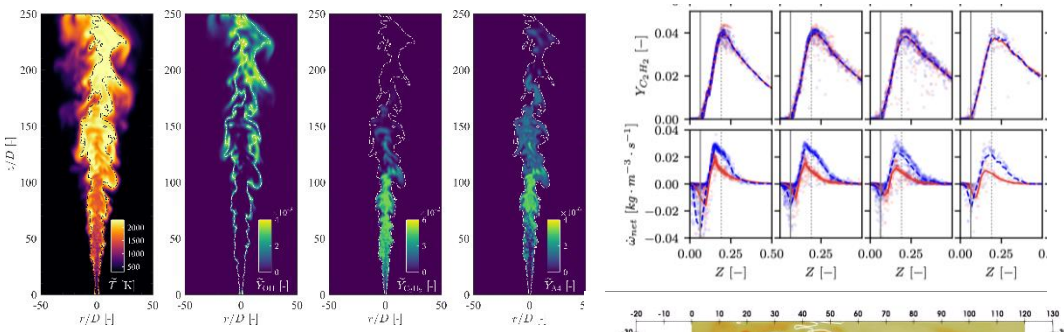
Emissions and pollutant formation

Develop advanced emissions models (Soot, Nox, etc)

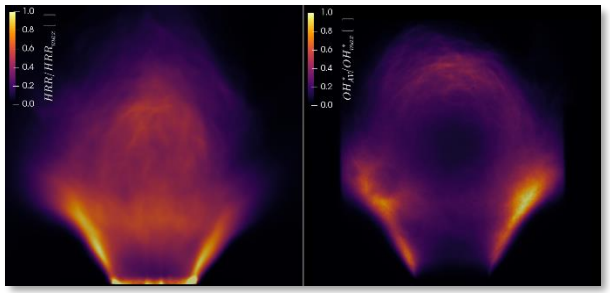
Motivation and scientific questions

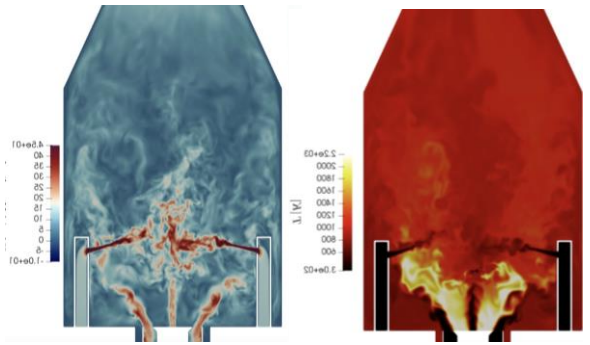
1) Influence of fuel on soot emissions in aeroengines
2) NOx, SO_2, and UHC
3) Soot formation and emissions signature

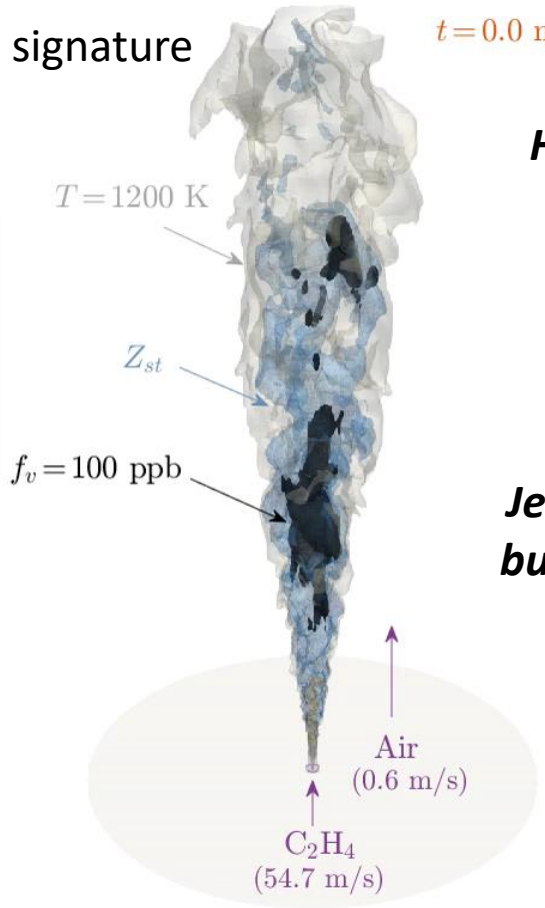
Sandia ISF



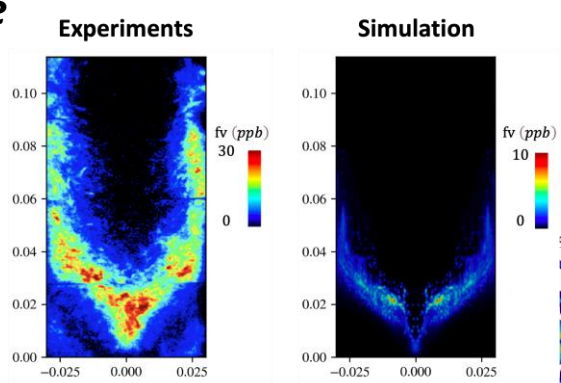
Cambridge RQL

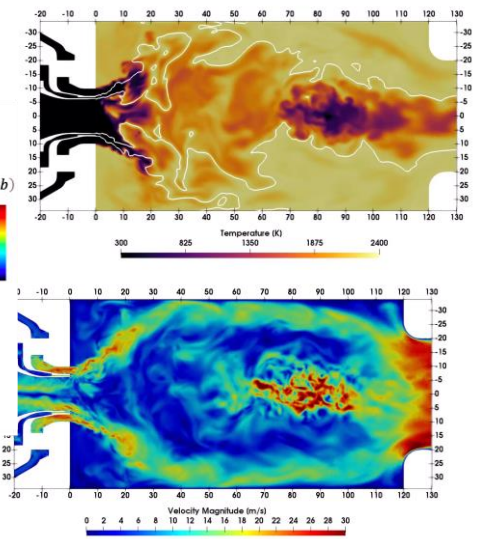






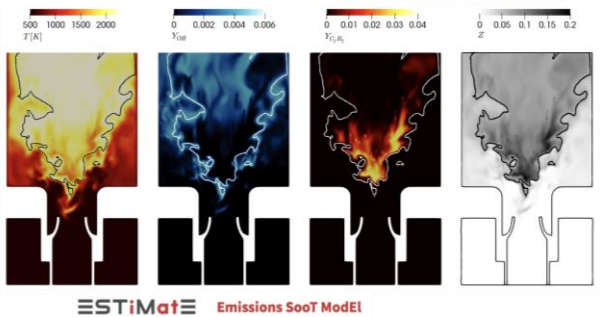
High-pressure aeroengine model





OpenFoam: LES - FGM - ATF / S-EQMOM

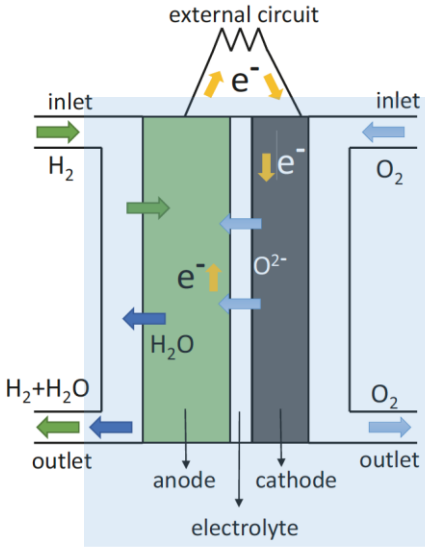
Jet A1 burner

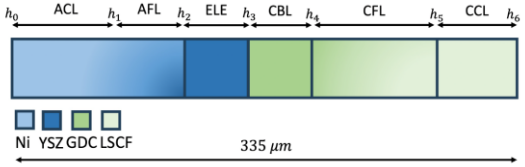


Electric propulsion systems

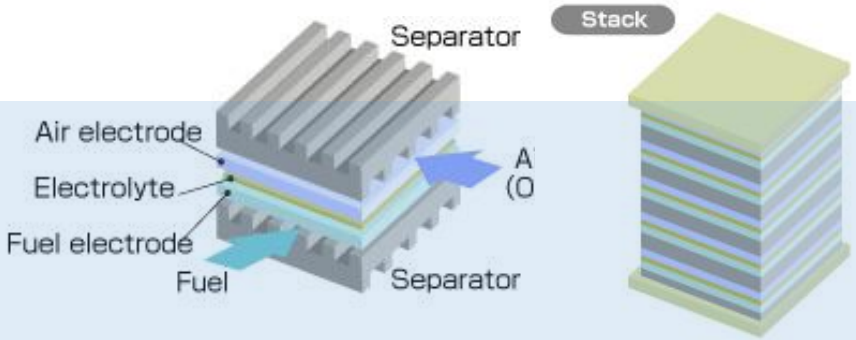
Development of 3D high-fidelity models of SOFC

Mechanisms description

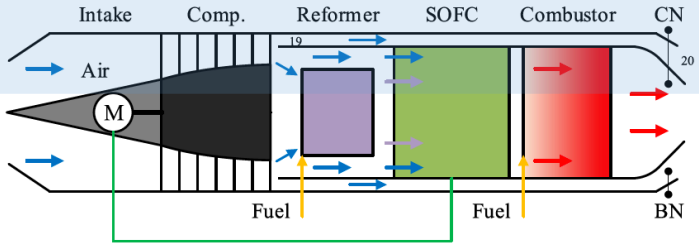




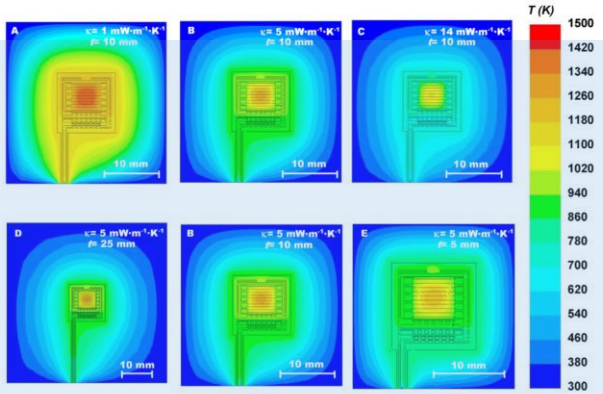
Cell numerical model



Hybrid engines model

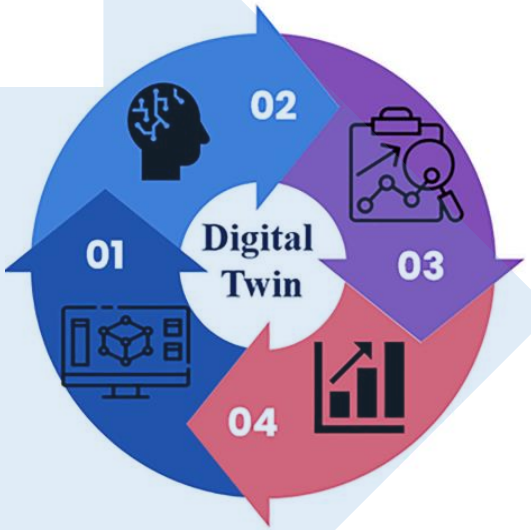


Multiphysics simulations



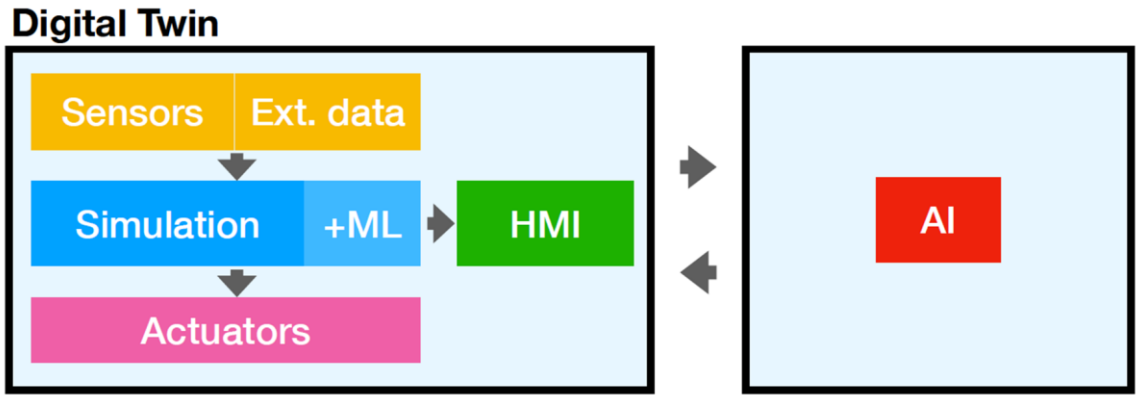
- Cell efficiency
- Safety aspects
- Design optimizations

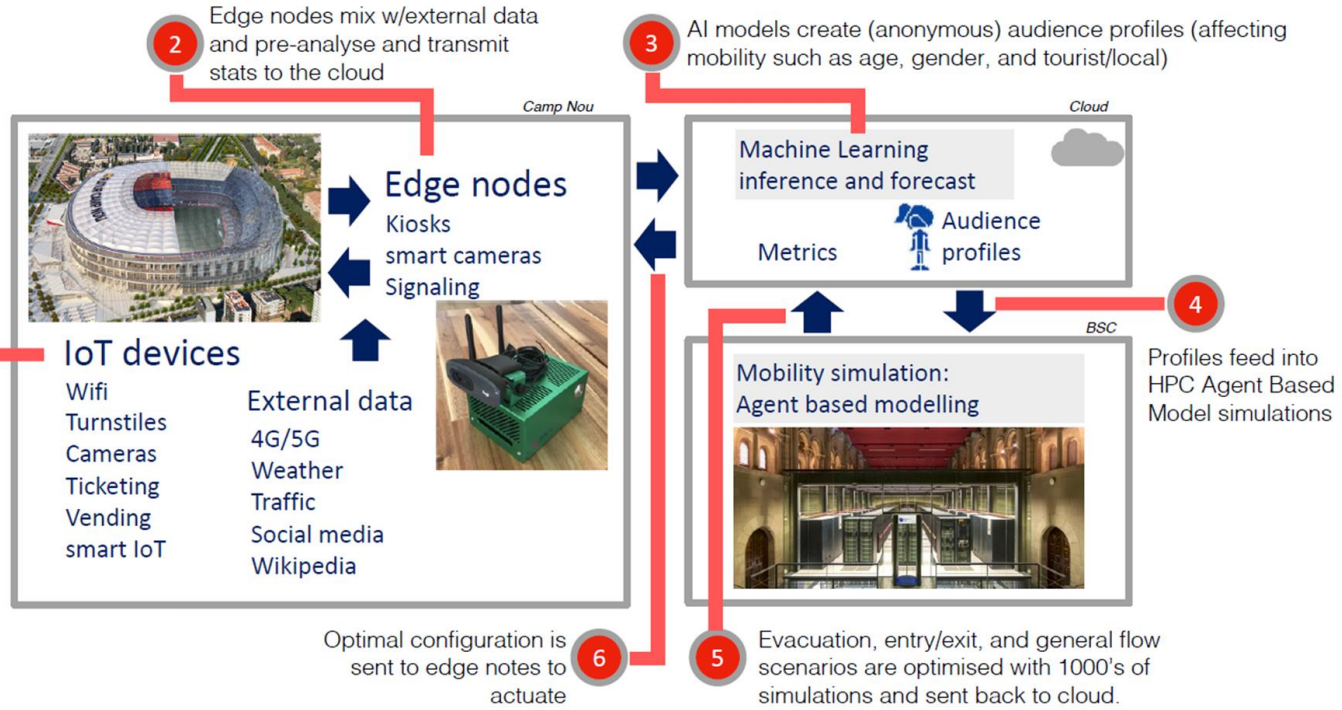
SOFC Digital twin

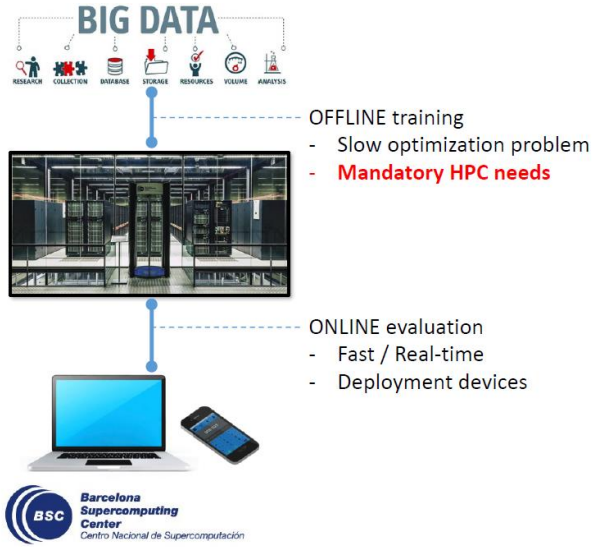


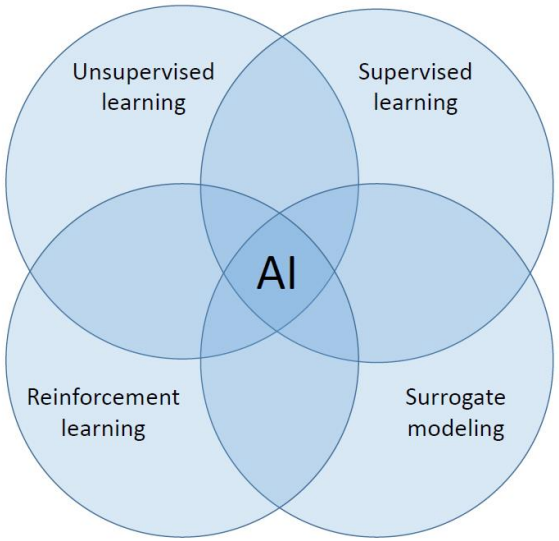
- Optimization
- Real-time monitoring
- Decisión making

AI and HPC for digital twins: multi-fidelity and multi-scale









BSC-CNS partners in dual-use projects

TECHNISCHE UNIVERSITÄT DARMSTADT

UNIVERSITY OF CAMBRIDGE

Navantia

isae Institut Supérieur de l'Aéronautique et de l'Espace ENSMA

CTR Stanford University CENTER FOR TURBULENCE RESEARCH

JÜLICH Forschungszentrum

SIEMENS

SAFRAN

Queen's University

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

ETH zürich

TU/e Technische Universiteit Eindhoven University of Technology

ROLLS ROYCE

AIRBUS

REPSOL

INTA

AIRBUS DEFENCE & SPACE

ERCOFTAC European Research Community On Flow, Turbulence And Combustion

Shell Aviation

HLRS High-Performance Computing Center | Stuttgart

Destinus

DLR Institute of Combustion Technology

Technische Universität Berlin

ITP Aero

tecnobit grupo oesía

KIT Karlsruher Institut für Technologie

CERFACS CENTRE EUROPÉEN DE RECHERCHE ET DE FORMATION AVANCÉE EN CALCUL SCIENTIFIQUE

Imperial College London

RWTH AACHEN UNIVERSITY

UMR 6614 CORIA COMPLEXE DE RECHERCHE INTERPROFESSIONNEL EN AEROTHERMOCHIMIE

SEAT

H2B2 Electrolysis Technologies

fives Industry can do it

BOEING

KTH VETENSKAP OCH KONST

POLITÉCNICA

uc3m Universidad Carlos III de Madrid

CT ENGINEERING DRIVEN PEOPLE

NUMECA INTERNATIONAL

E&M COMBUSTION energía y medio ambiente

CELSA GROUP

Barcelona Supercomputing Center-Centro Nacional de Supercomputación (BSC-CNS)

- **Spanish National Supercomputing Center**
- 100% Public Institution
- **Dual-use HPC** (hardware & software) **knowledge repository**
- Two main S&T pillars**: Engineering (CASE)**, **Computer Sciences**
- Support the **Spanish R&D promoted programmes**
- Support the National **Academia and Research** community
- Support the Spanish **Dual-use Technologies Industry**
- Fully complementary to **experimental experts**
- Bridge the gap between **research and industry**

EUROPEAN UNION
EUROPEAN DEFENCE FUND

COINCIDENTE
DGAM

GOBIERNO DE ESPAÑA
MINISTERIO DE DEFENSA

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

HPC for DUAL-USE TECHNOLOGIES (2024-2025): #1 Spain

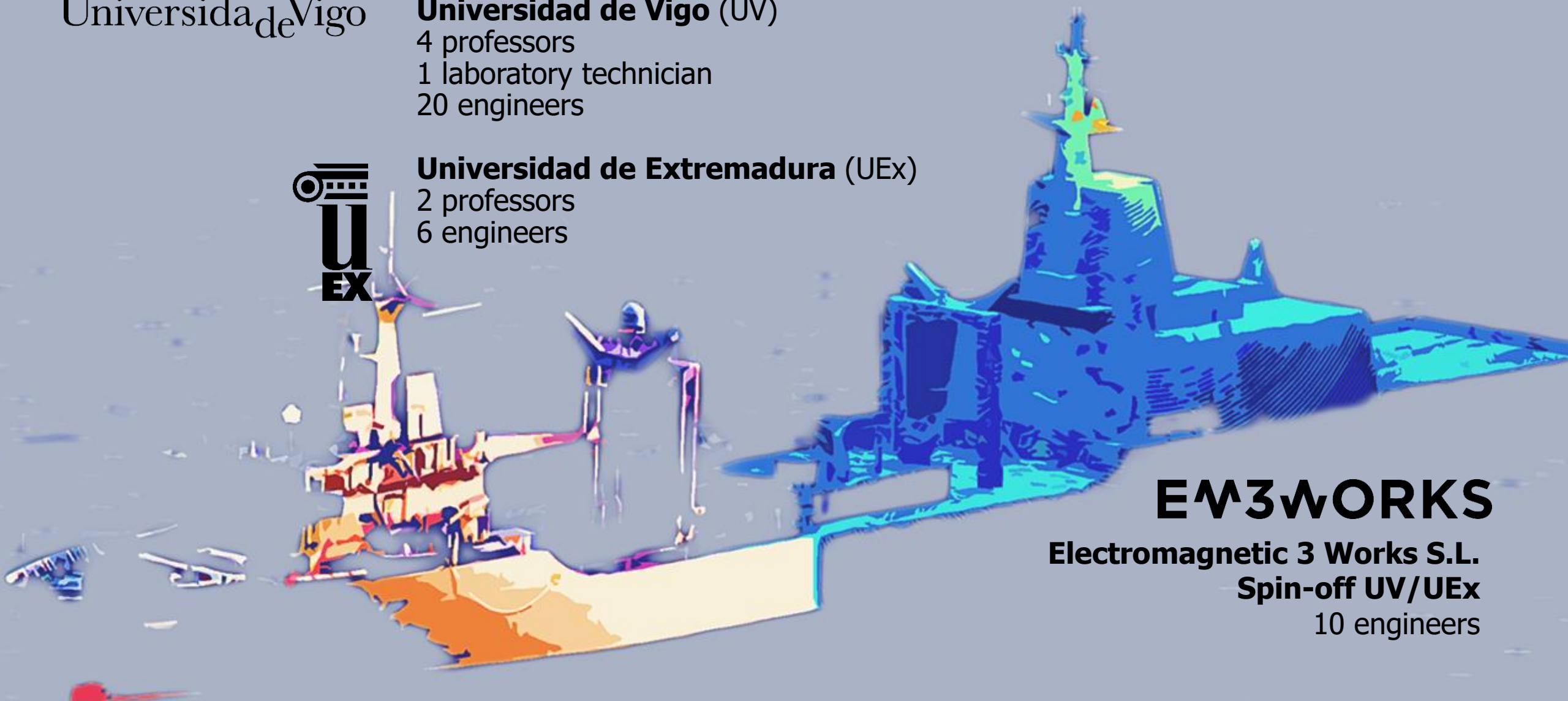
RES RED ESPAÑOLA DE SUPERCOMPUTACIÓN
PRACE
ETP 4 HPC
BDV

The EM3W team

Universidad de Vigo

Universidad de Vigo (UV)
4 professors
1 laboratory technician
20 engineers

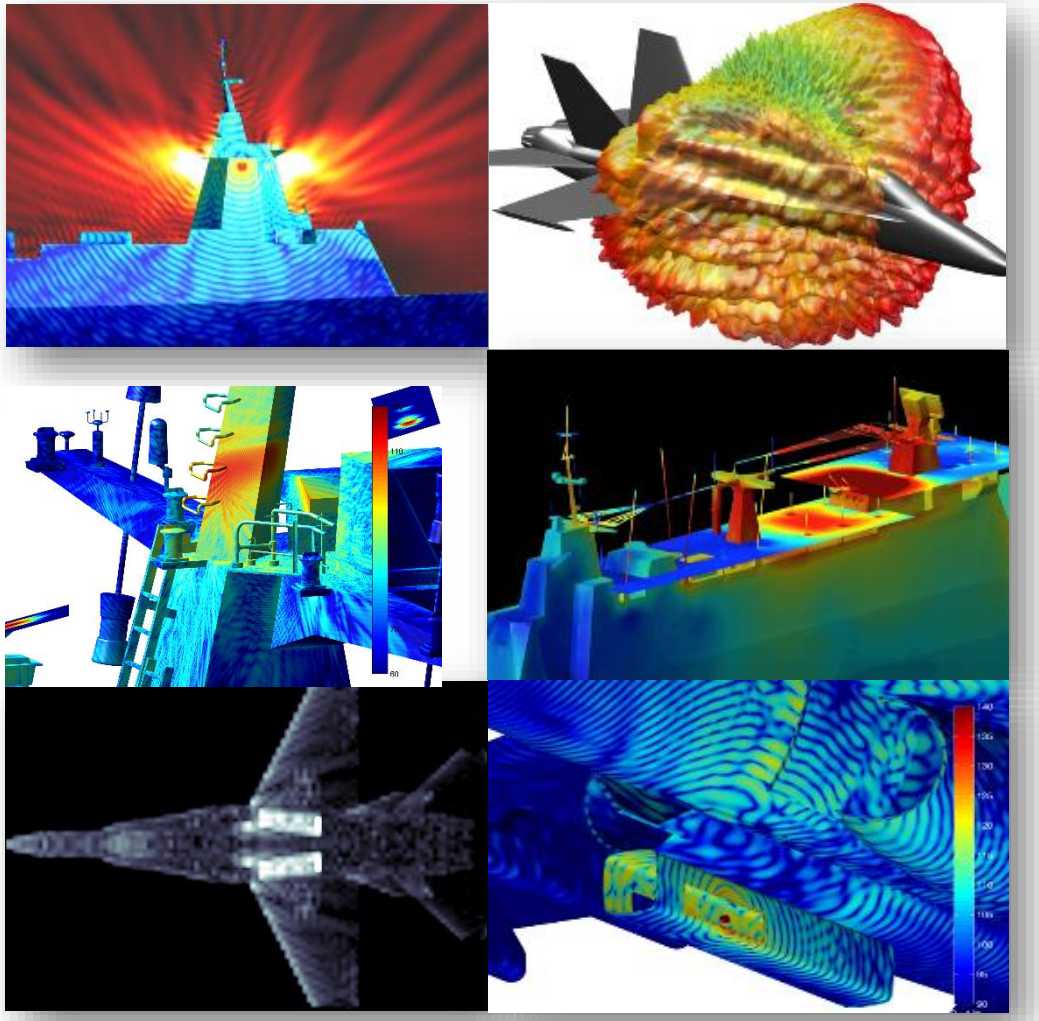
Universidad de Extremadura (UEx)
2 professors
6 engineers



EM3WORKS

Electromagnetic 3 Works S.L.
Spin-off UV/UEx
10 engineers

The complex warship environment

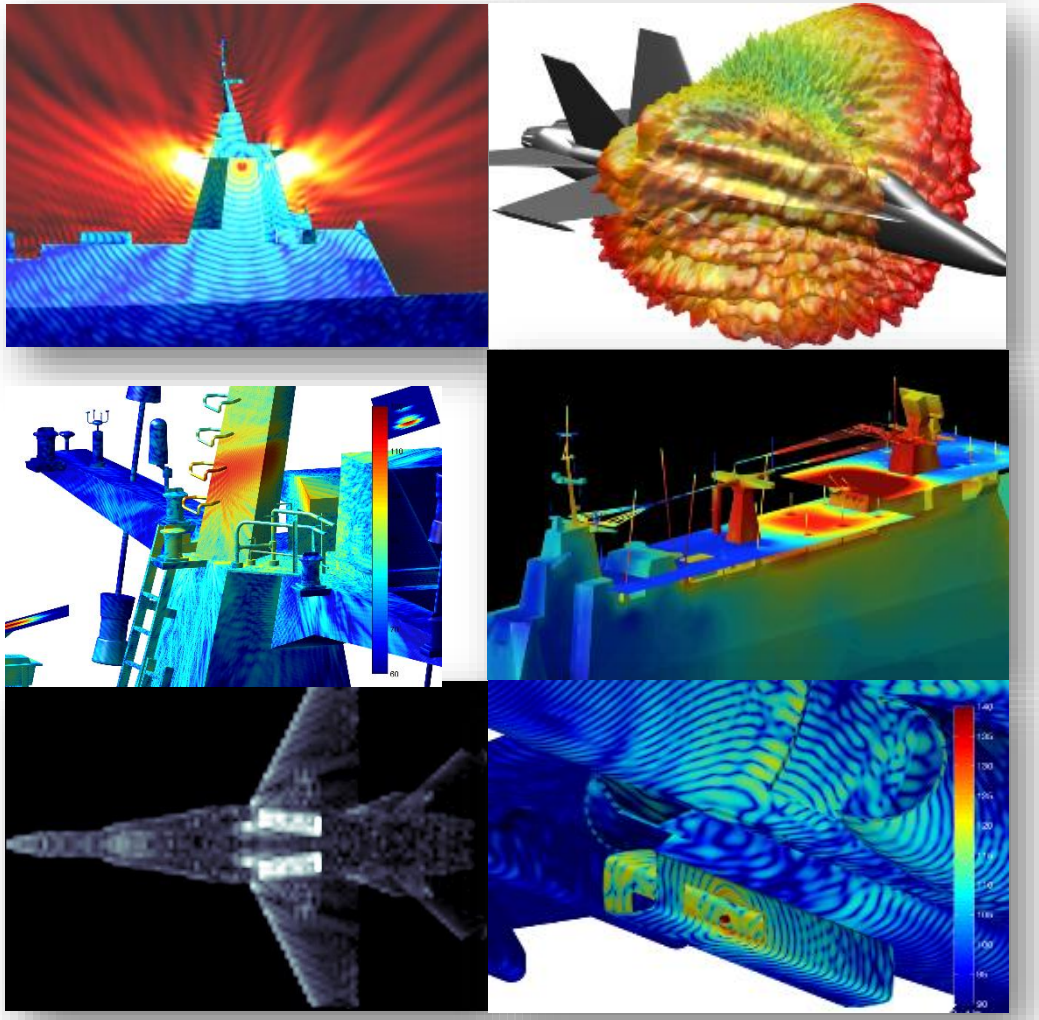


Warships are very complex electromagnetic (EM) environments, including hundreds of antennas belonging to multiple systems (electronic warfare, radar, and communications) in a very small space on the topside.

These systems integrate powerful transmitters and together with highly sensitive receivers, all working together in the whole frequency range (LF-K).

Sometimes transmitters may cause certain performance losses, make operation difficult, or even cause permanent damage (**burnout**) to the receivers, due to the interference caused on them, or even generate potentially dangerous situations due to EM radiation (RADHAZs)

Electromagnetic Environmental Effects (E3)



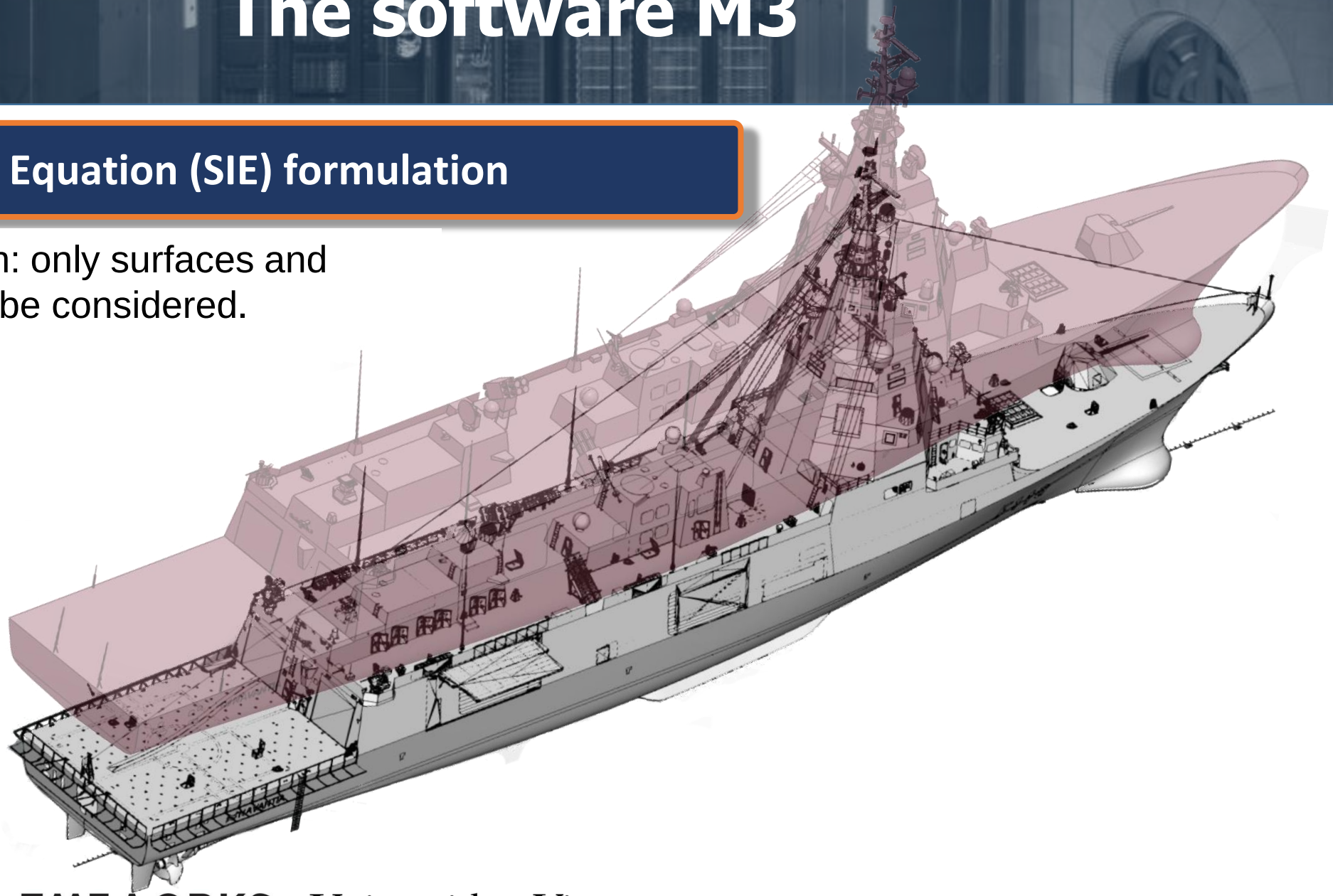
The effective management of all these issues is called E3 (Electromagnetic Environmental Effects) and has acquired a fundamental role in the initial design stages of a modern warship.

E3 includes disciplines such as: electromagnetic compatibility (EMC), electromagnetic interference (EMI) and hazardous radiation (RADHAZ) or electromagnetic radiation (EMR), both for personnel (HERP), armament (HERO) and fuels (HERF); along with TEMPEST control policies.

The software M3

Surface Integral Equation (SIE) formulation

2D parametrization: only surfaces and interfaces have to be considered.

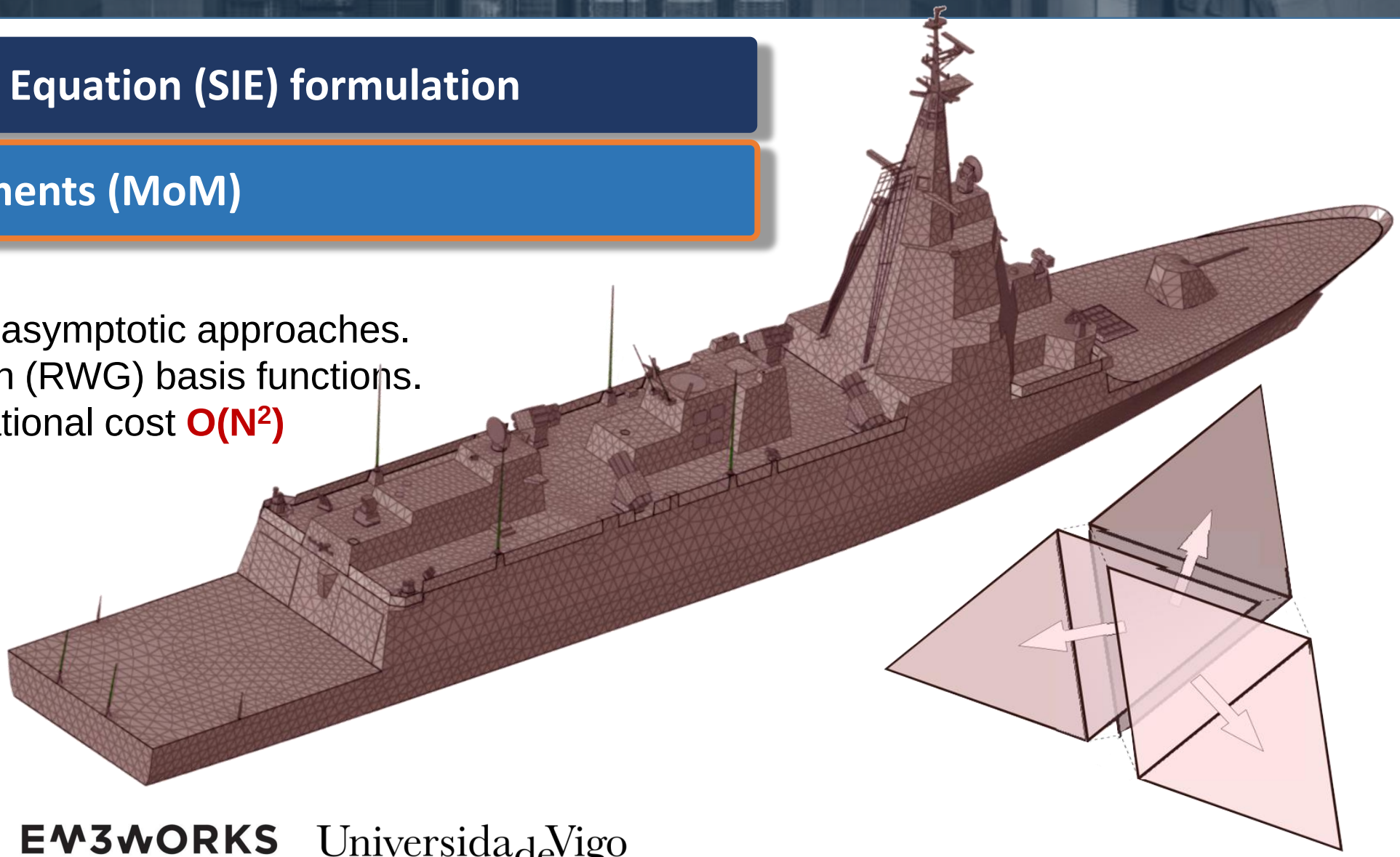


The software M3

Surface Integral Equation (SIE) formulation

Method of Moments (MoM)

Exact solution.
High precision, no asymptotic approaches.
Rao-Wilton-Glisson (RWG) basis functions.
Very high computational cost **$O(N^2)$**



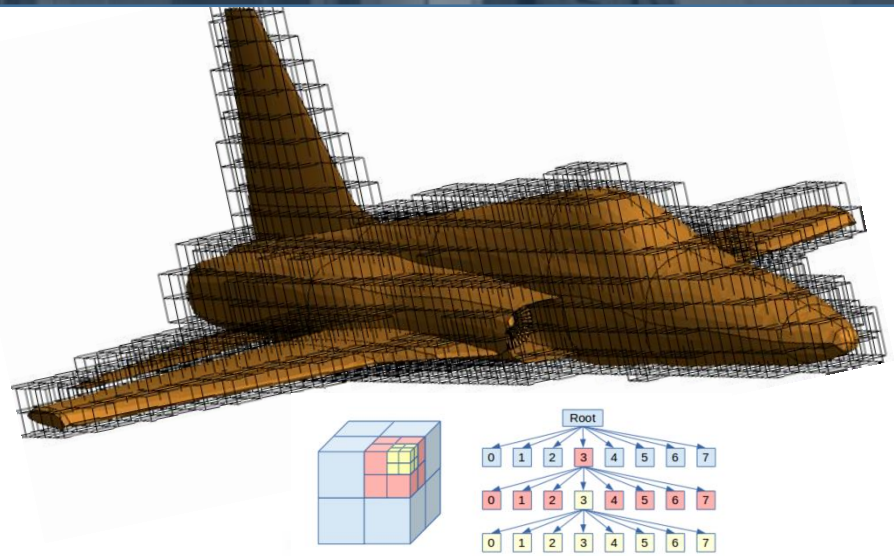
The software M3

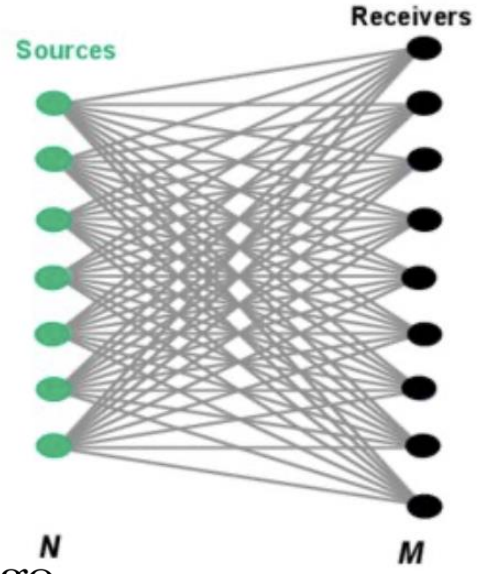
Surface Integral Equation (SIE) formulation

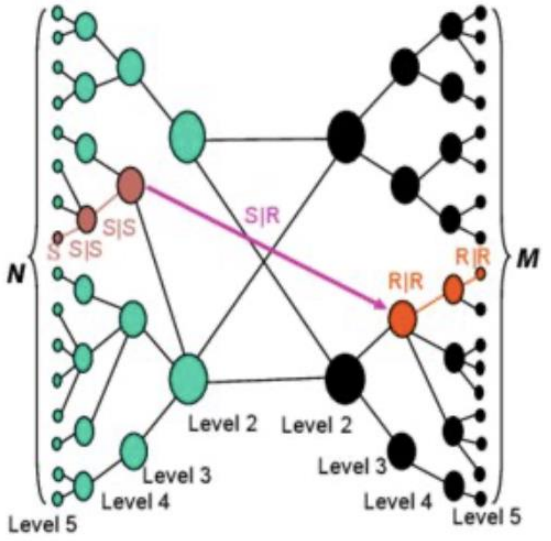
Method of Moments (MoM)

Multilevel Fast Multipole Algorithm (MLFMA)

Spectral acceleration
Lowest achievable cost in CEM
Computational cost **O(N log N)**







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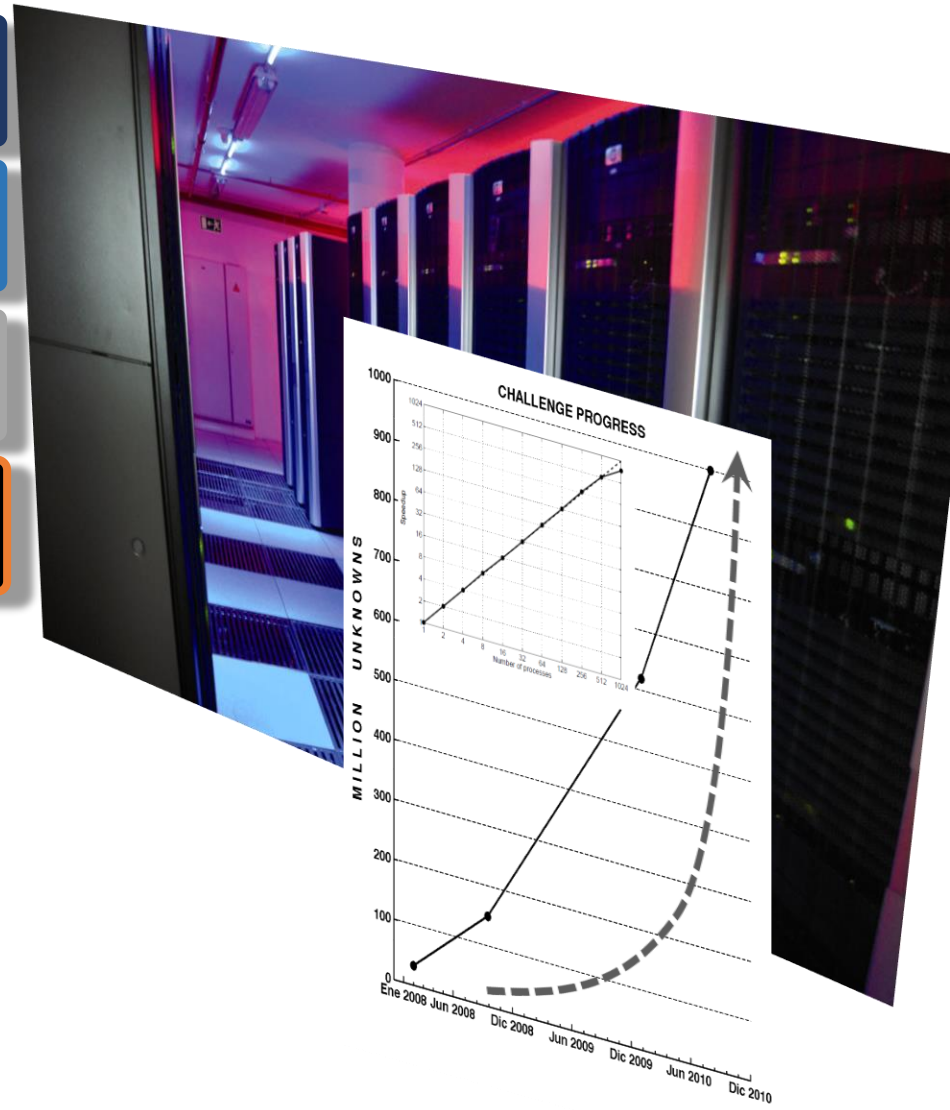
EM3WORKS

Universidad de Vigo

The software M3

- Surface Integral Equation (SIE) formulation
- Method of Moments (MoM)
- Multilevel Fast Multipole Algorithm (MLFMA)
- **MLFMA – Fast Fourier Transform (MLFMA-FFT)**

High scalability, maximum efficiency up to thousands of cores
Suitable for high performance computers (HPC)



The software M3

Surface Integral Equation (SIE) formulation

Method of Moments (MoM)

Multilevel Fast Multipole Algorithm (MLFMA)

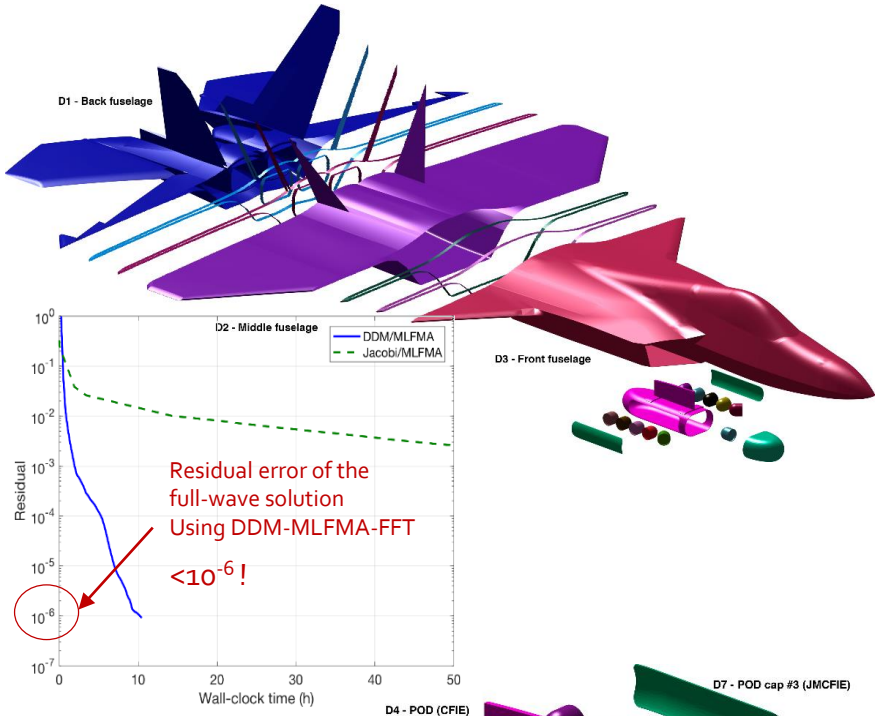
MLFMA – Fast Fourier Transform (MLFMA-FFT)

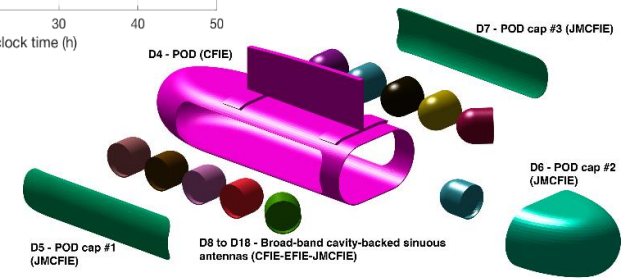
Domain Decomposition Method (DDM)

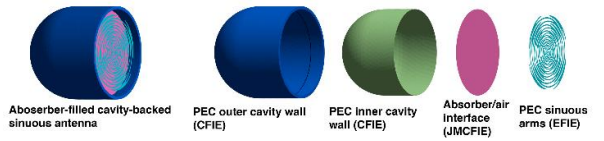
Divide and conquer strategy.

Multi-scale and **multi-material** problems.

Hyper-fast convergence







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EM3WORKS

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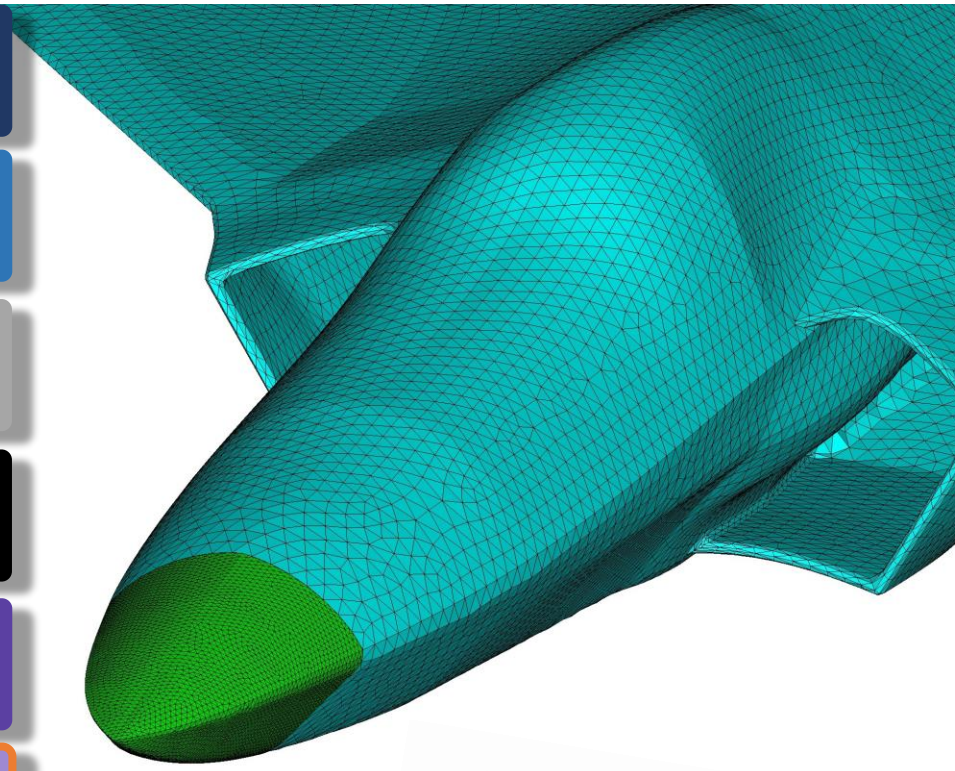
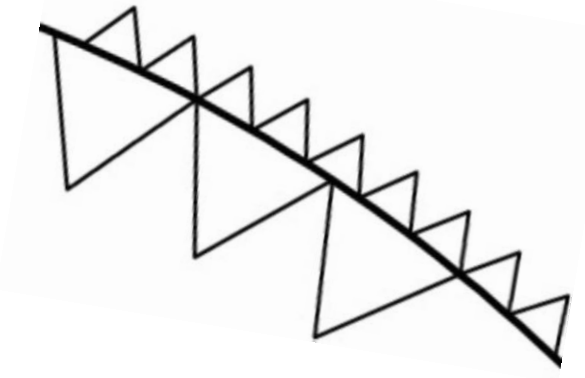
The software M3

- Surface Integral Equation (SIE) formulation
- Method of Moments (MoM)
- Multilevel Fast Multipole Algorithm (MLFMA)
- MLFMA – Fast Fourier Transform (MLFMA-FFT)
- Domain Decomposition Method (DDM)
- Discontinuous Galerkin





Non conformal meshing. Facilitating CAD and meshing process.

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Centro Nacional de Supercomputación

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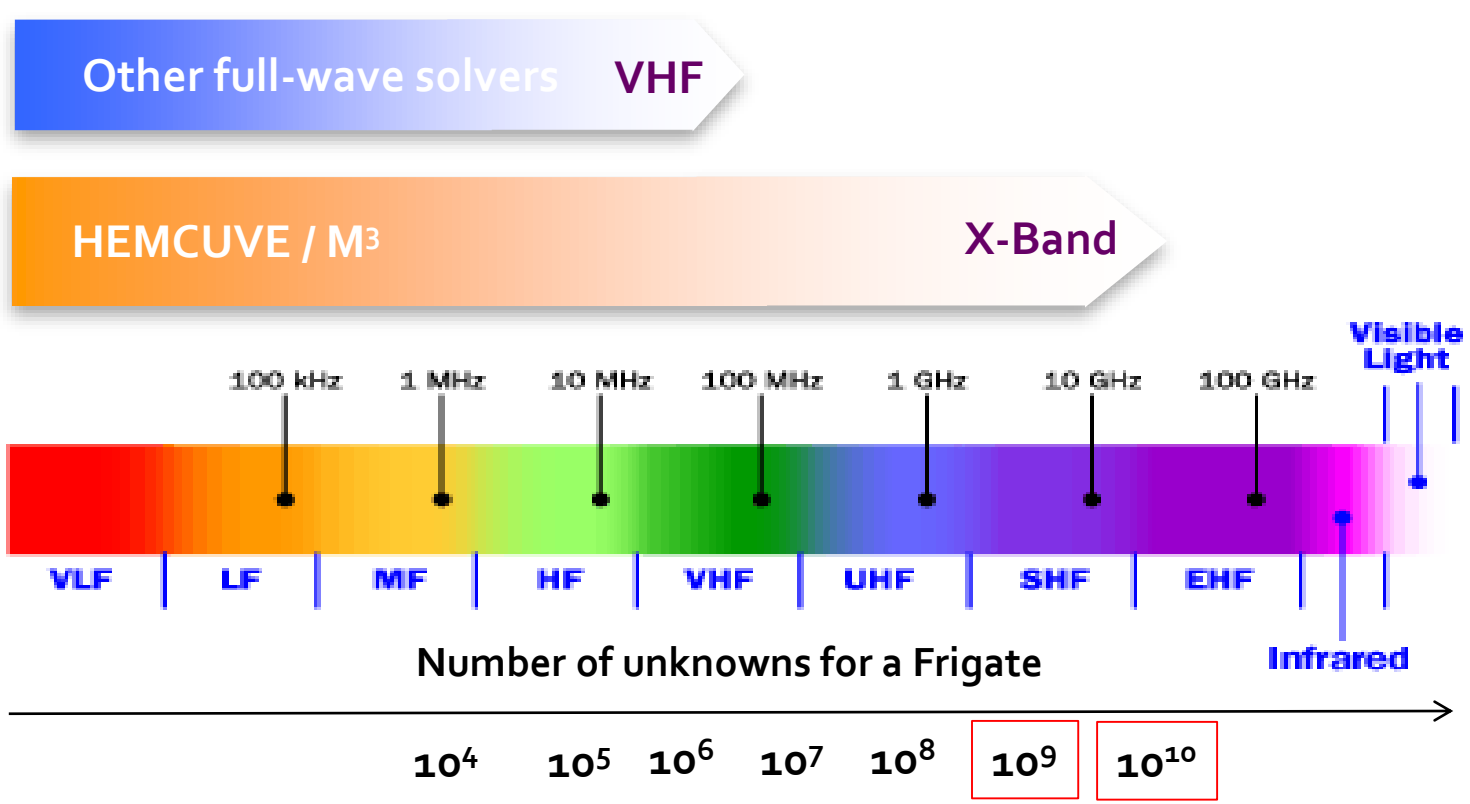
The software M3

PRACE Award 2009

ITANIUM SOLUTIONS ALLIANCE
101001
10110100110
00110110100001
1011010
COMPUTATIONALLY INTENSIVE
WINNER
INNOVATION AWARD



World Record in computational electromagnetics
10^9 unknows (year 2010)

HEMCUVE / M3
WORLD RECORD (2010)

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

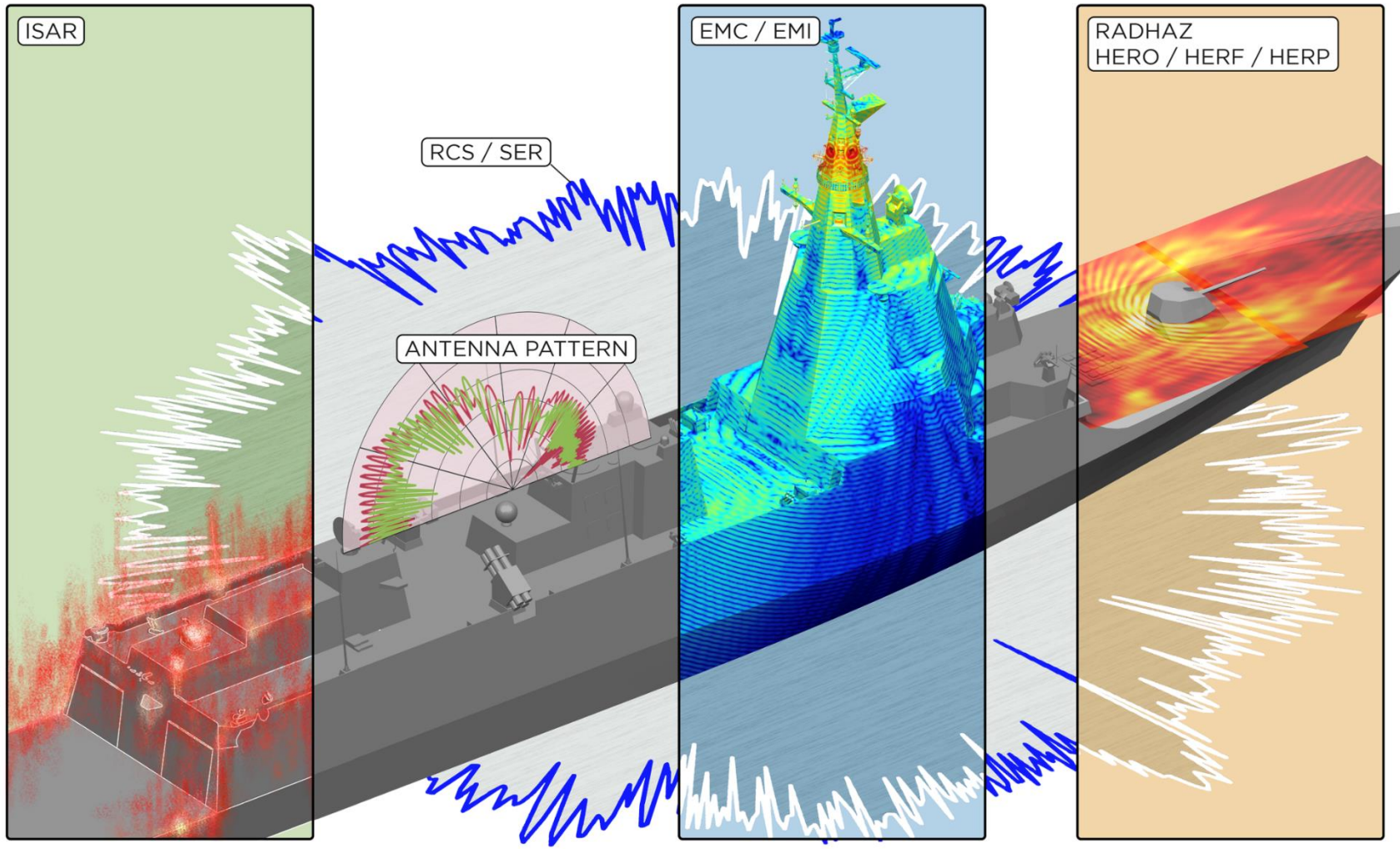
EM3WORKS

Universidad de Vigo

M3 naval applications

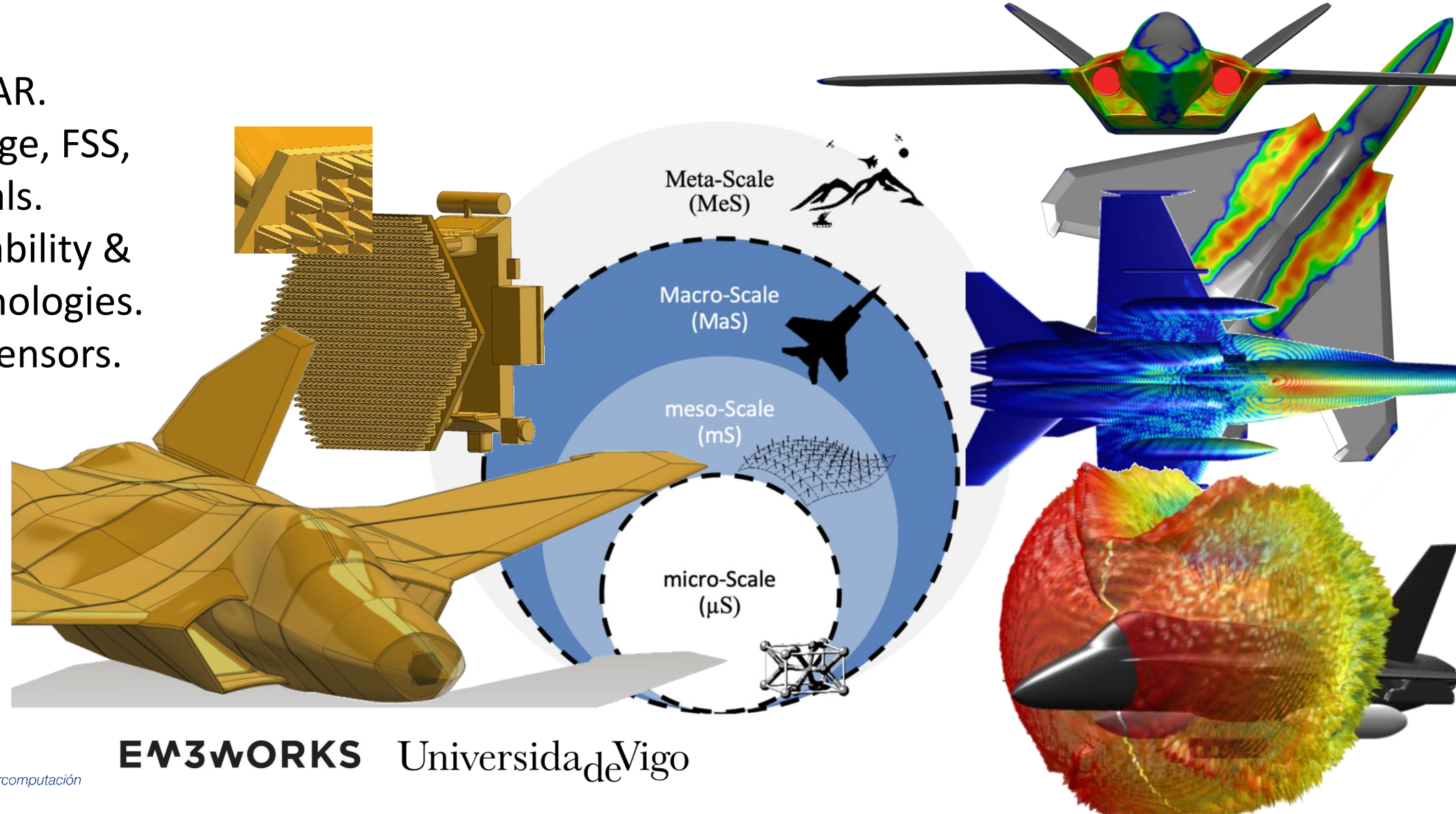
M3 solves challenging large-scale & deep-multiscale realistic problems, involving hundreds to thousands of millions of unknowns

EM Environmental Effects (E3), radar signature (RCS, ISAR), antenna (design, prototyping and design), etc.



M3 airborne applications

E3, RCS & ISAR.
Smart fuselage, FSS, metamaterials.
Low Observability & stealth technologies.
Embedded sensors.



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The big team

Navantia

ARMADA

25 years of close collaboration, working together towards the most efficient topside design !!!

LA SIMULACIÓN ELECTROMAGNÉTICA
EN BUQUES DE LA ARMADA ESPAÑOLA
Revista General de la Marina, Marzo 2019

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Background

Customers:

NAVANTIA,
Spanish Navy,
Norwegian Navy,
Australian Navy,
INDRA,
CASA,
ISDEFE,
Raytheon AUS,
CTAG,
SENER,
Ghenova,
Micromag 2000,

…
others.

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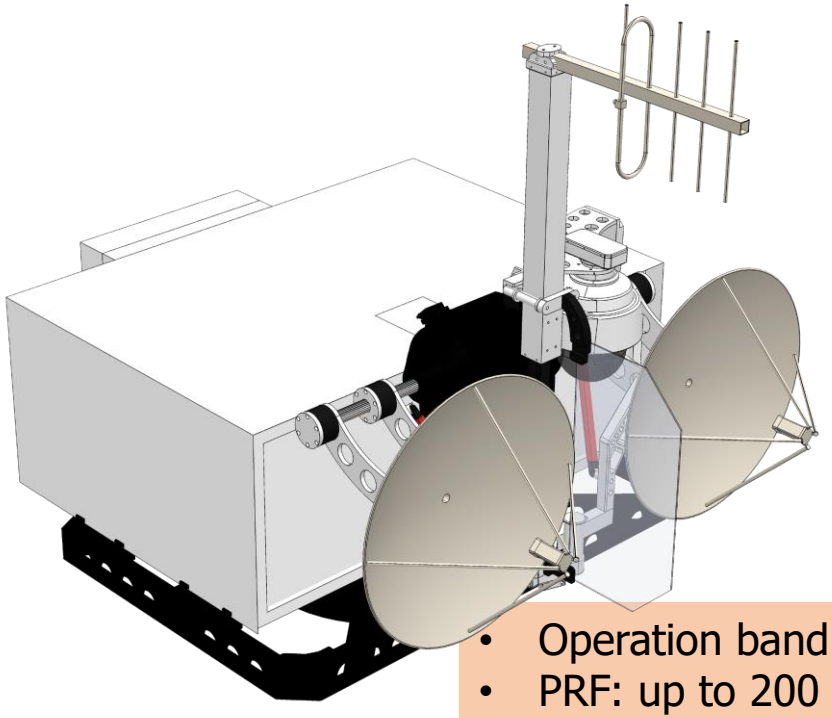
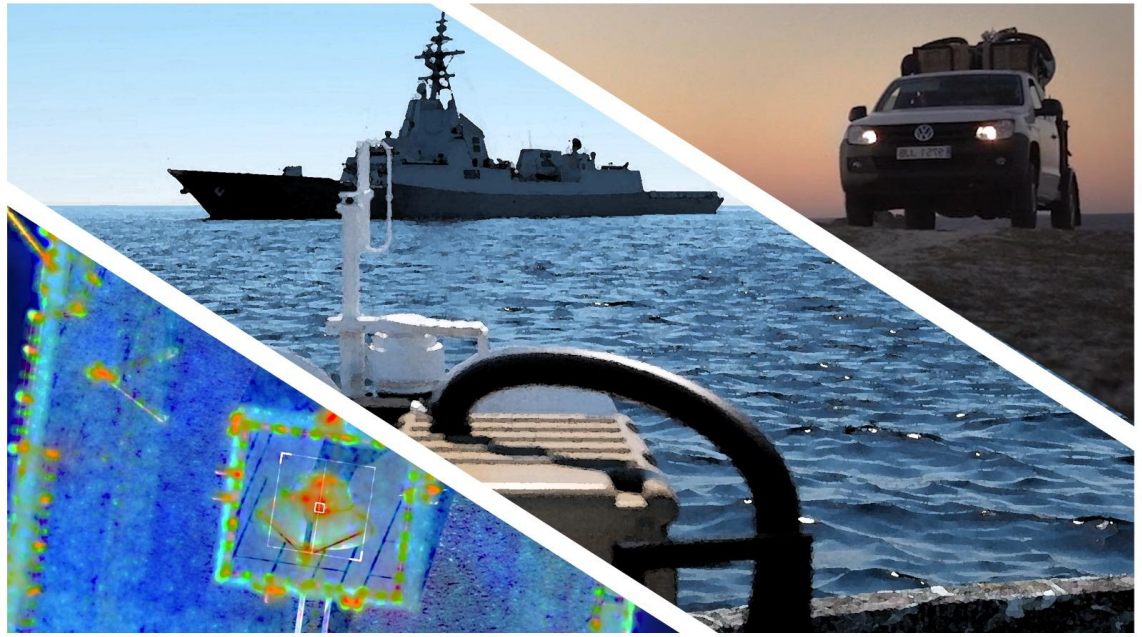
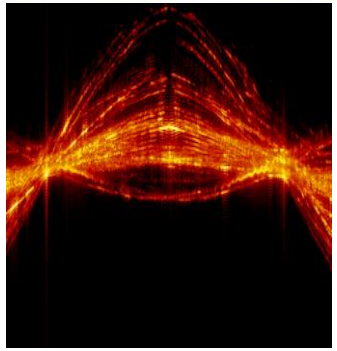
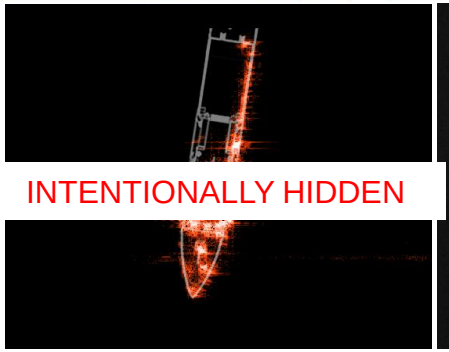
DIAR: radar signature measurement system

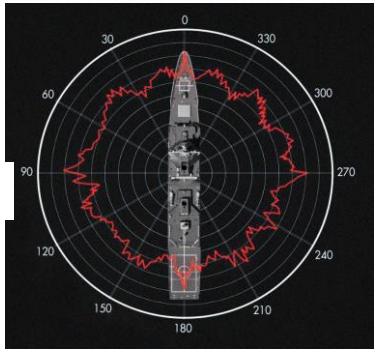


- Operation band: 6-18 GHz
- PRF: up to 200 kHz
- Polarization: HH, VV, HV, VH
- Targets: periscope, ship, chaff, ...
- Measurement Range: 0.2 - 16 km
- ISAR resolution: 10 cm
- Easy deployment and pick up: 30’
- Off-road vehicle









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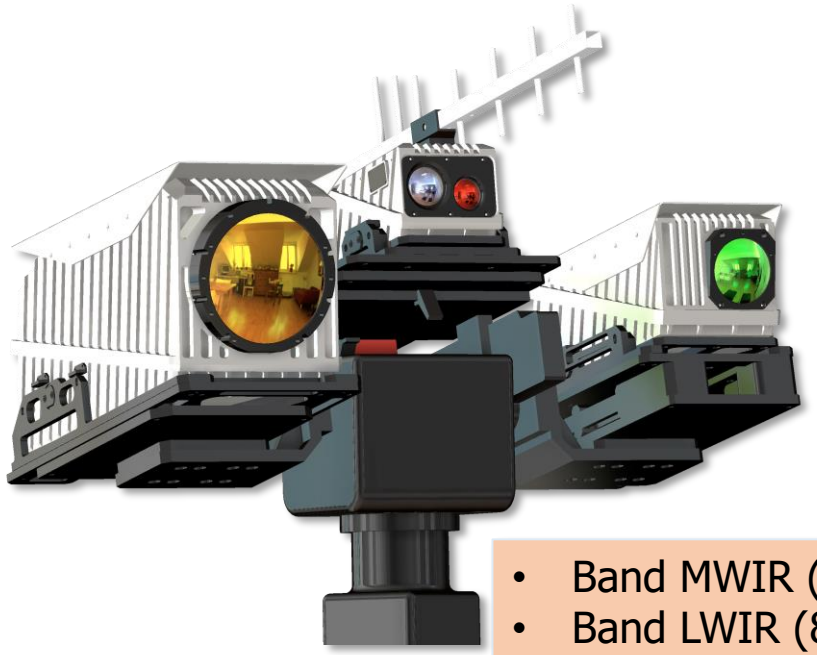
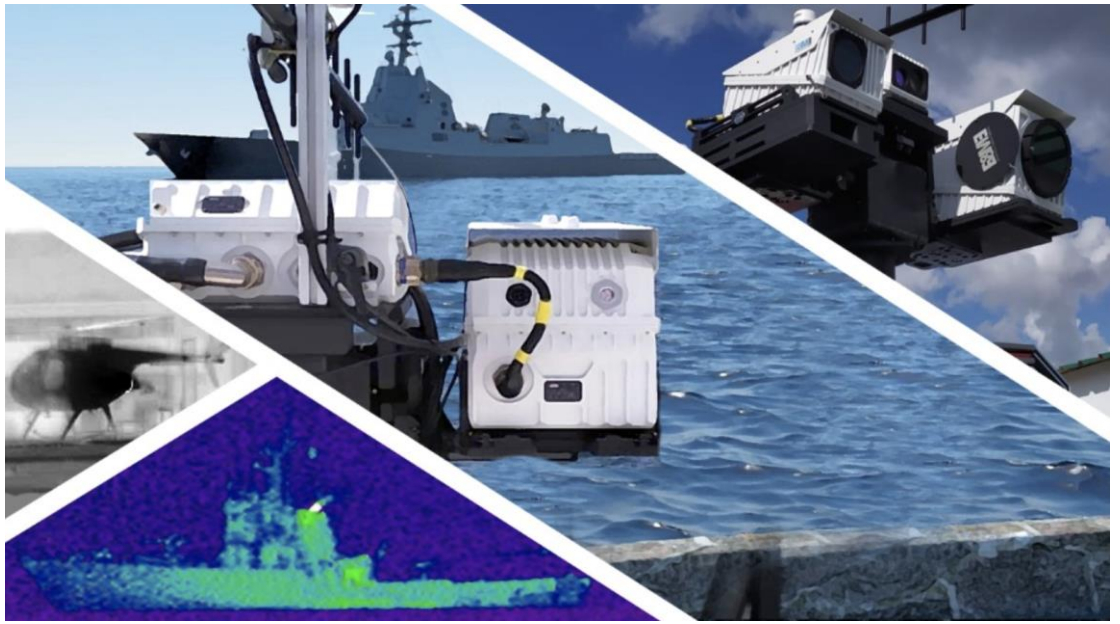
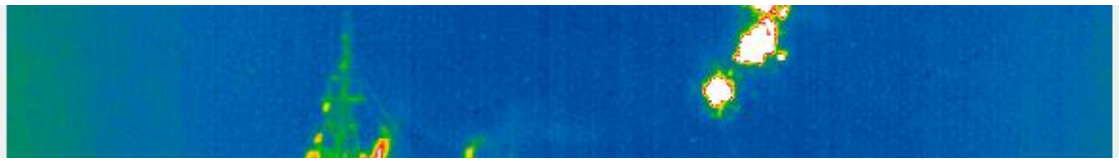
GOBIERNO DE ESPAÑA
MINISTERIO DE DEFENSA

DIFI: infrared signature measurement system



- Band MWIR (3-5 um)
- Band LWIR (8-12 um)
- LRF for distance measurement
- Automatic tracking
- Easy deployment and pick up: 30’
- Off-road vehicle





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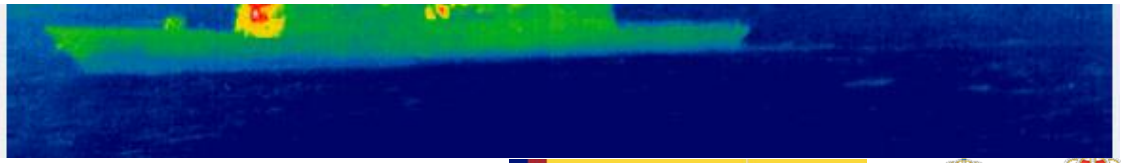
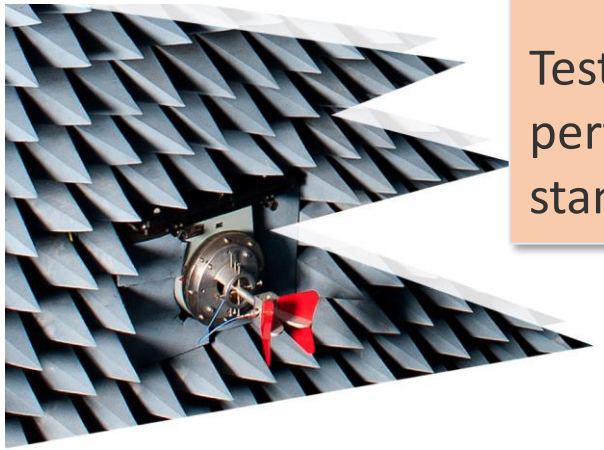


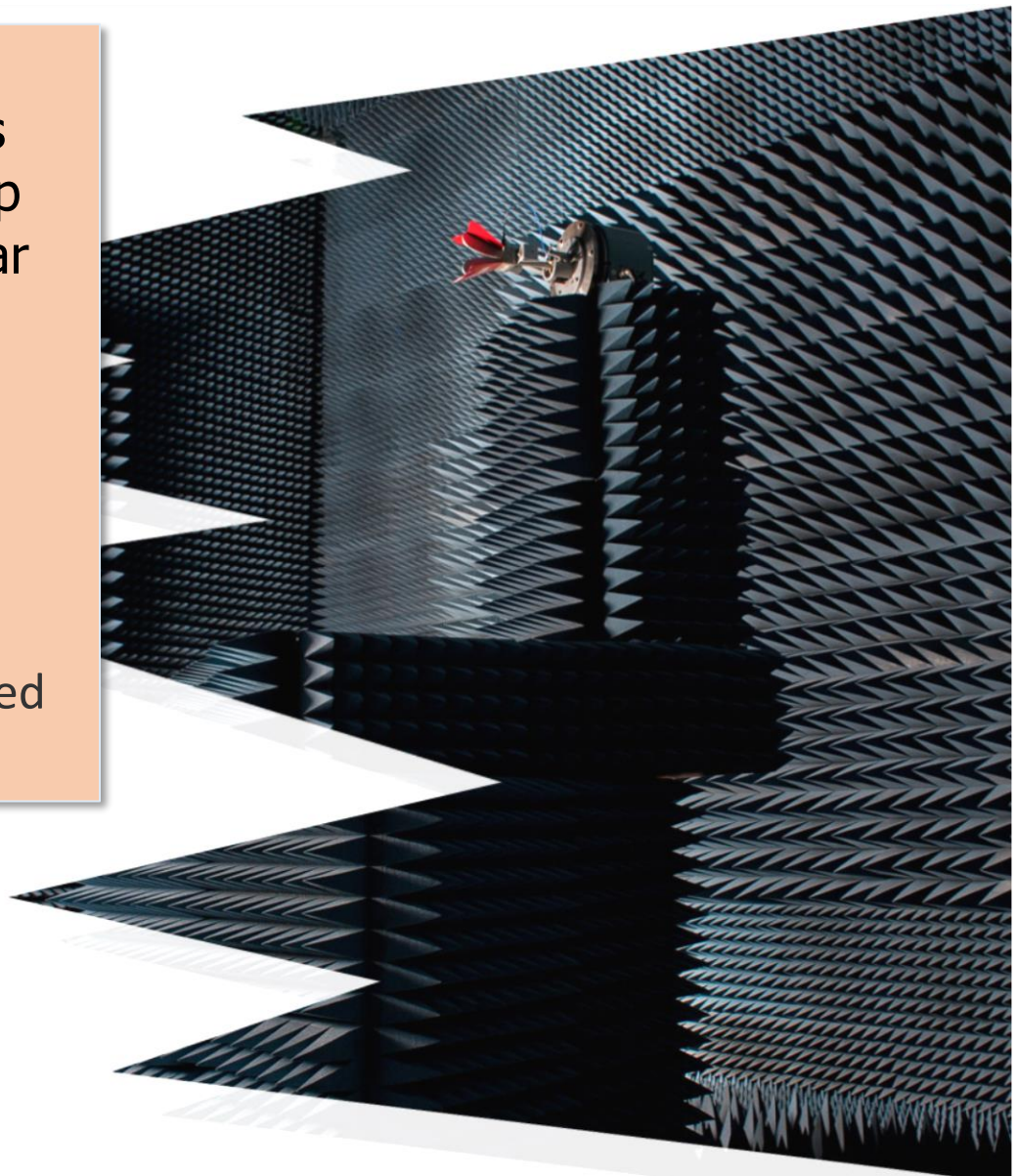
LMR: Radioelectric Measurement Laboratory



Spherical range measurement system (7x7x9 meters), provides radiation patterns of antennas up to 50 GHz, both far field and near field, VSWR and gain.

LMR also performs EMC precertification tests.

Tests about EMI and EMS can be performed, based on commonly used standards



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The science behind

More than 120 publications in SCI (Scientific Citation Index) journals, one in Science.

More than 200 presentations in Scientific Conferences

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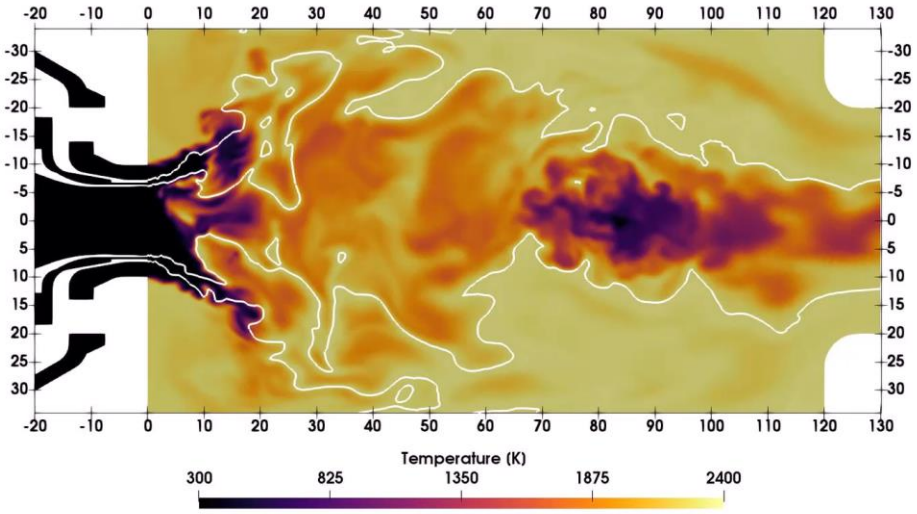
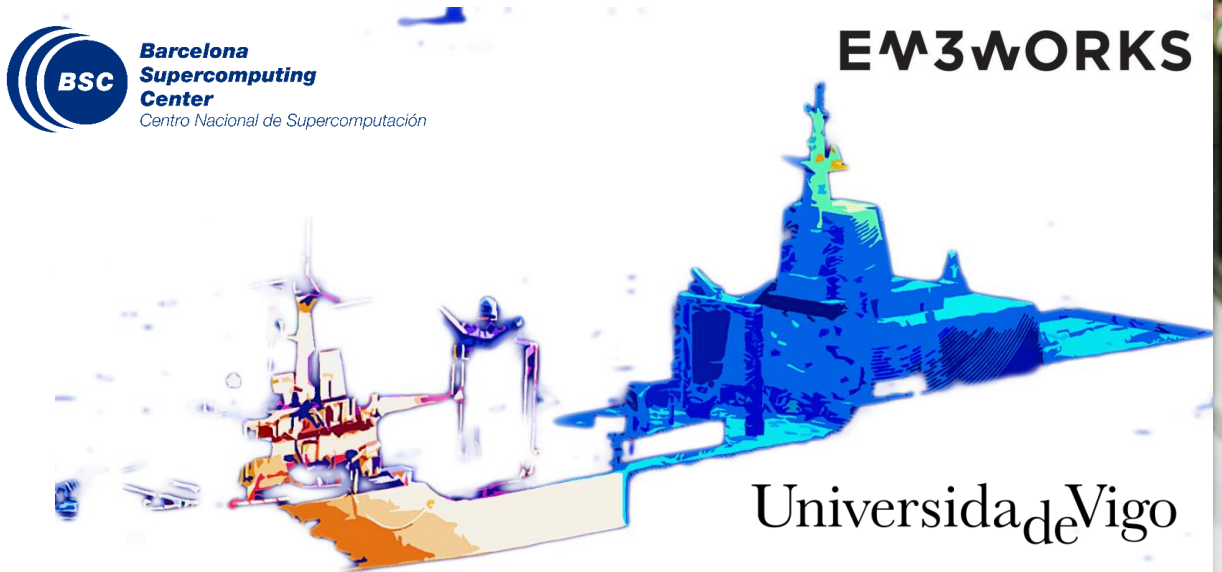
Conclusions about HPC and AI in digital engineering

Due to the complexity of **new developments** and their extremely high cost, it is necessary to rely on **digital engineering** throughout the whole entire **life cycle**, including **High Performance Computing**, **high-fidelity** modeling and **AI**.

This is the only way to **ensure compliance** with requirements before making **decisions** about **production.** In addition, high fidelity models are **critical** to the life cycle of **complex systems and SoS**.





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Use of a High Performance Computing (HPC) and AI for complex phenomena analysis on surface ship design

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UEX

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