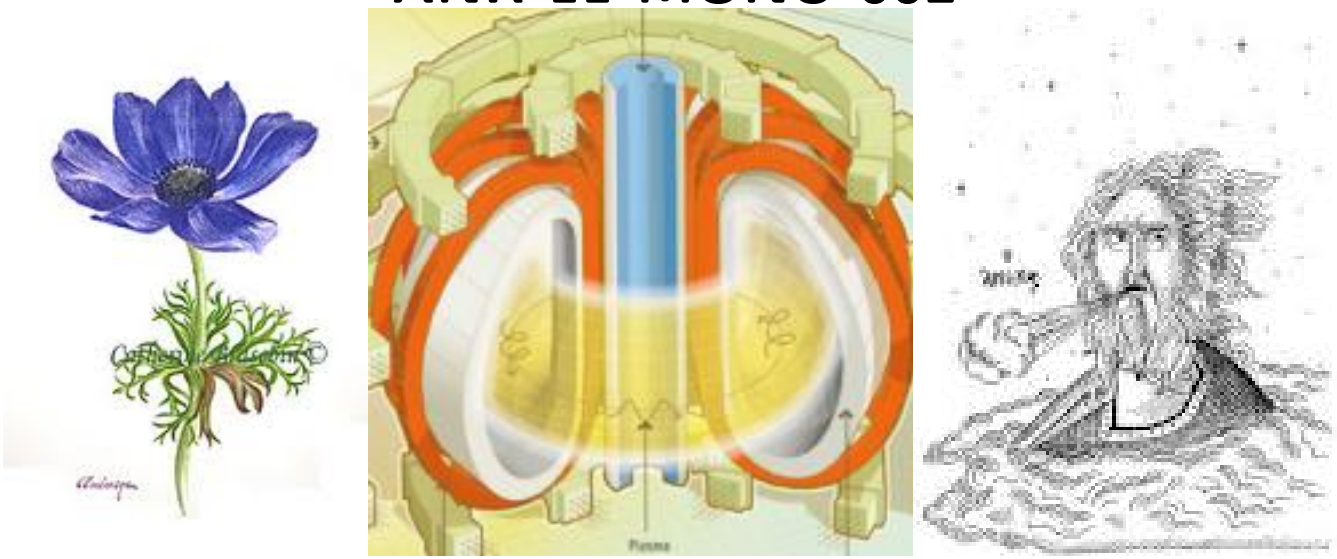
Advanced Numeric for Elm's : Models and Optimized Strategies (ANEMOS)

ANR-11-MONU-002



Oct. 2011 to Sep. 2015

Overview

1. General framework
2. Goals and Tasks
3. Partners and Funding
4. Preliminary Investigations

Context : What are Elm's ?

- Are Elm's deciduous and semi-deciduous trees comprising the genus Ulmus in the plant family Ulmaceae ?





- Elm's are edge-localized mode ("ELM") disruptive instabilities occurring in the edge region (SOL) of a tokamak plasma.

Context and motivation : What is the problem with Elm's ?

Major challenge in H-mode Tokamaks

The development of edge-localized modes poses a major challenge in magnetic fusion research with tokamaks, as these instabilities can damage plasma facing components, particularly divertor plates.

Need to be controlled

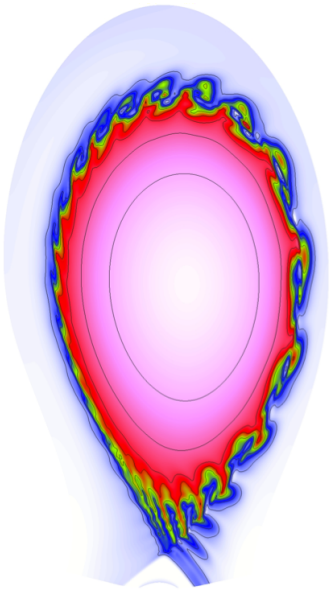
The mitigation or suppression of large edge localized modes (Elm's) is a critical issue for successful operation of ITER.

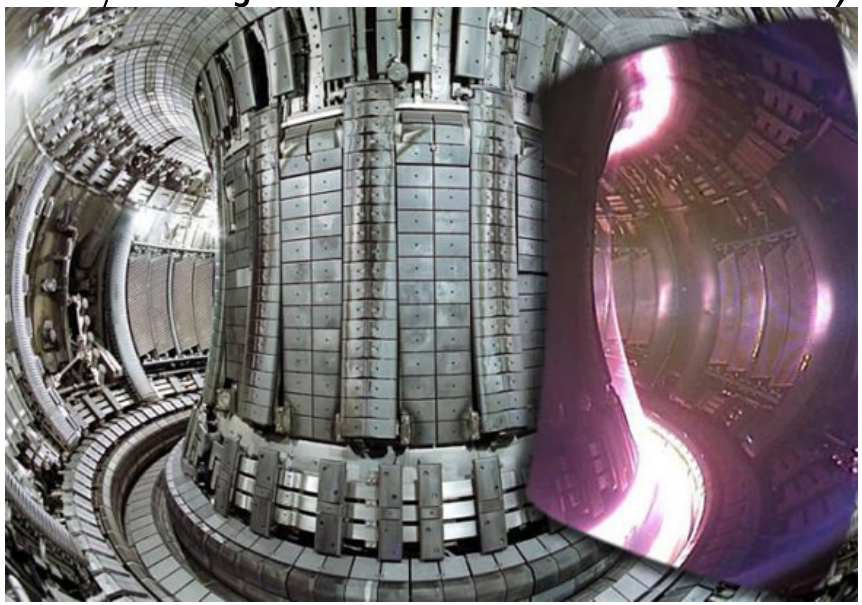
Preferred techniques for Elm's control in ITER.

- Elm's pacing using pellet injection.
- Elm's mitigation using resonant magnetic perturbations (RMP)

Background

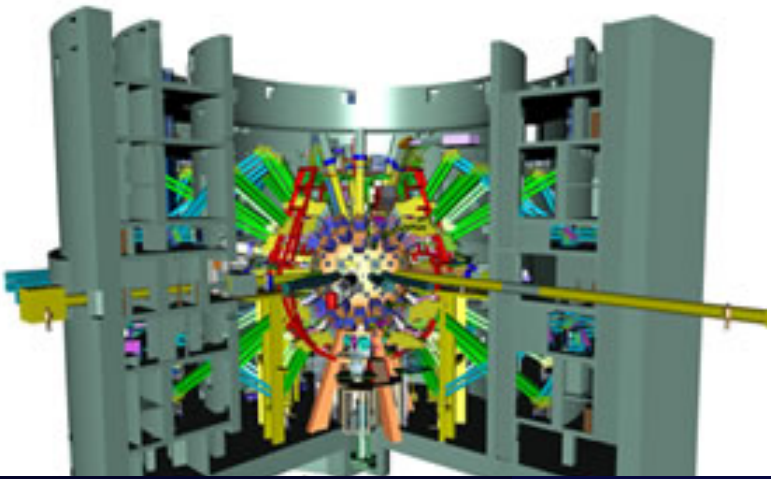
- ASTER (ANR-06-CIS / Projet ASTER : 2006-2009)

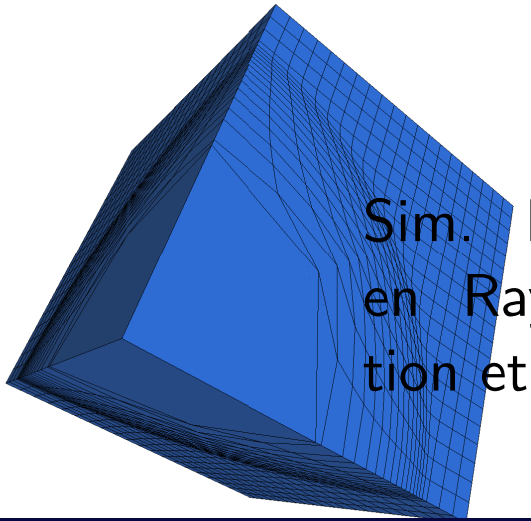




Adaptive MHD Simulation of Tokamak ELm's for iteR.

- SYNERGHY (ANR-06-C : 2006-2009)





Sim. Num. pour la Rech. en Rayonnement, Gravitation et Hydrodynamique.

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Goals for ANEMOS : Toward Elm's control.

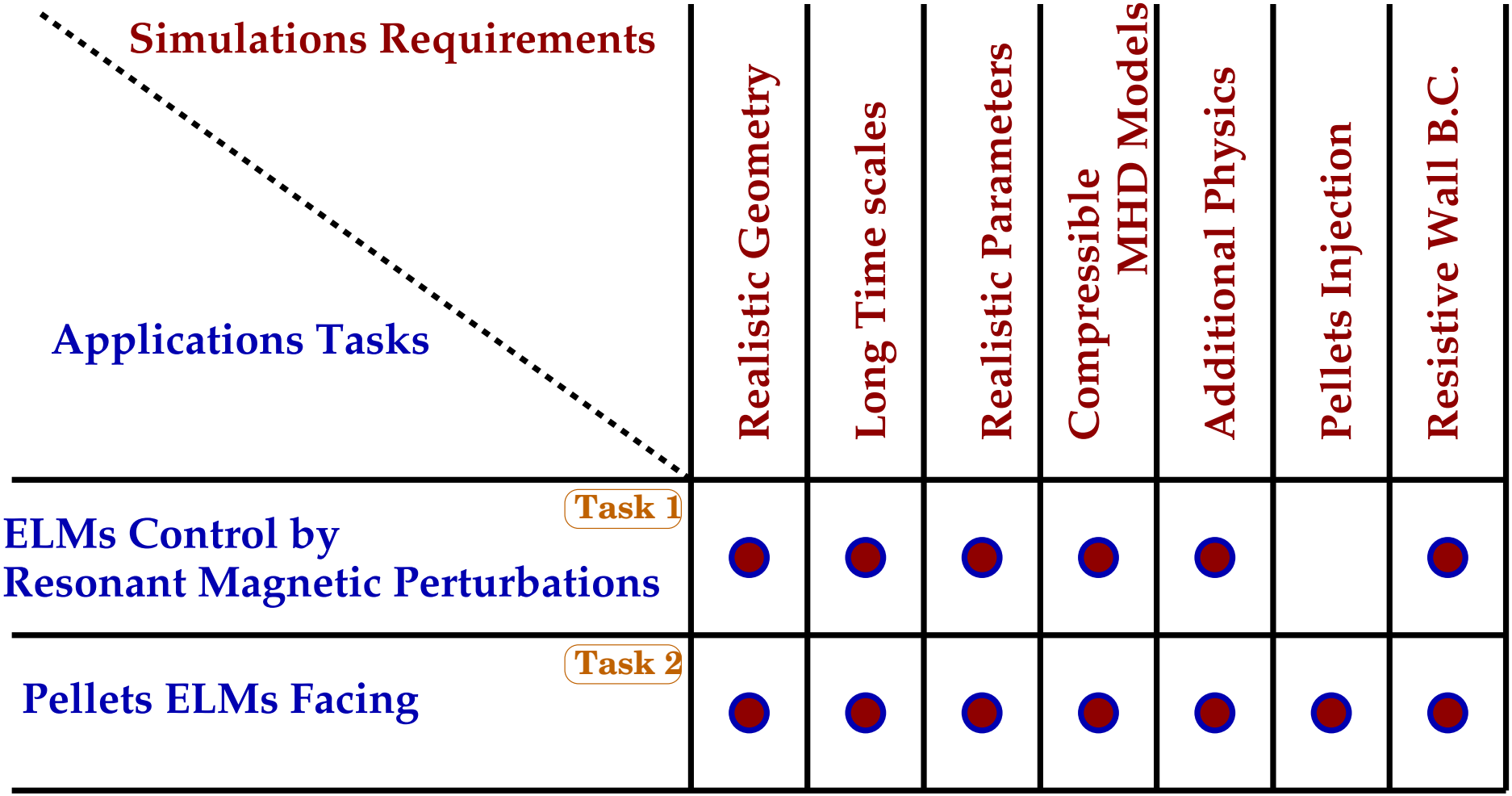
1. Developed and improved numerical tools (JorekX)
2. in order to simulate physical mechanisms of Elm's
3. and qualified some strategies for their control
4. Make them efficient on the most advanced computers available
5. to contribute to the science base underlying of proposed burning plasma
6. tokamak experiments such as ITER

Goals for ANEMOS : Toward Elm's control.

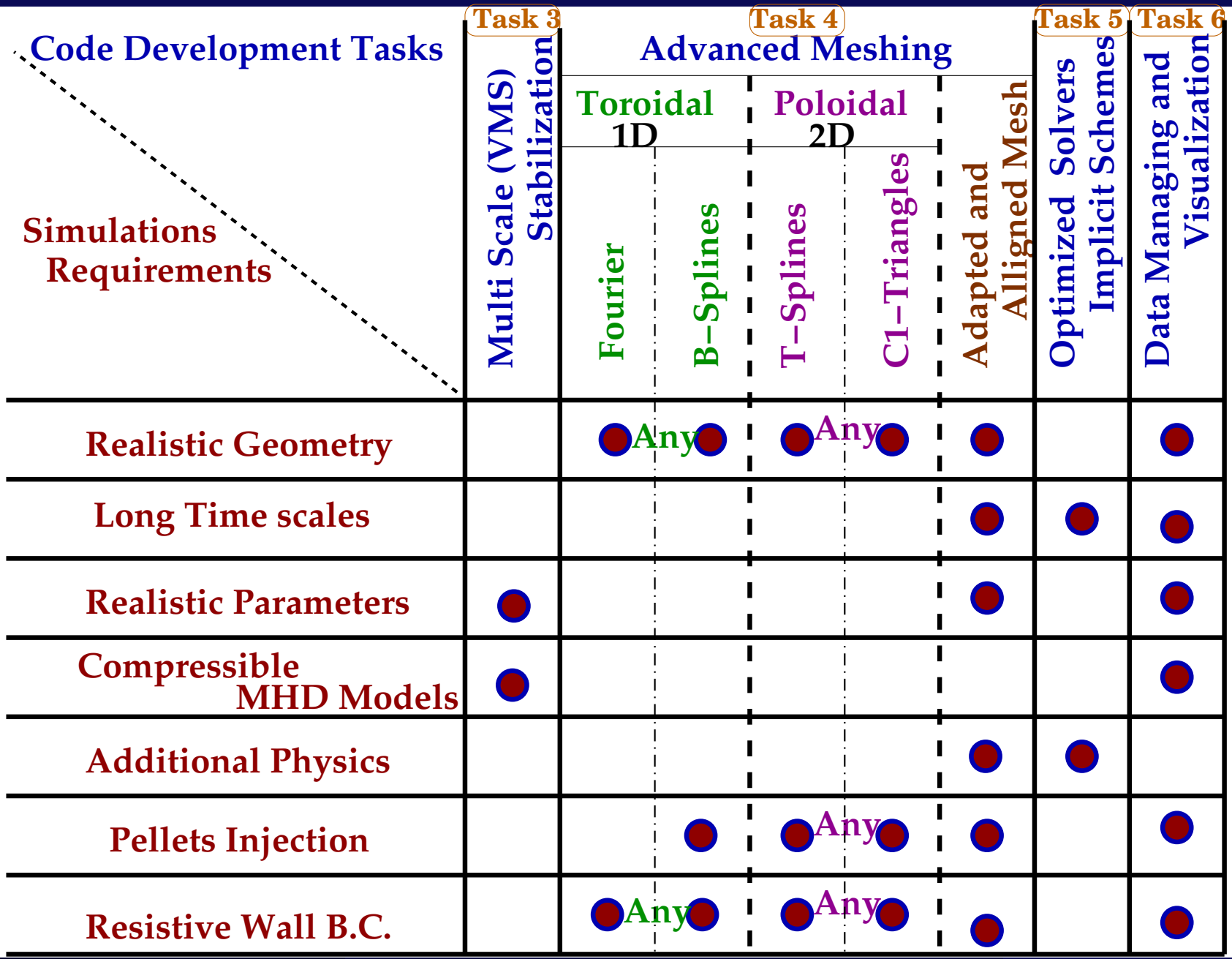
Main tasks for 4 years research investigations.

1. Elm's control by Resonant Magnetic Perturbations.
2. Modeling of pellets Elm's pacing.
3. Numerical algorithm optimizations and parallel scaling.
4. Higher-order-of-continuity advanced meshing.
5. Variational multiscale stabilization for compressible MHD models.
6. Visualization, data management and code integration.

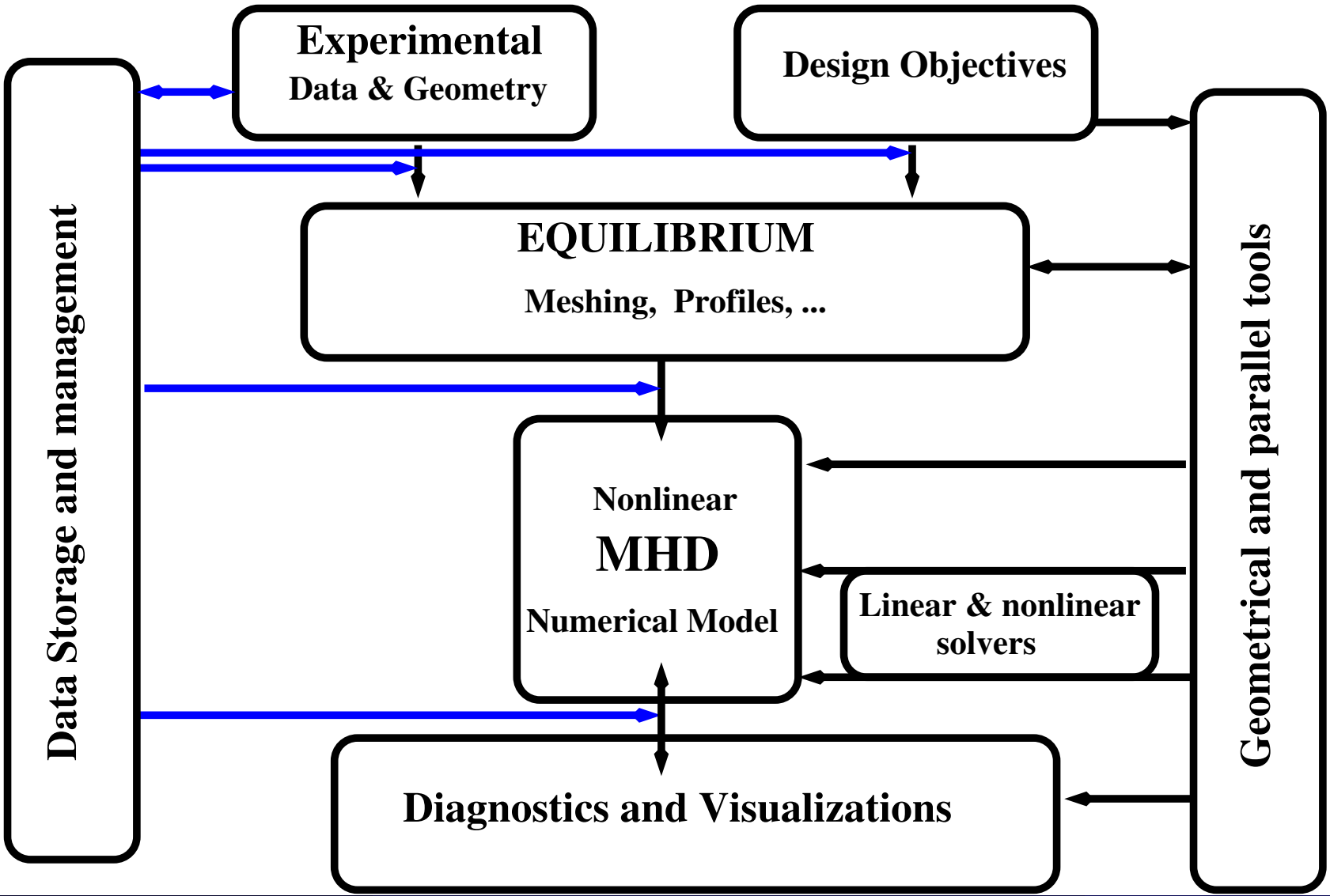
Applications Tasks versus Simulations Requirements



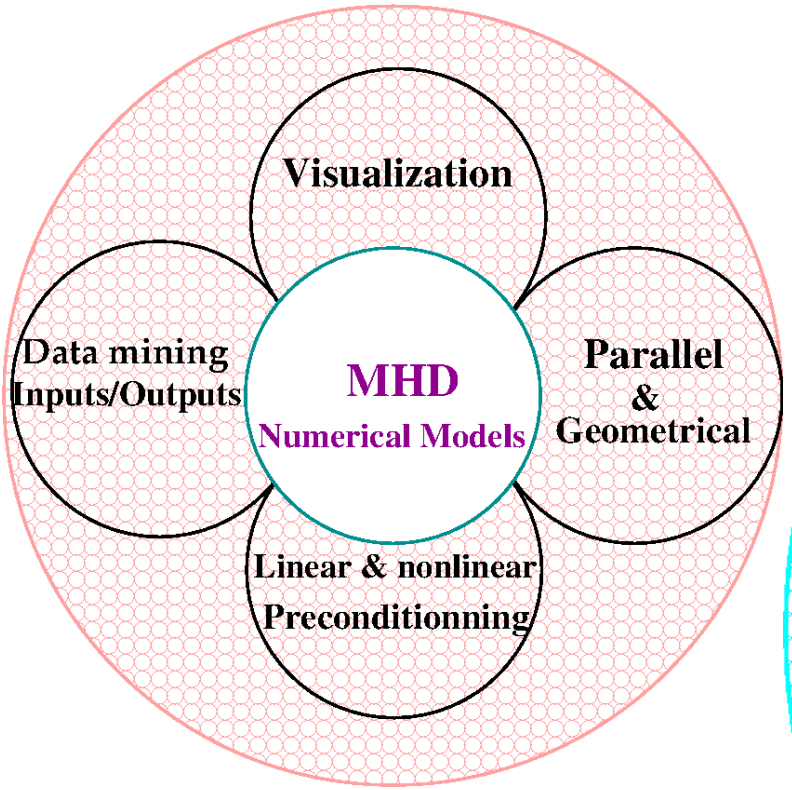
Simulations Requirements versus Code Development tasks.

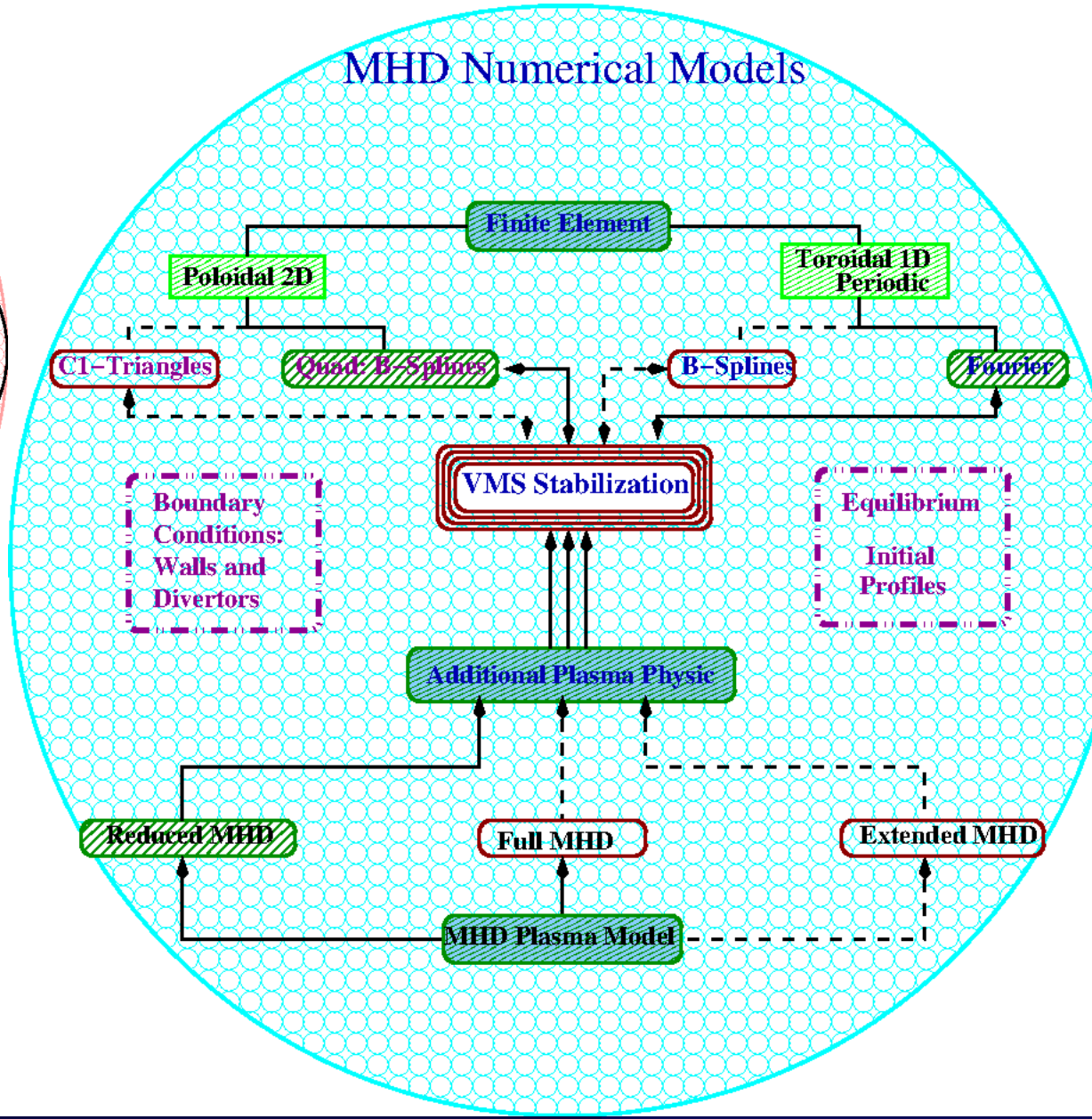


Software structure.



Software structure.





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Partners and Teams

- /JAD &INRIA **Nice Sophia-Antipolis** : 120 Months.
  B. Nkonga, A. Dervieux, H. Guillard, A. Sangam, ...
  A. Galligo, B. Mourain, ...

- /IRFM **Cadarache** : 70 Months
  M. Bécoulet, V. Grandgirard, G. Latu, C. Passeron, ...

- /BACCHUS **Bordeaux Sud-Ouest** : 35 Months
  P. Ramet, F. Pellegrini, ...

- /MDS **Ile de France Sud, Saclay** : 50 Months
  E. Audit, P. Kestener, D. Pomarede, B. Thooris, ...

Man power Funding :: **17 Years $\simeq$ 4.25 Men/Year**

PhD's	36	36	36		**3$\times$(3 years)**
Post. Doc.	24	22		36	**$\simeq$ 7 years**
Master		6	2	4	**1 year**

Schedule 48 months : 01/09/11 to 30/08/15

6 12	18 24	30 36	40 48
??	Report&show	Report	Final Report

Task 1 : Elm's control by Resonant Magnetic Perturbations.

Extended fluid models neo-classical viscosity.	Implementation of RPM physics and validations with more relevant parameters: JET size tokamak.	
Neoclassical Equilibrium for JET and ITER.	Nonlinear simulations of Elm's interactions with RMPs : ITER-size machine	

Task 2 : Modeling of pellets ELMs pacing.

Numerical tools for 3D curvilinear Beziers patches.	Numerical implementation of the code version using 3D curvilinear Beziers patches.	
Applications to Pellets Elm's Pacing:by mass source term and latter by a simple model for pellet dynamic		

Task 3 : Numerical algorithm optimizations and parallel scaling.

Reduce memory footprint	Optimize & load balance. Improve time-stepping scheme	
Investigate alternative sparse solvers		

Schedule 48 months : 01/09/11 to 30/08/15

6 12	18 24	30 36	40 48
??	Report&show	Report	Final Report

Task 4 : Higher order of continuity Advanced Meshing.

Global analysis, strategies for the resolution.	Implementations and Validations for MHD simulations.	
Development of automatic mesh aligned C1-Splines for general quadrangular subdivisions.	Development of automatic C1-Splines for triangular meshes.	

Task 5 : VMS stabilization for compressible MHD models.

Global analysis for MHD Models.	Code development for full MHD models: Improvement.	
Code development for reduced MHD. Numerical Validations.	Upgrade of VMS Stabilized Version of Jorek.	

Task 6 : Visualization, data management and code integration.

Analysis of existing software and graphical libraries	Formation to production of scientific pictures &movies. CEMRACS'14	
Visualization tool for quadrangular and curvilinear meshes.	Visualization techniques for high order resolution fields.	

National network on Fluid plasma Modeling (VENUS).

1. Edge Plasma Turbulence (SOLEDGE)
   - Understand mechanism of turbulence (IRFM & M2P2).
   - Modeling and analysis (JAD & IRFM & M2P2).
   - Large scale parallel simulations (IRFM & JAD).

   ANR ESPOIR (2009-2013) : JAD/IRFM/M2P2/LATP/LPIIM

2. Edge Plasma Instabilities (JOREK)
   - Elm's control by Resonant Magnetic Perturbations (IRFM).
   - Modeling of pellets ELMs pacing(JAD & IRFM & MdS).
   - Higher-order-of-continuity advanced meshing (JAD & IRFM & INRIA).
   - VMS stabilization for compressible MHD models (JAD & ITER).

   ANR ANEMOS (2011-2015) : JAD/IRFM/IRFU/INRIA-Bacchus

3. HPC-Platform for simulations of plasma in Tokamaks (PLATO)
   - Provide a large scale architecture developments tools(INRIA) .
   - Geometry and physics of Tokamaks(MdS & JAD & INRIA & IRFM).
   - Data management and visualization (MdS & INRIA).

   INRIA/ADT PLATO

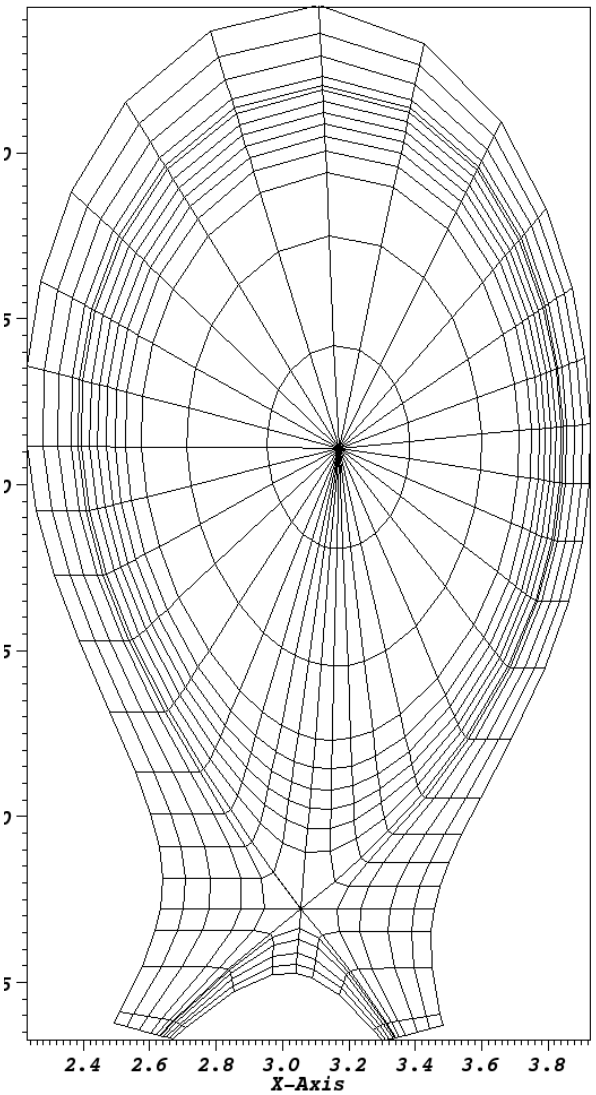
Intenational Network

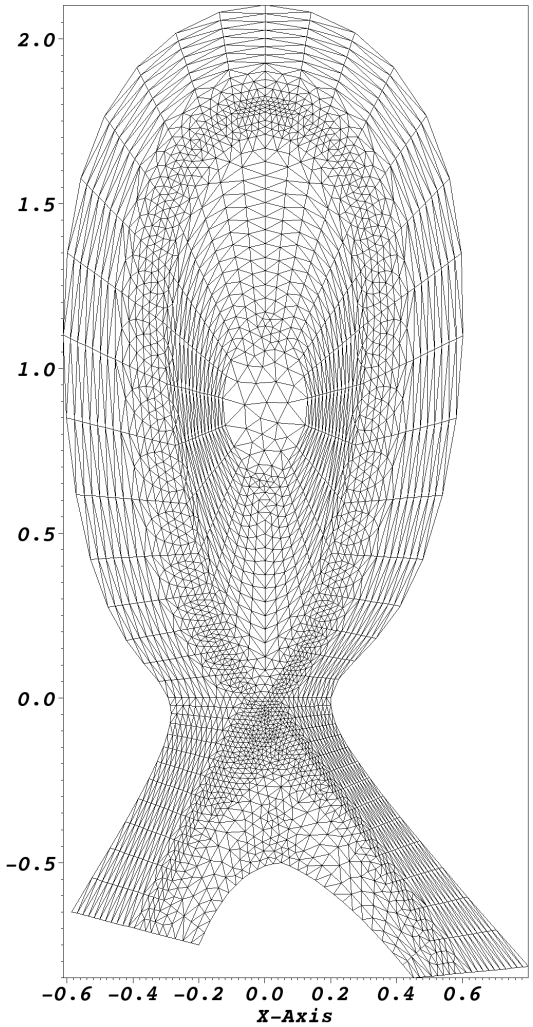
1. ITER.org, Cadarache :: G. Huysmans
2. CWI, Amsterdam :: B. Koren
3. Inst. of Plasma Physics, Czech Republic :
4. University of Saskatchewan, Canada
5. University of Texas, Austin USA
6. General Atomics, San Diego USA
7. EURATOM, Jülich Germany
8. Euratom-UKAEA, Abingdon UK
9. University, Polytechnicheskaya, St Petersburg Russia

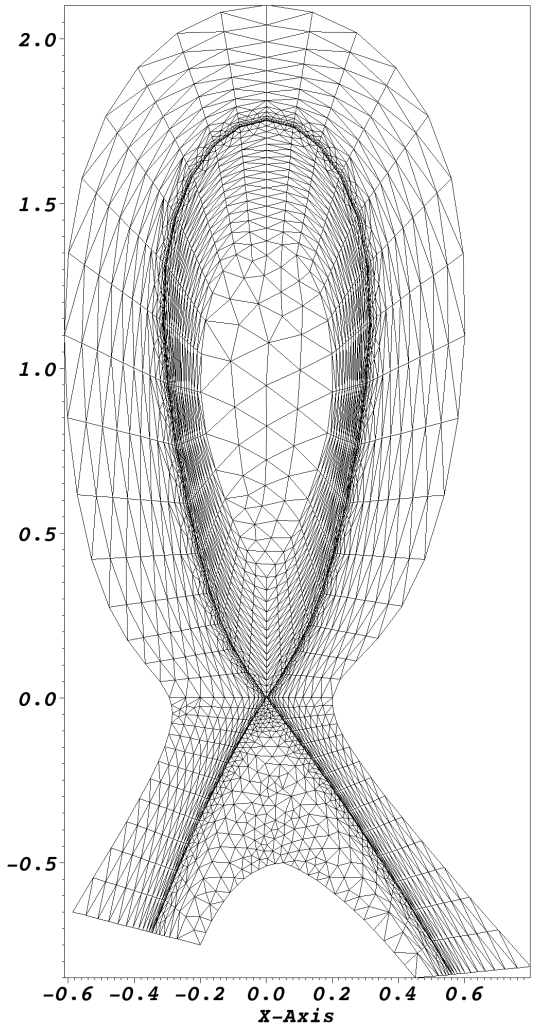
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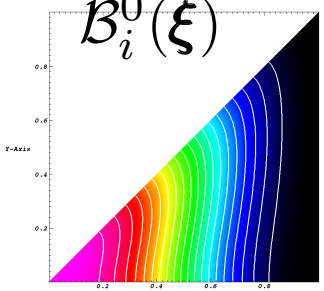
Advanced Meshing

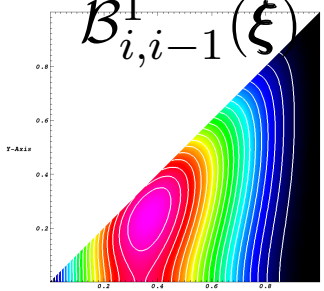


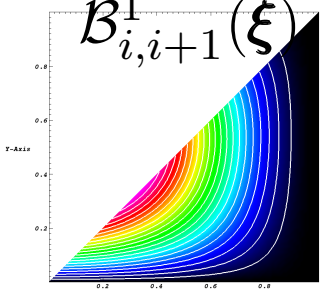


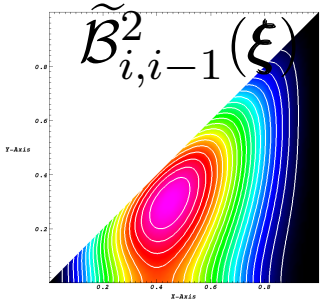


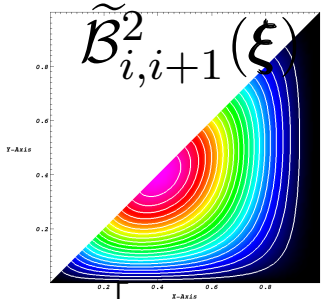
C1-Splines for triangular meshes : Bell Element

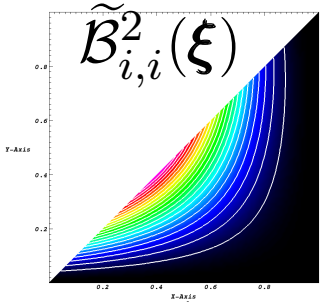












$$\mathbf{W}_e = \underline{\mathbf{W}}_e \cdot \underline{\boldsymbol{\mathcal{B}}}_e,$$

$$\frac{\partial \mathbf{W}_e}{\partial \xi_n} = \underline{\mathbf{W}}_e \cdot \frac{\partial \underline{\boldsymbol{\mathcal{B}}}_e}{\partial \xi_n}$$

$$\frac{\partial \mathbf{W}_e}{\partial \xi_n}\frac{\partial \underline{\boldsymbol{\mathcal{B}}}_e}{\partial \xi_m} = \left(\frac{\partial \underline{\boldsymbol{\mathcal{B}}}_e}{\partial \xi_m} \otimes \frac{\partial \underline{\boldsymbol{\mathcal{B}}}_e}{\partial \xi_n}\right) \underline{\mathbf{W}}_e$$

$$\widetilde{\mathcal{B}}_i^0(\boldsymbol{\xi}) = \lambda_i^2\left[6\lambda_i^3 - 15\lambda_i^2 + 10\lambda_i + 15\left(1+\eta_{i+1}\right)\lambda_{i-1}^2\lambda_{i+1} + 15\left(1-\eta_{i-1}\right)\lambda_{i-1}\lambda_{i+1}^2\right]$$

$$\widetilde{\mathcal{B}}_{i,i-1}^1(\boldsymbol{\xi}) = \lambda_{i-1}\lambda_i^2\left[-3\lambda_i^2 + 4\lambda_i + 3\lambda_{i+1}^2 + \frac{9+15\eta_{i+1}}{2}\lambda_{i-1}\lambda_{i+1}\right]$$

$$\widetilde{\mathcal{B}}_{i,i+1}^1(\boldsymbol{\xi}) = \lambda_i^2\lambda_{i+1}\left[-3\lambda_i^2 + 4\lambda_i + 3\lambda_{i-1}^2 + \frac{9-15\eta_{i-1}}{2}\lambda_{i-1}\lambda_{i+1}\right]$$

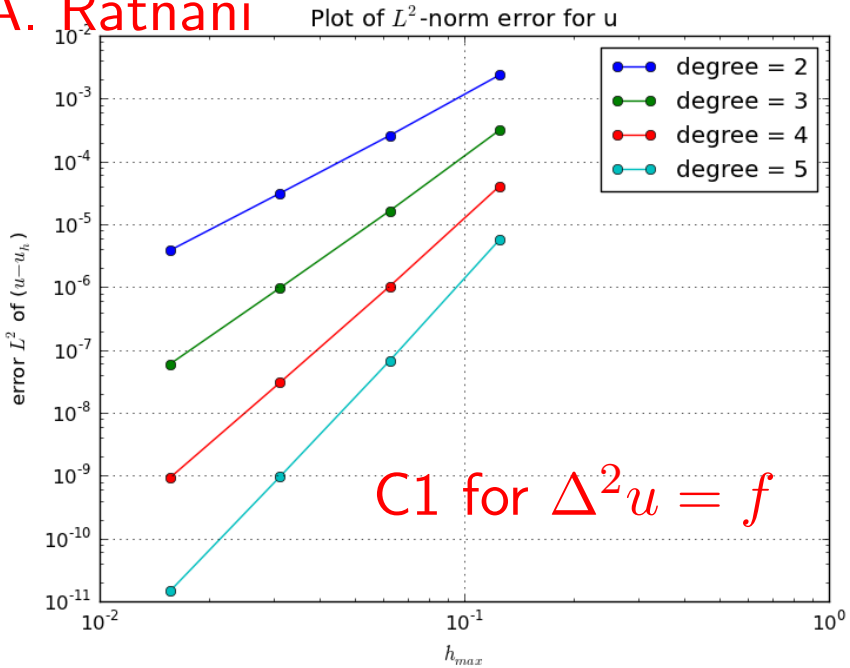
$$\widetilde{\mathcal{B}}_{i,i-1}^2(\boldsymbol{\xi}) = \frac{1}{2}\lambda_i^2\lambda_{i+1}\left[-\lambda_i^2 + \lambda_i + \lambda_{i-1}^2 + \frac{9-15\eta_{i-1}}{6}\lambda_{i-1}\lambda_{i+1}\right]$$

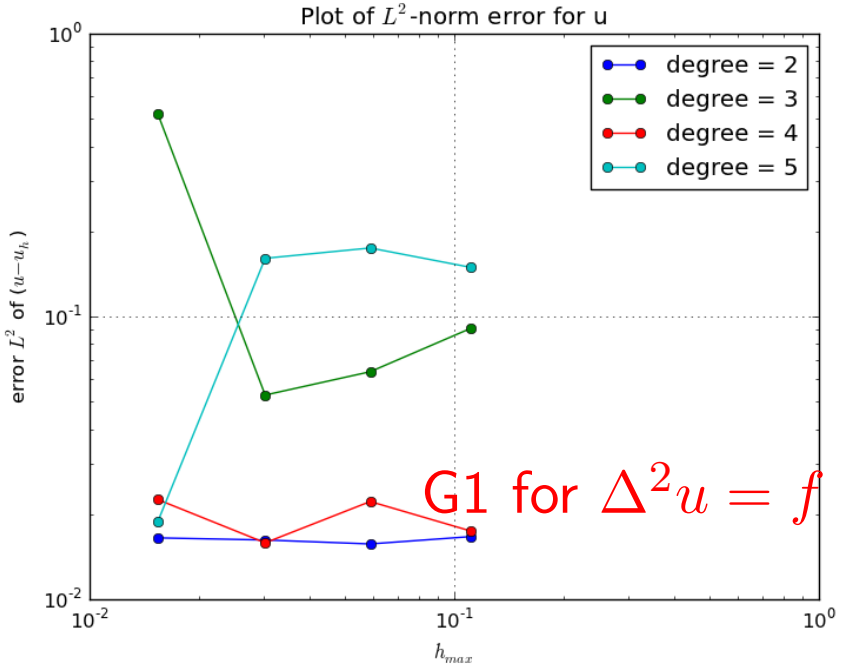
$$\widetilde{\mathcal{B}}_{i,i+1}^2(\boldsymbol{\xi}) = \frac{1}{2}\lambda_{i-1}\lambda_i^2\left[-\lambda_i^2 + \lambda_i + \lambda_{i+1}^2 + \frac{9+15\eta_{i+1}}{6}\lambda_{i-1}\lambda_{i+1}\right]$$

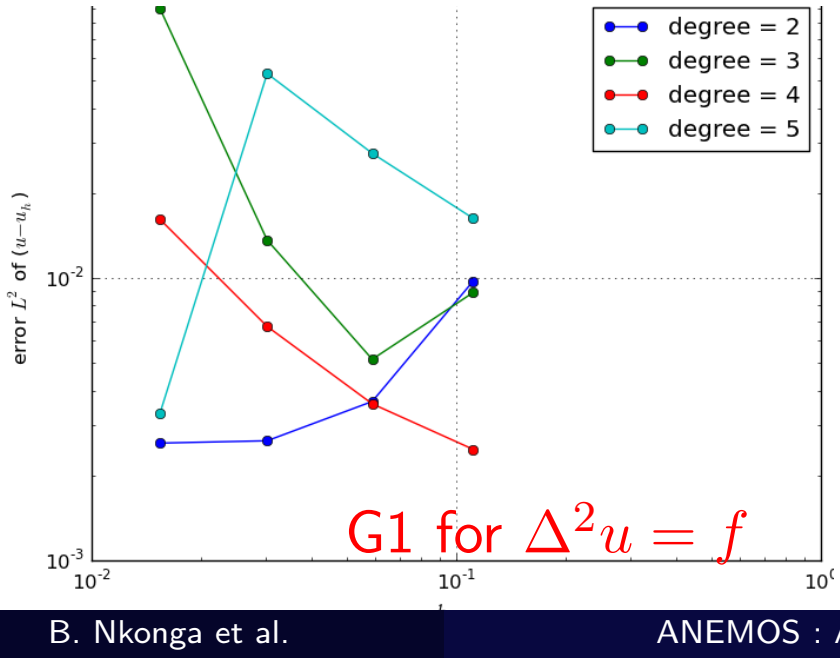
$$\widetilde{\mathcal{B}}_{i,i}^2(\boldsymbol{\xi}) = -\frac{1}{2}\lambda_{i-1}\lambda_i^2\lambda_{i+1}$$

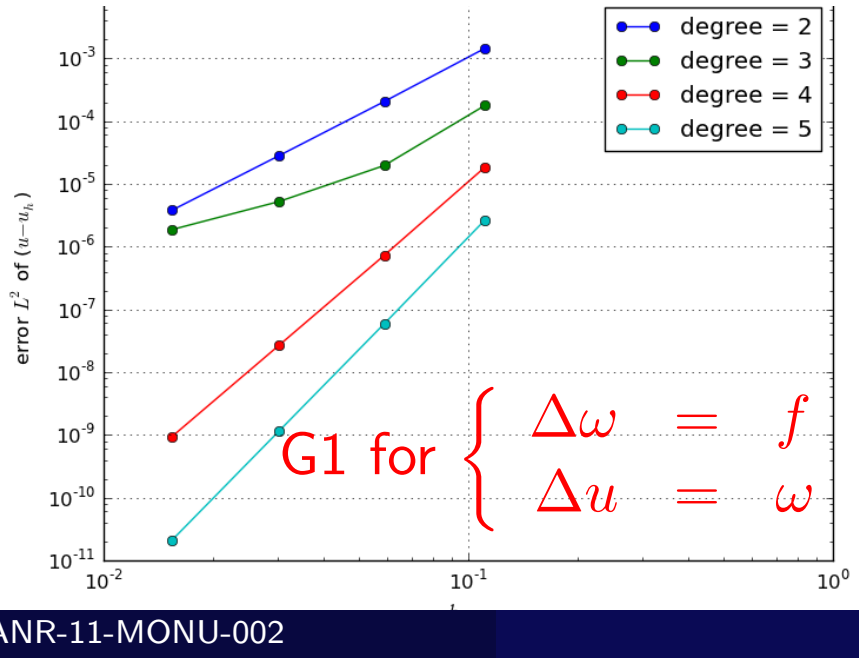
B-Splines Quad : G1 Vs. C1 Continuity for $\Delta^2 u = f$

A. Ratnani





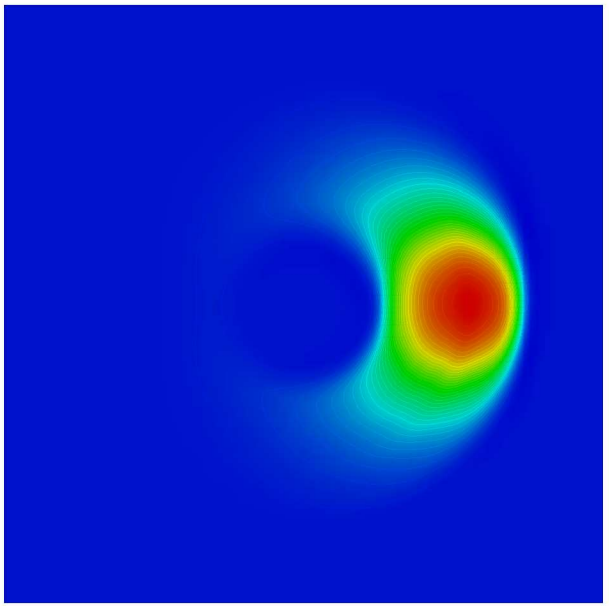




Scalable nonlinear solver : Additive Schwartz vs. Balancing.

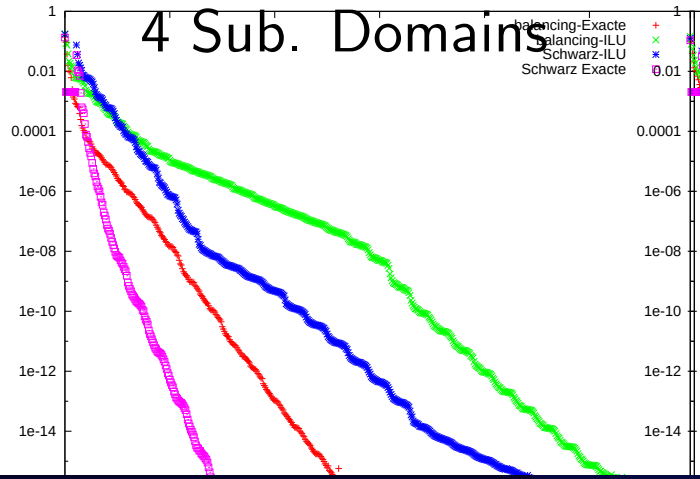
2D anisotropic thermal conduction

- $\frac{\kappa_\perp}{\kappa_\parallel} = 10^{-11}$
- 10^4 points, 2×10^4 P1-Triangles
- Mesh non aligned

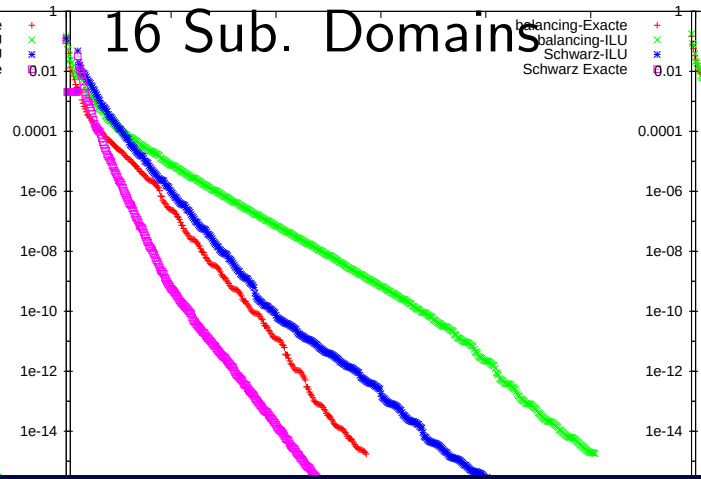


A. Dervieux, H. Alcin

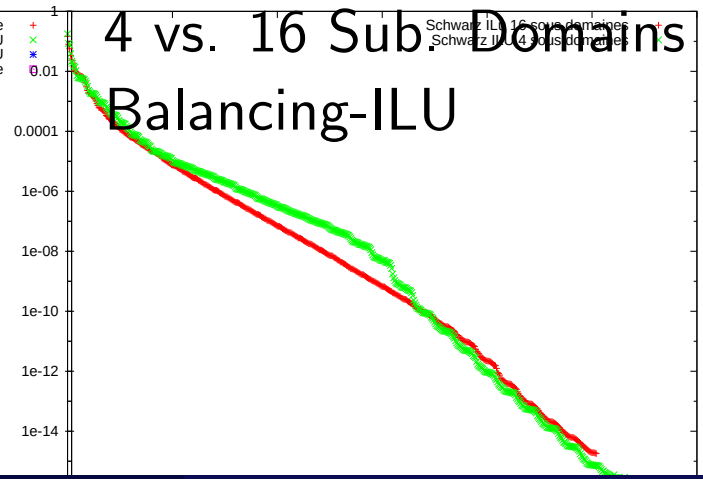
4 Sub. Domains



16 Sub. Domains



4 vs. 16 Sub. Domains
Balancing-ILU



Stabilization.

Taylor Galerkin/VMS-SUPG Stabilization

$$\int_\Omega \left((\boldsymbol{I} + \theta\delta t \underline{\boldsymbol{\mathcal{D}}}_h) \frac{\partial \mathbf{W}_h}{\partial t} + \mathcal{L}_h(\boldsymbol{\partial}, \mathbf{W}_h) \right) \cdot \underline{\boldsymbol{\mathcal{B}}}_e d\boldsymbol{\xi} = -\int_\Omega (\underline{\boldsymbol{\mathcal{T}}}_h \boldsymbol{\mathcal{L}}_h) \cdot (\underline{\boldsymbol{\mathcal{D}}}_h^* \underline{\boldsymbol{\mathcal{B}}}_e)\, d\boldsymbol{\xi}$$

Non stationary VMS Stabilization $\theta > 0$

$$\int_\Omega \frac{(1+\theta)\delta\mathbf{W}_h^n - \theta\delta\mathbf{W}_h^{n-1}}{\delta t} \cdot \underline{\boldsymbol{\mathcal{B}}}_e d\boldsymbol{\xi}$$
$$+ \int_\Omega \mathcal{L}_h \left(\boldsymbol{\partial}, \frac{1+\theta}{2}\delta\mathbf{W}_h^n + \frac{(2-\theta)\mathbf{W}_h^n + \theta\mathbf{W}_h^{n-1}}{2} \right) \cdot \underline{\boldsymbol{\mathcal{B}}}_e d\boldsymbol{\xi} = 0$$

Marginal stability for $\theta = 0$ (CN scheme).

Conclusion.

Forthcoming presentations

1. Modeling : M. Bécoulet
2. HPC and Optimizations : P. Ramet
3. HPC and Visualization : E. Audit

More to be achieved during ANEMOS.

Thanks