1 Code Development for integrated modelling Project

The EUROfusion Project on Code Development for Integrated Modelling (WP-CD) supports the achievement of the European Fusion Roadmap at Horizon 2020 goals, via the development of existing modelling codes with a particular focus on integrated modelling.

The primary objectives of WPCD are:

1. Provide a suite of codes that can be validated on existing machines and used for JT-60SA, ITER and DEMO predictions:

- build on the existing modelling codes developed by the EUROfusion Consortium members including the Integrated Modelling (EU-IM) infrastructure, toolset and codes developed under the former EFDA ITM Task Force,
- add new physics to the existing models
- couple codes into integrated workflows
- optimize codes.

2. Specific ITER simulation work in support of ITER IO and F4E with specified deliverables.

WPCD operates under a work plan aiming to provide in the long term a full suite of integrated simulation workflows, incorporating core-edge-SOL/PFC coupling, first-principles models and control elements. A central task is the development of the new modular European Transport Simulator, ETS, which is being deployed to JET modelling infrastructure for validation and application to experimental analysis. In addition to code and workflow development, rigorous code verification is also performed under WPCD, within the EU-IM framework; whereas validation of the released integrated modelling workflows against the experiments is performed under the rerelated Task Forces. EUROfusion WPCD webpage [1].

The EU-IM Team includes both EUROfusion WPCD and WPISA CPT contributors, see EU-IM Team [2].

This list reproduces the status of members in 2015 and is possibly not exhaustive.

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2 The European Integrated Modelling (EU-IM) approach

The choice of Integrated Modelling made by the former EFDA ITM-TF and pursued now under EUROfusion WPCD is unique and original: it entails the development of a comprehensive and completely generic tokamak simulator including both the physics and the machine, which can be applied for any fusion device.

The simulation platform was designed to be fully modular, flexible, and independent of a programming language. The choice of modularity implies that each module contains a single physical model and that the communication between the modules is standardised: a set of common rules (ontology) clearly specify the format of the data to be consistently exchanged between modules (data-structure). The complexity of coupling the codes together is therefore transferred to the definition of a generic data-structure (allowing to describe and exchange information concerning both physical quantities and technical objects, not assuming the origin of those), extensible to allow the integration of new physics, as well as more elaborate machine geometries and experimental data in the future. A central project is the development of the so-called **European Transport Simulator (ETS)** aimed to meet all the EU-IM requirements, namely modularity, flexibility and standardized interfaces. In terms of the physics, the ETS is designed to solve the standard set of one-dimensional time dependent equations which describe the evolution of the core plasma. The solver itself is designed with a modular approach enabling the separation of the physics from the numerics, thereby facilitating the testing/usage of the numerical schemes that best suit a particular physical simulation.

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3 The ITM-TF Mission

The ITM-TF operated under EFDA from 2004 until 2013.

[1] http://users.euro-fusion.org/iterphysicswiki/index.php/
[2] http://www.euro-fusionscipub.org/eu-im/

The main mission of ITM-TF was to provide a software infrastructure framework for EU integrated modelling activities as well as a validated suite of simulation codes for the modelling of present experiments, ITER and DEMO plasmas.

The ITM-TF operated until 2013 under a work programme formulated to support this goal, structuring the EU modelling effort around existing experiments and ITER scenario prediction while maintaining a long term strategic aim to provide a validated set of European modelling tools for ITER exploitation.

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4 ITM-TF Achievements

During the first phase of the ITM-TF, surveys and cross-verification of the available European models and numerical codes were performed within the individual IMPs and the data-structure was extensively discussed and defined. Equilibrium, linear MHD stability, core transport and RF wave propagation, as well as the poloidal field systems and a few diagnostics were the first topics addressed. Data structures have been finalised for these and then expanded to address, among others, non-linear MHD, edge physics, turbulence and neutral beam propagation. In parallel to the development of the physics concepts, ITM-TF developed the tools to manipulate the data structure and use it in fully flexible and modular simulation workflows. The ITM database contains machine descriptions from JET, Tore Supra, MAST, FTU, FAST, AUG, ITER as well as some experimental data from Tore Supra and JET. The ITM-TF futher achieved the development of the first release version of a fully modular and versatile simulator, the ETS, with all the essential functionalities. The validation of the ETS simualtor started in 2010 against the state-of-the-art transport codes and ETS now starts to be used for the first physics applications.

Next steps are the validation of the simulator for a complete discharge on existing experimental data with the available modules, the integration of more quantitative physics models ("ab-initio") and the integration of the whole modelling of the device.

Some posters that describe the ITM were presented at an ITM EXPO at the 2011 EPS fusion conference in Strasbourg. Copies can be found here (7.1.1).

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5 ITM-TF Structure

The EFDA ITM-TF was structured into four Integrated Modelling Projects (IMPs) focusing on the following physics areas:

- **IMP12** plasma equilibrium and MHD
- **IMP3** transport code and whole discharge evolution
- **IMP4** transport and micro-instabilities
- **IMP5** heating, current drive (H&CD) and fast particles

The "Infrastructure and Software Integration Project" (**ISIP**) was in charge of developing, maintaining and operating the code platform structure and implementing the ITM data-structure. A key function of ISIP was to provide infrastructure support to the IMPs.

At present, under EUROfusion, this expertise and tasks are ensured by the **Core Programming Team** under the **Infrastructure and Support Activities Work Package (WP-ISA CPT)** .

Two further projects ensured the link with the experimentalists and the provision of the experimental databases:

- **AMNS** the "Atomic, Molecular, Nuclear Surface" Data
- **EDRG** "Experimentalists and Diagnosticians Resource Group"

The "ITER Scenario Modelling Working Group" (**ISM**) was established in 2007 as part of ITM-TF with the aim to assist in systematic predictive modelling of all ITER reference scenarios by using the major existing integrated modelling tools, whilst the ITM code platform was in development. ISM also supported the verification and validation of the ETS, which aims to become the main tool for EU modelling activity.

last update: 2016-02-01 by dpcITM-TF Contributors

ITM-TF contributors are defined in the Appendix of G.L. Falchetto et al., Nuclear Fusion 54,043018, 2014.

This list reproduces the status of ITM-TF members in 2012 and is not exhaustive. A grateful thank you to all those who contributed and promoted EU-ITM since its beginnigs.

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last update: 2015-12-11 by gfalchet

6 ITM Publications

6.1 Journals

1. G.L. Falchetto et al., ITM-TF contributors and JET-EFDA Contributors, The European Integrated Tokamak Modelling (ITM) Effort: Achievements and First Physics Results. Nuclear Fusion 54,043018, 2014.

2. Coelho, R., et al.,Synthetic diagnostics in the EU-ITM simulation platform, 7th Workshop on Fusion Data Processing Validation and Analysis, Frascati (IT), March 2012; Fusion Science and Technology 63(1), 1-8, 2013.

3. O. Sauter and S. Yu. Medvedev, Tokamak Coordinate conventions: COCOS, Computer Phys. Commun. 184, 293 (2013)

4. Y. Frauel, et al., Easy use of high performance computers for fusion simulations. Fusion Engineering and Design, in press, 2012.

5. D.P. Coster, V. Basiuk, G. Pereverzev, D. Kalupin, R. Zagorksi, R. Stankiewicz, P. Huynh, F. Imbeaux, et al, The European Transport Solver, IEEE Transactions on Plasma Science 38 (9), 2085 (2010) .

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7. B. Guillerminet, F. Iannone, F. Imbeaux, G. Manduchi, A. Maslennikov, V. Pais, P. Strand, Gateway: New high performance computing facility for EFDA task force on integrated Tokamak modelling, Proceedings of the 7th IAEA Technical Meeting on Control, Data Acquisition, and Remote Participation for Fusion Research, Fusion Engineering and Design Volume 85, Issues 3-4, July 2010, Pages 410-414

8. D. Tskhakaya, A. Soba, R. Schneider, M. Borchardt, E. Yurtesen, J. Westerholm, PIC/MC code BIT1 for plasma simulations on HPC, 18th Euromicro International Conference on Parallel, Distributed and Network-Based Processing (PDP), IEEE Conference Publications, Page(s): 476 - 481 (2010)

9. A. Cardinali et al., Minority heating by ICRH: a tool for investigating burning plasma physics in FAST, Nuclear Fusion, 49:095020, 2009.

10. V. Kotov, D. Reiter, Two-point analysis of the numerical modelling of detached divertor plasmas, Plasma Phys. Control. Fusion, 51 (2009) 115002.

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14. G. Vlad et al., Particle simulation of energetic particle driven Alfvn modes in NBI heated DIII-D experiments, Nuclear Fusion, 49:075024, 2009.

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16. G.L. Falchetto, B.D. Scott, P. Angelino, A. Bottino, T. Dannert, V. Grandgirard, S. Janhunen, F. Jenko, S. Jolliet, A. Kendl, B.F. McMillan, V. Naulin, A.H. Nielsen, M. Ottaviani, A.G. Peeters, M.J. Pueschel, D. Reiser, T.T. Ribeiro and M. Romanelli "The European turbulence code benchmarking effort: Turbulence driven by thermal gradients in magnetically confined plasmas". Plasma Phys. Control. Fusion 50, 124015 (2008).

6.2 Conference Papers

1. G.L. Falchetto, D. Coster , R. Coelho, et al. ITM-TF contributors and JET-EFDA Contributors, The European Integrated Tokamak Modelling (ITM) Effort: Achievements and First Physics Results [3] 439-TH/P2-25, to appear in Proceedings of the 24th IAEA Fusion Energy Conference (FEC 2012), San Diego, US. *poster* [4]

2. D. Kalupin, V. Basiuk, D. Coster, et al. ITM-TF contributors and JET-EFDA Contributors, The European Transport Solver: an integrated approach for transport simulations in the plasma core [5] 4-TH/P2-01, to appear in Proceedings of the 24th IAEA Fusion Energy Conference (FEC 2012), San Diego, US. *poster* [6]

3. X. Litaudon, I. Voitsekhovitch et al. and the EU-ITM ITER Scenario Modelling group, Modelling of Hybrid Scenario: from present-day experiments towards ITER [7], TH/P2-05, to appear in Proceedings of the 24th IAEA Fusion Energy Conference (FEC 2012), San Diego, US. *poster* [8]

4. COSTER, D.P., KLINGSHIRN, H.-J., et al.,Core-Edge Coupling: developments within the EFDA Task Force on Integrated Tokamak Modelling, P1.073, 39th EPS Conference on Plasma Physics& 16th Int. Congress on Plasma Physics, Stockholm 2012.

5. KSLOMPOLO, S., et al., Preparing tokamak 3D wall and magnetic data for particle tracing simulations, P5.058, 39th European Physical Society Conference on Plasma Physics, Stockholm 2012.

6. FIGINI, L., et al.,Benchmarking of electron cyclotron heating and current drive codes on ITER scenarios within the European Integrated Tokamak Modelling framework, in European Physical Journal Web of Conferences, proceedings of EC-17 - 17th Joint Workshop on Electron Cyclotron Emission and Electron Cyclotron Resonance Heating (Deurne, The Netherlands, 7 - 11 May 2012).

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9. ZWINGMANN, W., et al, Validation Procedure of the Tokamak Equilibrium Reconstruction Code EQUAL with a Scientific Workflow System, P4-180, 37th EPS Conference on Plasma Physics, Dublin 2010.

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[3] https://www.efda-itm.eu/WORLD/imports/world/public/Falchetto_ITM_IAEA_paper.pdf
[4] https://www.efda-itm.eu/WORLD/imports/world/public/Falchetto_ITM_IAEA_poster.pdf
[5] https://www.efda-itm.eu/WORLD/imports/world/public/Kalupin_IAEA_paper.pdf
[6] https://www.efda-itm.eu/WORLD/imports/world/public/Kalupin_IAEA_poster.pdf
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27. V. Parail et al., 22nd IAEA Fusion Energy Conference, Geneva, Switzerland.

28. F. Saint-Laurent, B. Faugeras, C. Boulbe, S. Bremond, P. Moreau, J. Blum - Plasma position control and current profile reconstruction for Tokamaks - ICALEPCS Conference Kobe - Japon 2009

29. Scott B., Towards understanding of the L-H transition in tokamaks, JET Task Force T Workshop, February 15-17 2010. Includes the two main workflow results.

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7 ITM Overview and Invited Talks

7.1 2011

- KONZ, C., et al, First physics applications of the Integrated Tokamak Modelling (ITM-TF) tools to the MHD stability analysis of experimental data and ITER scenarios, O2.103, 38th EPS Conference on Plasma Physics, Strasbourg 2011.

- **7.1.1 Posters prepared for the 2011 EPS ITM Expo**
  - *ITM* [9]
  - *ITM Code Camps* [10]
  - *ISIP* [11]
  - *ISIP + IMP12: Control* [12]
  - *EDRG* [13]
  - *AMNS* [14]
  - *ISM* [15]
  - *IMP12 Equilibrium and Stability* [16]
  - *IMP3 Core* [17]
  - *IMP3 Edge* [18]
  - *IMP4* [19]
  - *IMP5-I* [20]
  - *IMP5-II* [21]
  - *EUFORIA* [22]
  - *MAPPER* [23]

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7.2 2010

- Overview of the European Integrated Tokamak Modelling Task Force [24] (EU-US Workshop on Software Technologies for Integrated Modelling, Gothenburg, 2010-12-01 – 2010-12-03)

[9] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_EXPO_EPS2011/ITM_poster_EPS2011_n1.pdf
[10] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_EXPO_EPS2011/ITM_poster_CCs_n2.pdf
[11] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_EXPO_EPS2011/ISIP_poster_EPS2011_n3.pdf
[12] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_EXPO_EPS2011/ISIP_IMP12_Control_poster_EPS2011_n.pdf
[13] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_EXPO_EPS2011/EDRG_poster_EPS2011_n4.pdf
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[16] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_EXPO_EPS2011/IMP12_EPS2011_equil+stab_n5.pdf
[17] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_EXPO_EPS2011/IMP3-Core_EPS2011_n7.pdf
[18] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_EXPO_EPS2011/IMP3-Edge_EPS2011_n8.pdf
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[21] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_EXPO_EPS2011/IMP5_poster2_EPS2011_n10.pdf
[22] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_EXPO_EPS2011/EUFORIA_ITMEXPO_n14.pdf
[23] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_EXPO_EPS2011/MAPPER-Combined2_n15.pdf
[24] https://www.efda-itm.eu/WORLD/imports/world/public/ITM_Overview_GF.pdf

7.3 2009

- Fusion, EFDA, ITM and EUFORIA [25] Presented at the "Grids and e-Science 2009 Advanced Workshop on the future and sustainability of production Grids" (15-19 June 2009)
- Plasma Physics: Scientific and Computational Challenges: Fusion, EFDA, ITM and EUFORIA [26] Presented at "Grid Computing: a new tool for Science and Innovation - IX International Conference on Science, Arts and Culture - ECSAC, Losinj Croatia" (2009-08)
- Scientific Workflows in Fusion: EUFORIA & EFDA-TF-ITM [27] Presented at "ParCo2009, International Conference on Parallel Computing 1-4 September 2009, cole Normale Suprieure de Lyon, Lyon, France"

7.4 2008

- The European turbulence code cross-verification effort: turbulence driven by thermal gradients in magnetically confined plasmas [28]presented at EPS 2008 by G. Falchetto - on behalf of EFDA-TF-ITM-IMP#4

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8 Glossary

Collaborative Development Environment (CDE)

A **collaborative development environment (CDE)** is an online meeting space where a software development project's stakeholders can work together, no matter what timezone or region they are in, to discuss, document, and produce project deliverables. The name was coined by Grady Booch [29].

Consistent Physical Object (CPO)

A Consistent Physical Object (CPO) is a physics based, hierarchical data structure employed by the ITM-TF for a complete description of a physics area, e.g. `equilibrium` . All ITM-TF code modules interact through the exchange of CPOs. The CPOs also form the basic block of data written to the ITM database.

Content Management System (CMS)

A **content management system (CMS)** is the collection of procedures used to manage work flow in a collaborative environment. These procedures can be manual or computer-based. The procedures are designed to:

- Allow for a large number of people to contribute to and share stored data
- Control access to data, based on user roles. User roles define what information each user can view or edit
- Aid in easy storage and retrieval of data
- Reduce repetitive duplicate input
- Improve the ease of report writing
- Improve communication between users

In a CMS, data can be defined as nearly anything - documents, movies, pictures, phone numbers, scientific data, etc. CMSs are frequently used for storing, controlling, revising, semantically enriching, and publishing documentation.

FC2K

FC2K is a tool for wrapping a Fortran or C++ source code into a Kepler actor. Before using it, your physics code should be ITM-compliant (i.e. use CPOs as input/output).

Gforge

[25] https://www.efda-itm.eu/WORLD/imports/world/public/Santander_2009-06_Coster.pdf
[26] https://www.efda-itm.eu/WORLD/imports/world/public/Coster_ECSAC_2009-08v1.pdf
[27] https://www.efda-itm.eu/WORLD/imports/world/public/Coster_ParCo_2009-09v1.pdf
[28] https://www.efda-itm.eu/WORLD/imports/world/public/FalchettoEPS2008_I2.023.pdf
[29] http://en.wikipedia.org/wiki/Grady_Booch

Gforge [30] hosts all projects (software and infrastructure) under the ITM-TF.

ITM Gateway

The ITM Gateway is a compute cluster located at Portici (near Napoli in Italy). It is uses for development and fusion simulations in the ITM-TF.

ITM Portal

The ITM Portal [31] is the web portal for the ITM-TF, i.e. it hosts the ITM-TF web pages and projects under Gforge.

Integrated Simulation Editor (ISE)

The Integrated Simulation Editor ISE allows you to visualize and edit data from an ITM database entry. It also allows running a Kepler workflow based on the opened data entry.

Universal Access Layer (UAL)

The UAL (Universal Access Layer) is a multi-language library that allows exchanging Consistent Physical Objects (CPOs) between various modules, and to write to an ITM database.

actor

Actors take execution instructions from a director. In other words, actors specify *what* processing occurs while the director specifies *when* it occurs.
In the ITM-TF, actors are usually modules which contain physics codes like `EQUAL` or `HELENA`.

calibration

The process of adjusting numerical or physical modelling parameters in the computational model for the purpose of improving agreement with experimental data.

data mapping

An XML file containing all the mapping essentials for mapping from a local experimental database for a specific tokamak device to the ITM database. The mapping essentials include for instance the download method, local signal names, gains and offsets, time base, and eventual interpolation option to ensure that only one time base is set for each CPO that is built from multiple local signals. A java code (exp2ITM developed under ISIP), with the MD and DM files as inputs, is then run to connect to the local device database, retrieve the required experimental data and populate the ITM database instance for that shot/device and dataversion.

director

A director controls (or directs) the execution of a workflow, just as a film director oversees a cast and crew.

error

A recognisable deficiency in any phase or activity of modelling and simulation that is not due to lack of knowledge.

kepler

Kepler is a software application for the analysis and modeling of scientific data. Kepler simplifies the effort required to create executable models by using a visual representation of these processes. These representations, or "scientific workflows", display the flow of data among discrete analysis and modeling components.

machine description

The machine description (MD) of a device basically builds on the set of engineering and diagnostic settings characterising a tokamak device. This includes, for instance, the vessel/limiter description, the PF coils and circuiting and lines of sight of diagnostics. In practice, all MD information is encapsulated in an XML file that emanates from the MD tagged datastructure schemas. An MD instance of a given device is then stored into the ITM database as shot 0 for that device database.

[30] https://gforge.efda-itm.eu
[31] https://portal.efda-itm.eu

model

A representation of a physical system or process intended to enhance our ability to understand, predict, or control its behaviour.

- A **conceptual model** consists of the observations, mathematical modelling data, and mathematical (e.g., partial differential) equations that describe the physical system. It will also include initial and boundary conditions.
- The **computational model** is the computer program or code that implements the conceptual model. It includes the algorithms and iterative strategies. Parameters for the computational model include the number of grid points, algorithm inputs, and similar parameters, etc.

modelling

The process of construction or modification of a model

prediction

Use of a model to foretell the state of a physical system under conditions for which the model has not been validated.

simulation

The exercise or use of a model.

uncertainty

A potential deficiency in any phase or activity of the modelling process that is due to the lack of knowledge.

validation

The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.

verification

The process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model.

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9 Links to related external projects

- EUFORIA Project [32]
- MAPPER Project [33]
- EFDA High Level Support Team (HLST) [34]
- EFDA Goal Oriented Training in Theory (GOTiT) [35]

9.1 EUFORIA

EUFORIA (EU Fusion fOR Iter Applications) is a project funded by European Union under the Seventh Framework Programme (FP7) which will provide a comprehensive framework and infrastructure for core and edge transport and turbulence simulation, linking grid and High Performance Computing (HPC), to the fusion modelling community.

[32] http://www.euforia-project.eu/
[33] http://www.mapper-project.eu/
[34] http://www.efda-hlst.eu/
[35] http://solps-mdsplus.aug.ipp.mpg.de/GOTiT/

9.1.1 Scientific Rationale and Main Objectives

The EUFORIA project will enhance the modelling capabilities for ITER sized plasmas through the adaptation, optimization and integration of a set of critical applications for edge and core transport modelling targeting different computing paradigms as needed (serial and parallel grid computing and HPC). Deployment of both a grid service and a High Performance Computing services are essential to the project. A novel aspect is the dynamic coupling and integration of codes and applications running on a set of heterogeneous platforms into a single coupled framework through a workflow engine a mechanism needed to provide the necessary level integration in the physics applications. This strongly enhances the integrated modelling capabilities of fusion plasmas and will at the same time provide new computing infrastructure and tools to the fusion community in general.

9.1.2 EUFORIA Resources

- The main EUFORIA Website [36]
- The EUFORIA Public Wiki [37]
- The EUFORIA Internal Wiki (password protected) [38]
- JRA3 (Workflows) Wiki [39]
- Support [40]
- The EUFORIA Wikipedia entry in English [41], Deutsch [42], Español [43], Français [44], Slovenian [45] and Suomi [46]

9.1.3 Public EUFORIA pages

To access the public EUFORIA pages [47], an ITM password is needed.

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last update: 2016-02-01 by dpc

[36] http://www.euforia-project.eu/EUFORIA/
[37] http://wiki.euforia-project.eu/
[38] http://iwiki.euforia-project.eu/
[39] http://scilla.man.poznan.pl:8080/confluence
[40] https://support.euforia-project.eu/
[41] http://en.wikipedia.org/wiki/EUFORIA_project
[42] http://de.wikipedia.org/wiki/EUFORIA-Projekt
[43] http://es.wikipedia.org/wiki/Proyecto_EUFORIA
[44] http://fr.wikipedia.org/wiki/Projet_EUFORIA
[45] http://sl.wikipedia.org/wiki/Projekt_EUFORIA
[46] http://fi.wikipedia.org/wiki/EUFORIA-projekti
[47] https://www.eufus.eu/documentation/ITM/html/euforia_public.html