eHeroes
eheroes.eu

Giovanni Lapenta for the eHeroes Consortium

Centrum voor Plasma-Astrofysica

Katholieke Universiteit Leuven

BELGIUM

This research has received funding from the European Commission's Seventh Framework Programme (FP7/2007-2013) under the grant agreement n° 284461 (eHeroes project, www.eheroes.eu). .

The Goal

Understanding the ***conditions*** *and the* ***threats*** *in the space environment for the* ***manned*** *and* ***robotic*** *missions of exploration heading to the* ***Moon****,* ***Mars*** *and beyond*

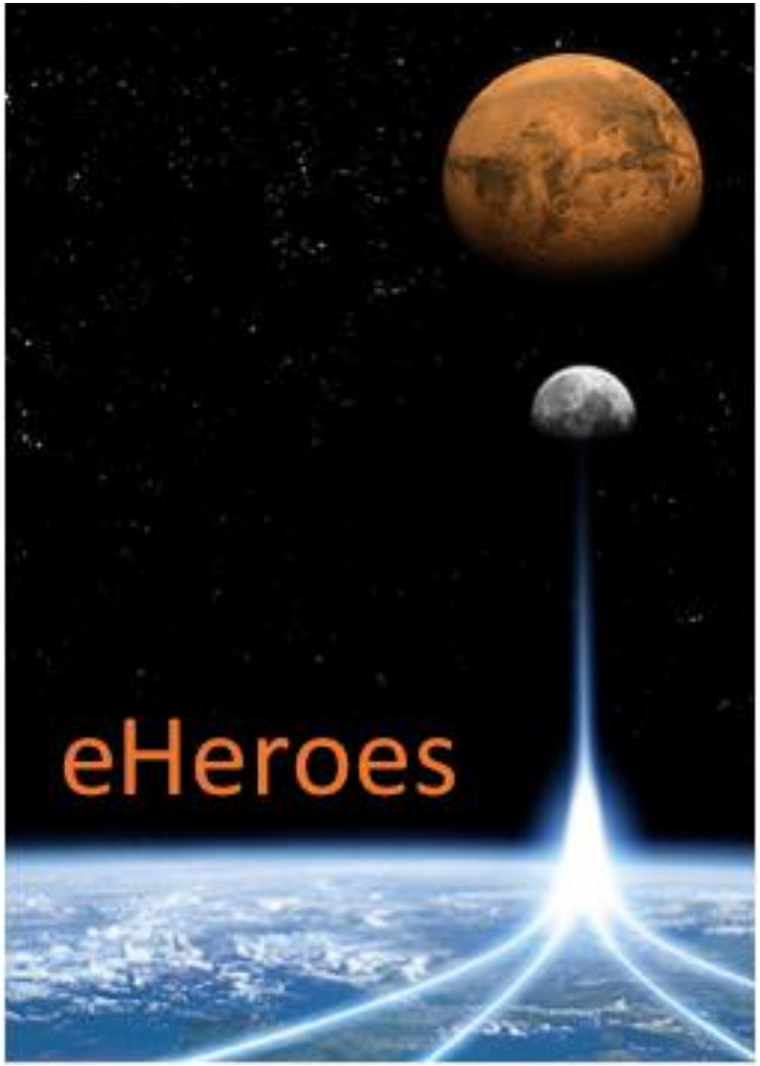


Image courtesy of ESA

SOTERIA EC to continue as eHeroes

eheroes.eu

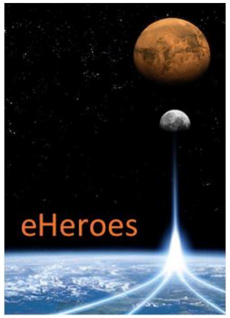
Coordinator: G. Lapenta

Data (ground & space) and simulation on:

- Space Weather
- Solar sources and their evolution
- Terrestrial Impact
- Space Activities

Collaborative Project FP7- Space

SEVENTH FRAMEWORK PROGRAMME



Soteria

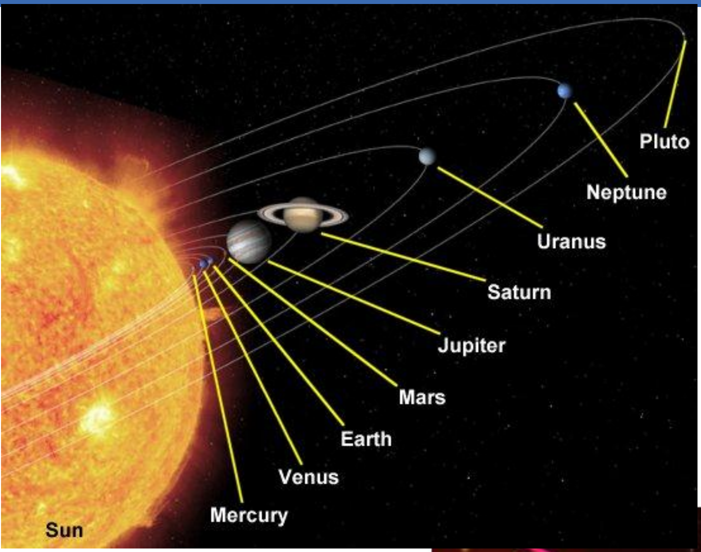
- Focus on data dissemination

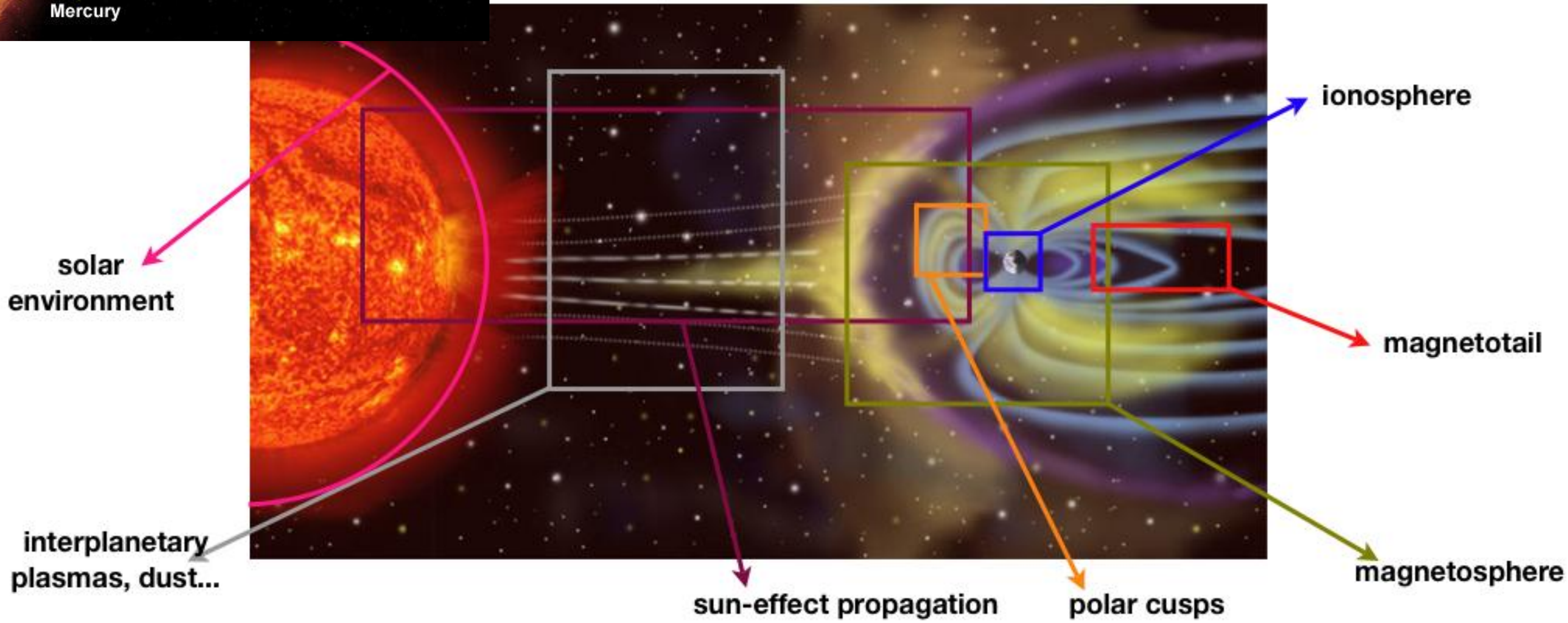
eHeroes

- adds emphasis to space exploration (specifically manned missions to the Moon and Mars)

Participant short name	Participant organisation name	Country
KU Leuven	Katholieke Universiteit Leuven	Belgium
SRC-PAS	Space Research Centre, Polish Academy of Sciences	Poland
NOVELTIS	NOVELTIS SAS	France
LPI	P.N. Lebedev Physical Institute, Russian Academy of sciences	Russian Federation
UOulu	Oulun Yliopisto	Finland
UCL	University College London	UK
UNIGRAZ	Universitaet Graz	Austria
ROB	Royal Observatory of Belgium	Belgium
HVAR	Hvar Observatory, Faculty of Geodesy, University of Zagreb	Croatia
KO	Konkoly Observatory	Hungary
CNRS-OBSPARIS	Observatoire de Paris, LESIA	France
UCT	University of Catania	Italy
INAF	Istituto Nazionale di Astrofisica - National Institute for Astrophysics	Italy
PMOD-WRC	Schweizerisches Forschungsinstitut für Hochgebirgsklimaund Medizin Davos	Switzerland
UGOE	Georg-August_Universität Göttingen Stiftung Öffentlichen Rechts	Germany

Overview of the Space Covered by eHeroes

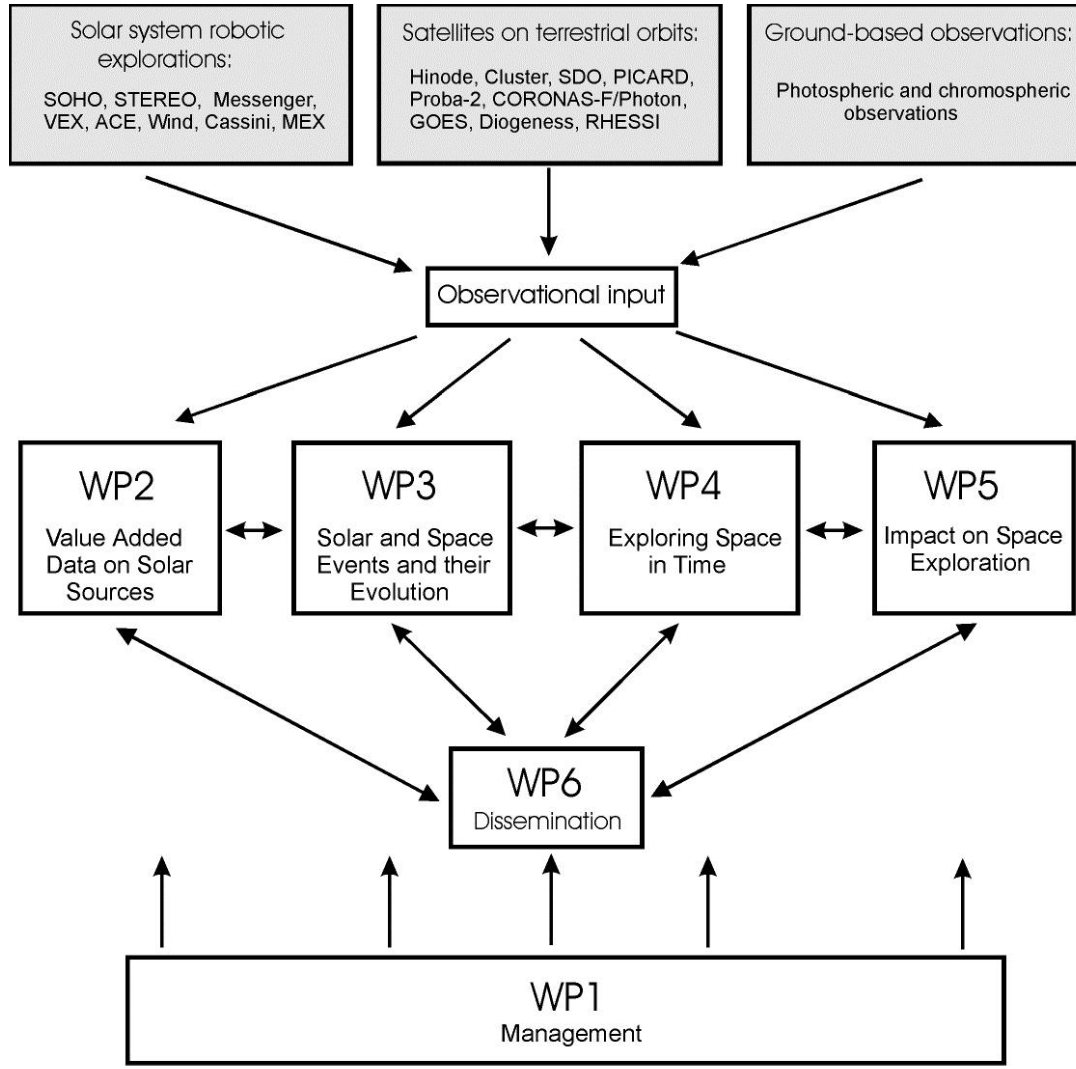




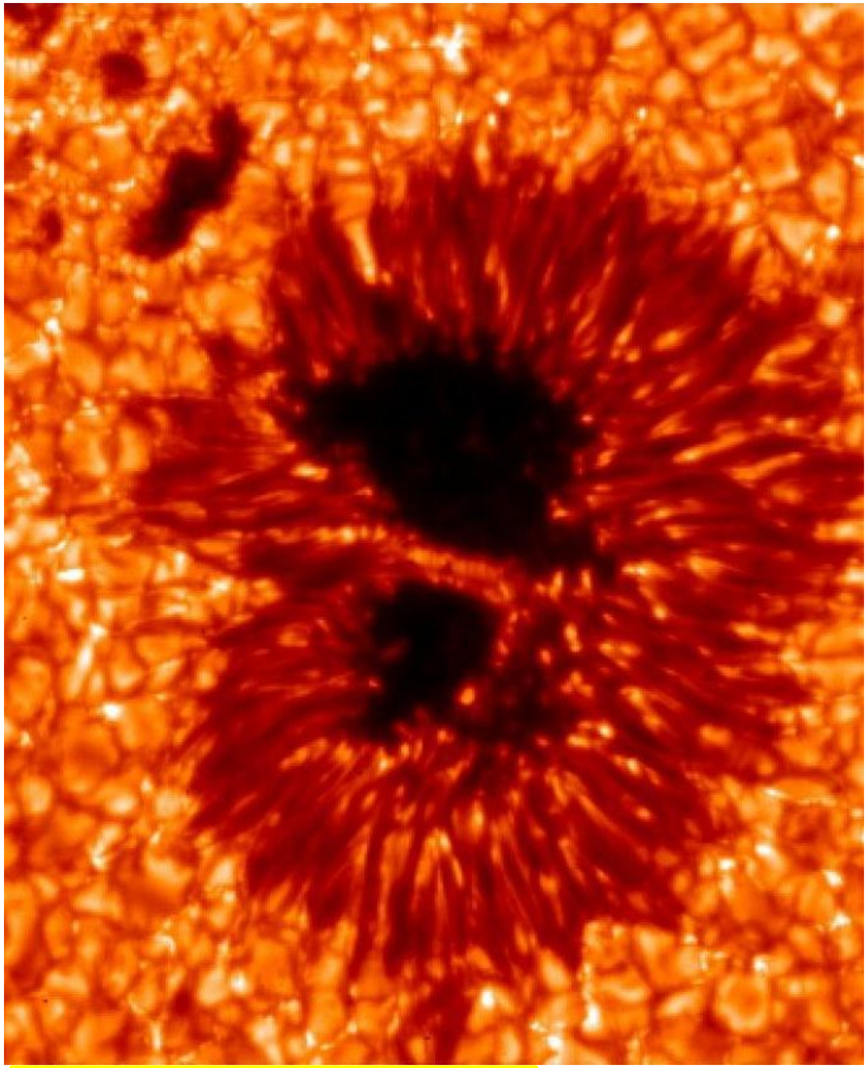
Structure

WP No	Work package title	Leader	Lead Beneficiary
1	Management	Giovanni Lapenta	KU Leuven
2	Value-added Data on Solar Sources	Andras Ludmany	KO
3	Solar and Space Events and their Evolution	Lidia van Driel-Gesztelyi	OBSPARIS
4	Exploring Space in Time	Kalevi Marsula	UOulu
5	Impact on Space Exploration	Sergey Kuzin	LPI
6	Dissemination	Petra Vanlommel	ROB

WP1: Management



WP2: Value-added Data on Solar Sources



Hinode: sunspot

Source: matter, magnetic fields
Coronal mass ejections
Flares

Relevance to space weather and climate:

- photospheric flare precursors
- analysis and extrapolation of magnetograms
- sources of the solar wind
- high-cadence irradiance variation and modelling

WP3: Solar and Space Events and their Evolution

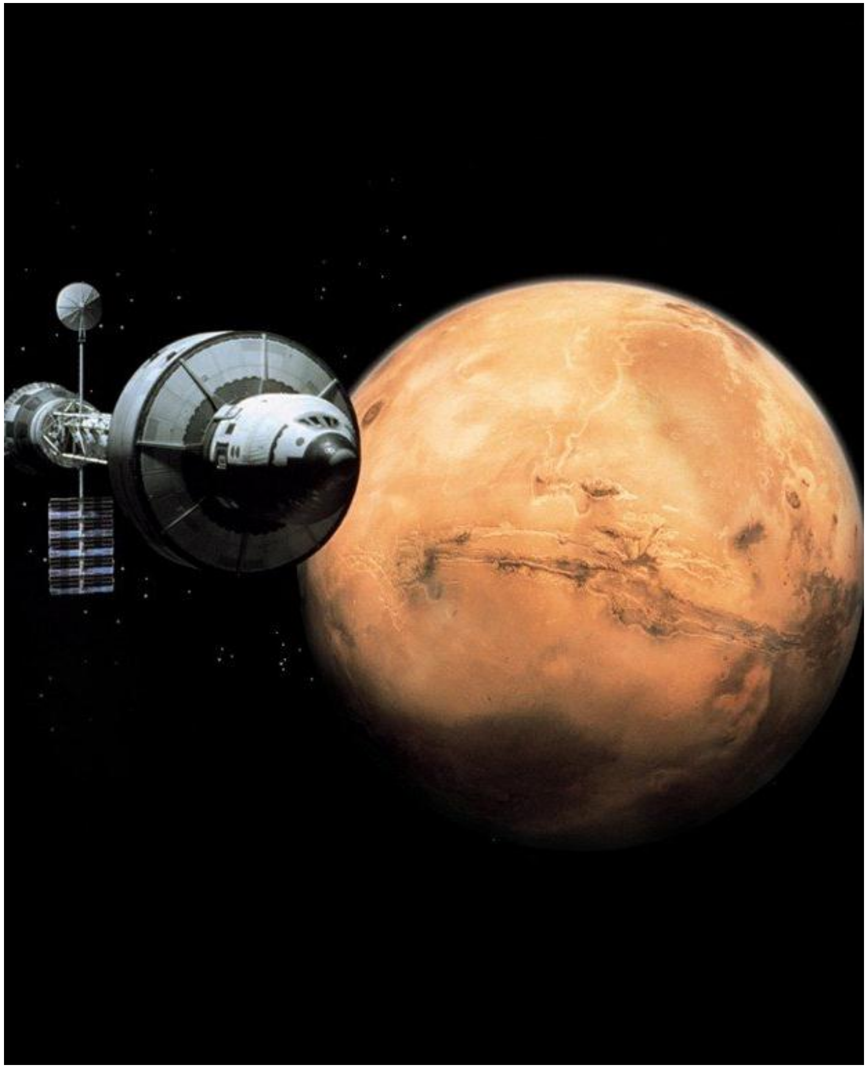
SDO: prominence

- Event precursors
- Observations, modeling and simulations of CME initiation and flare energy release
- Source region, acceleration mechanisms and interplanetary propagation of SEPs
- Evolution of CMEs and ICMEs in the heliosphere over large distances
- Dissemination of fast event-analysis

WP4: Exploring Space in Time

- Focus on long term, climate of space to design mission time-frame
- Activity forecasting methods
- Optimum parameters for the spatial-temporal distribution of flares and CMEs
- Maps of spatial-temporal distributions of flares and CMEs

WP5: Impact on Space Exploration



Exploring the heliospace with multiple satellites, a data assimilation-based optimisation approach.

Perils, threats, operation:

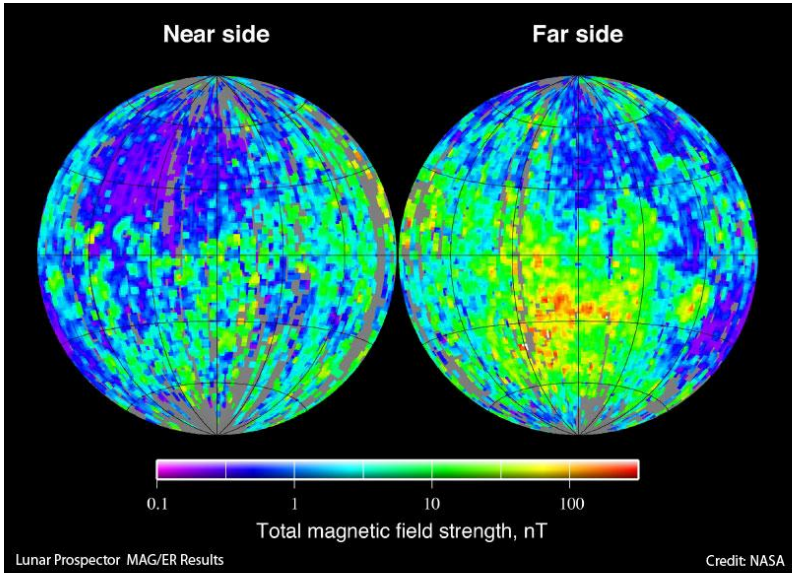
- Missions to the Near Earth Environment
- Mission to the Moon
- Mission to Mars

Variability of particle environment

Computer simulation:

- environment of spacecrafts
- Moon environment

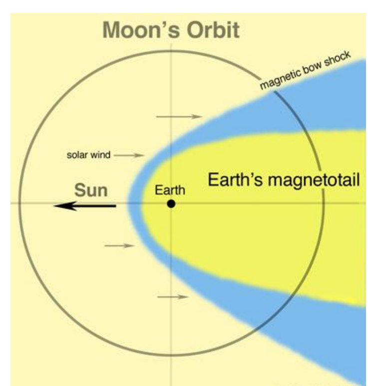
KU Leuven Position open on computer simulation for space exploration

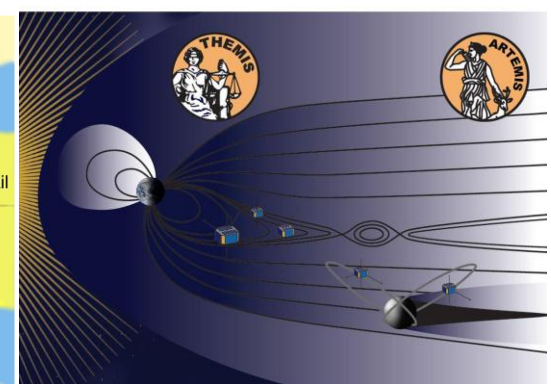


PIC kinetic modelling of:

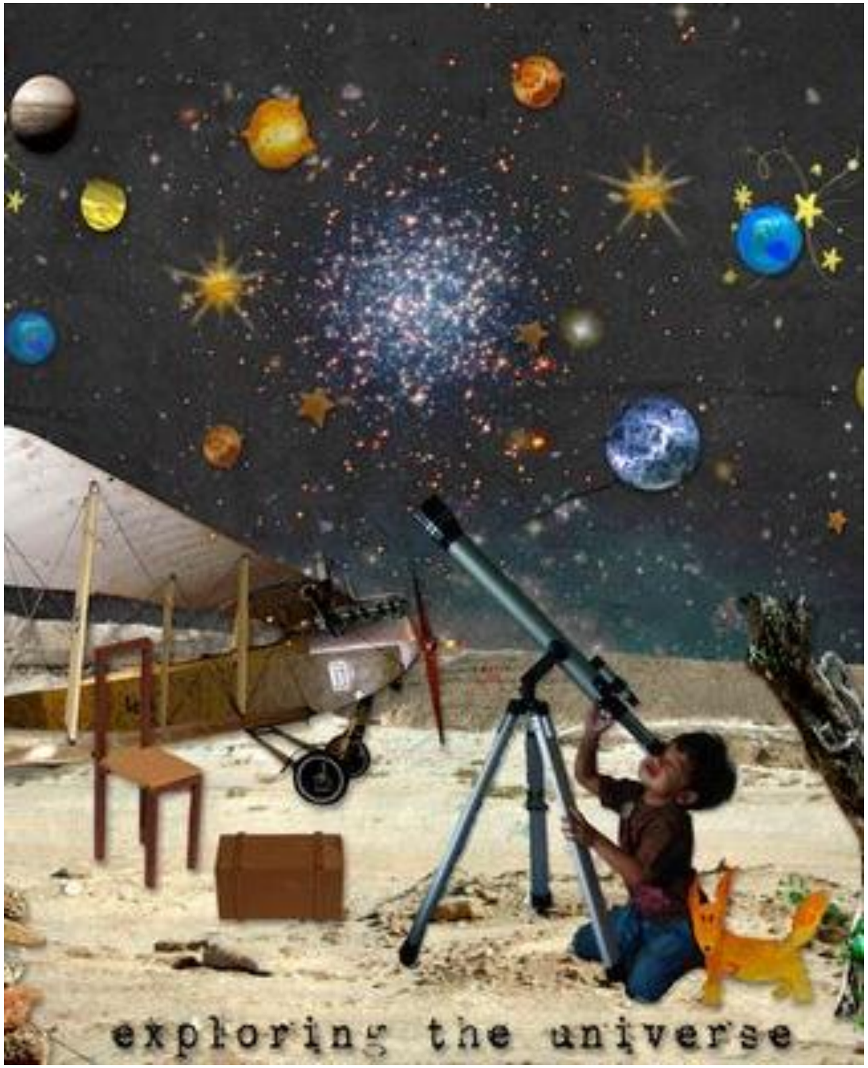
- Global Lunar interaction with its environment (solar wind or magnetosphere)
- Lunar surface and magnetic anomalies
- Man-made probes (e.g. solar orbiter, solar probe)

Collaboration with NASA Lunar Science Institute: simulation of lunar dust impact, Artemis data





WP6: Dissemination



Hitchhikers' guide to space

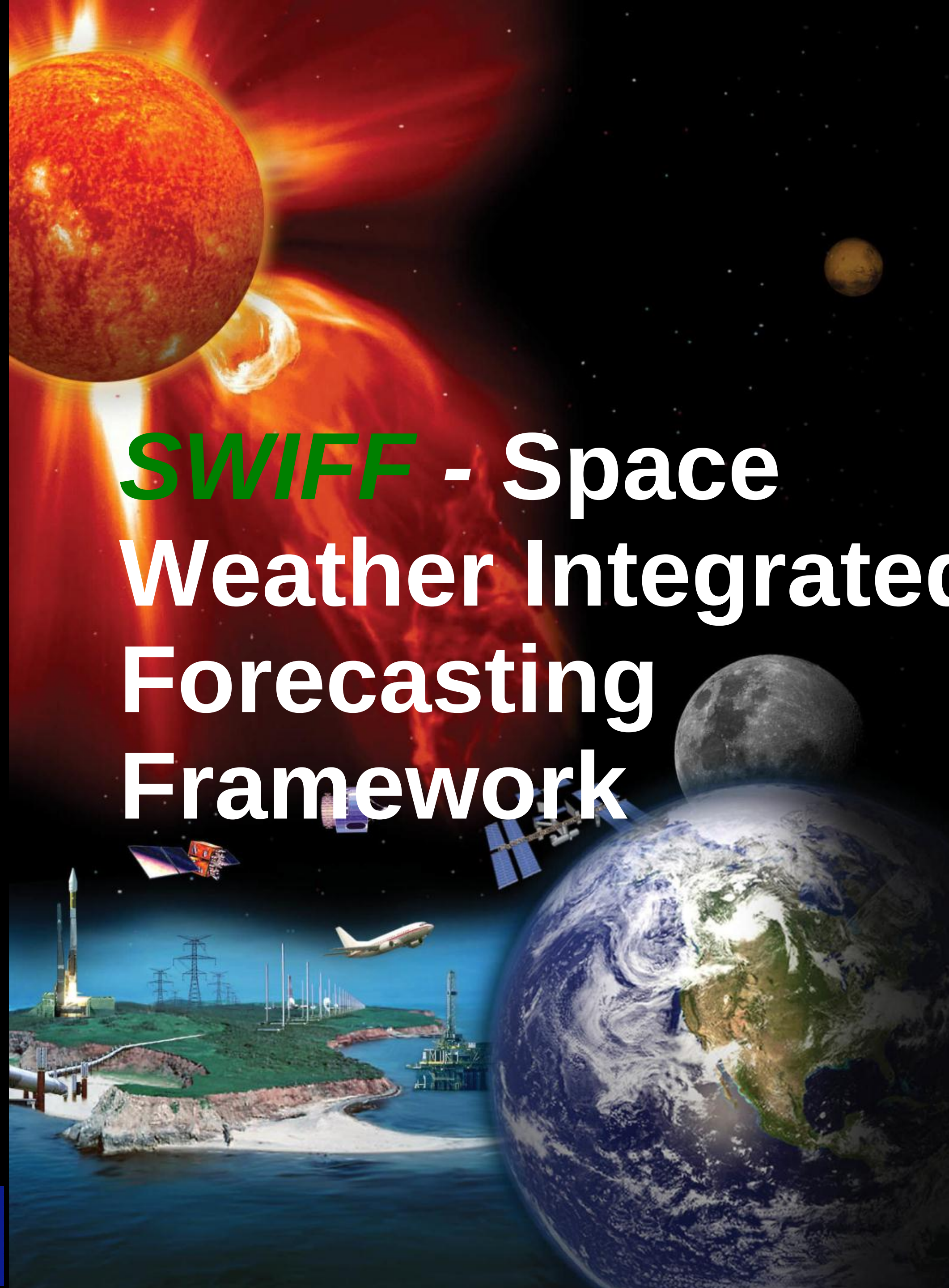
The Space Weather News

Information

Space Weather School

Swiff.eu

SWIFF - Space Weather Integrated Forecasting Framework



Coordinator:

Giovanni Lapenta

Centrum voor Plasma-Astrofysica

Katholieke Universiteit Leuven

BELGIUM

SPACE-WEATHER INTEGRATED FORECASTING FRAMEWORK — SWIFF

SEVENTH FRAMEWORK PROGRAMME

SWIFF: Space Weather Integrated Modelling Framework

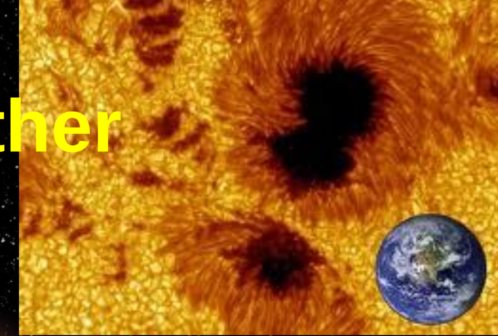
swiff.eu

Collaborative Project
FP7- Space

- Create a mathematical-physical framework to integrate multiple-physics (fluid with kinetic)
- Focus on coupling small-large scales
- Federation of models based on physical and amthematical understanding of the coupling
- Physics-based rather than software-based
- Founding approach: implicit, adaptivity and multilevel

Science Lead	Participant organisation name	Country
Coordinator: G. Lapenta	Katholieke Universiteit Leuven	Belgium
V. Pierrard	Belgian Institute for Space Aeronomy	Belgium
F. Califano	Università di Pisa	Italy
A. Nordlund	Københavns Universitet	Denmark
A. Bemporad	Astronomical Observatory Turin - Istituto Nazionale di Astrofisica	Italy
P. Travnicek	Astronomical Institute, Academy of Sciences of the Czech Republic	Czech Republic
C. Parnell	University of St Andrews	UK

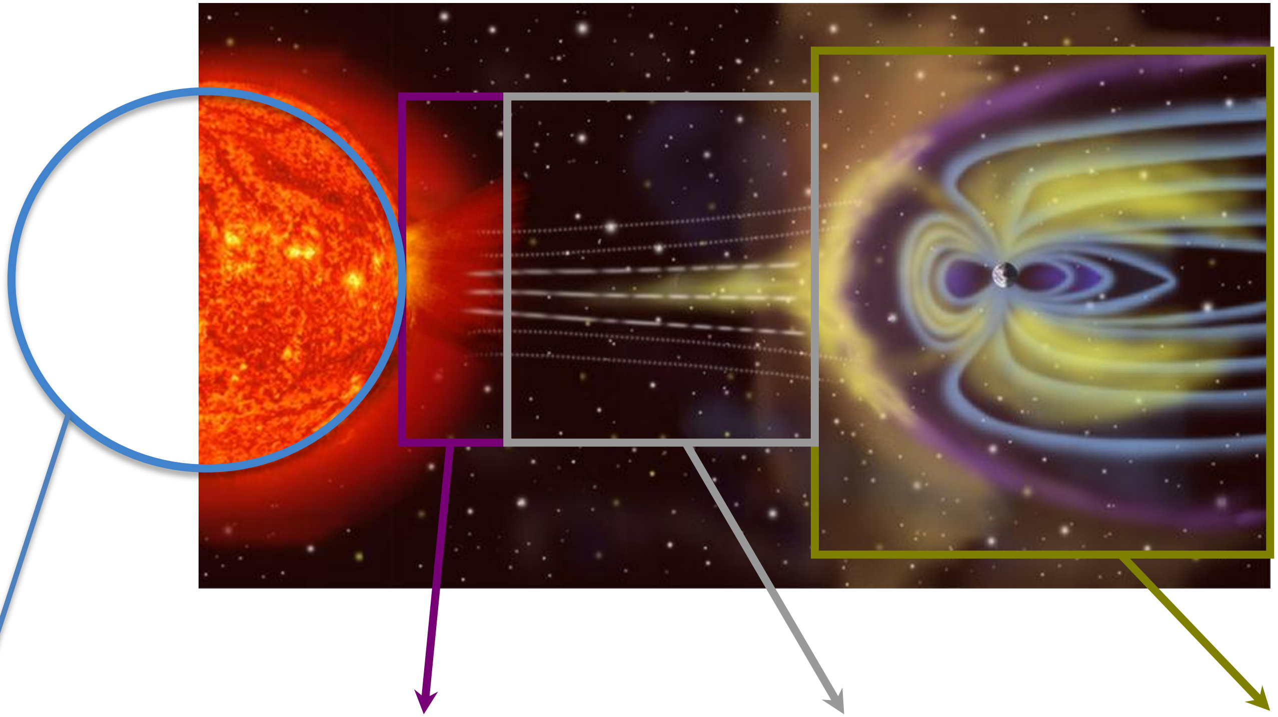
Challenges of space weather



Challenge of Space Weather

- Multiple scales
- Multiple physics

Space weather: Chain of events



Solar Interior → Solar atmosphere → Interplanetary space → Earth Environment

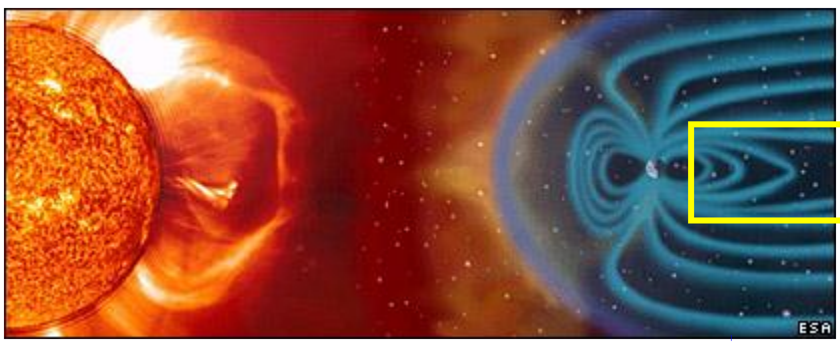
Vertical integration: Multiscale challenge

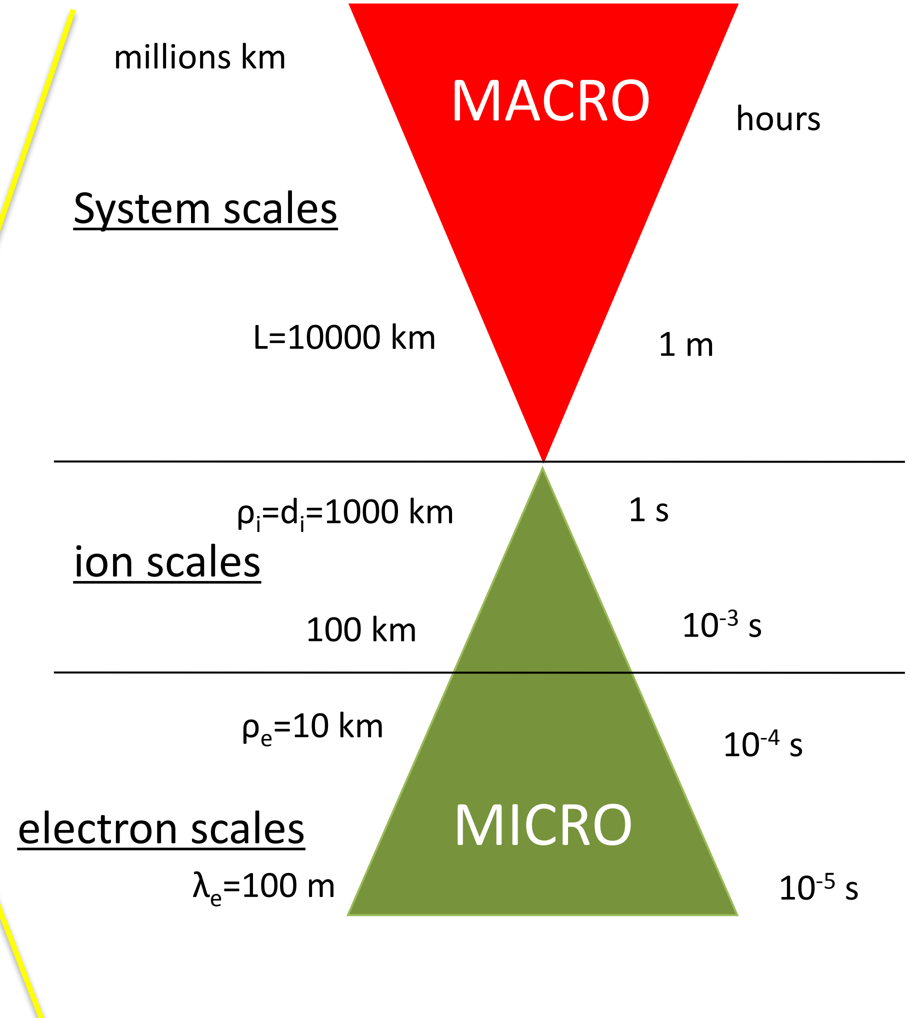
Overall event duration: hours to days

AU = 150 million Km (1.49 10^8 km)

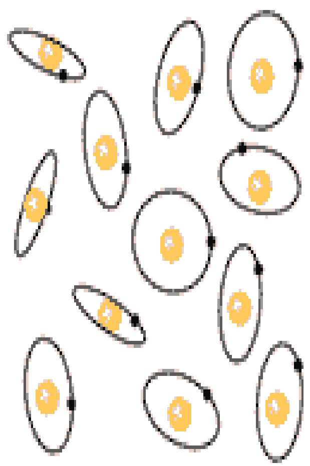
Solar Radius = 6.9 10^5 km

Earth Radius = 6.4 10^3 km

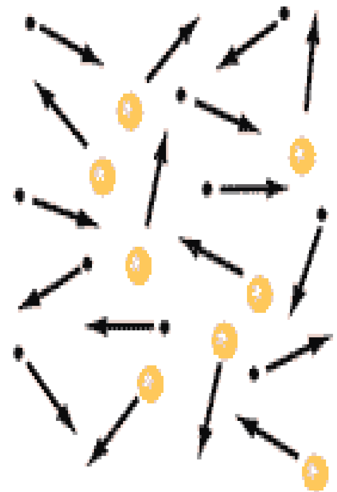




Multiphysics: A plasma and its models



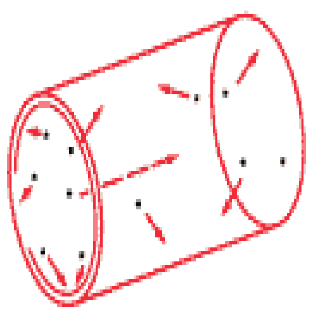
GAS



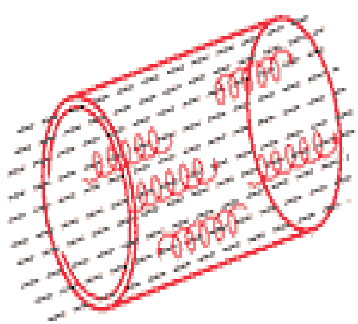
PLASMA

Kinetic approach: study the distribution function (probability of finding a particle with a given velocity in a given point at a given time):

$$\left\{ x_p, v_p \right\} \qquad f(\mathbf{x}, \mathbf{v}, t)$$



Motion of charged particles without magnetic field.

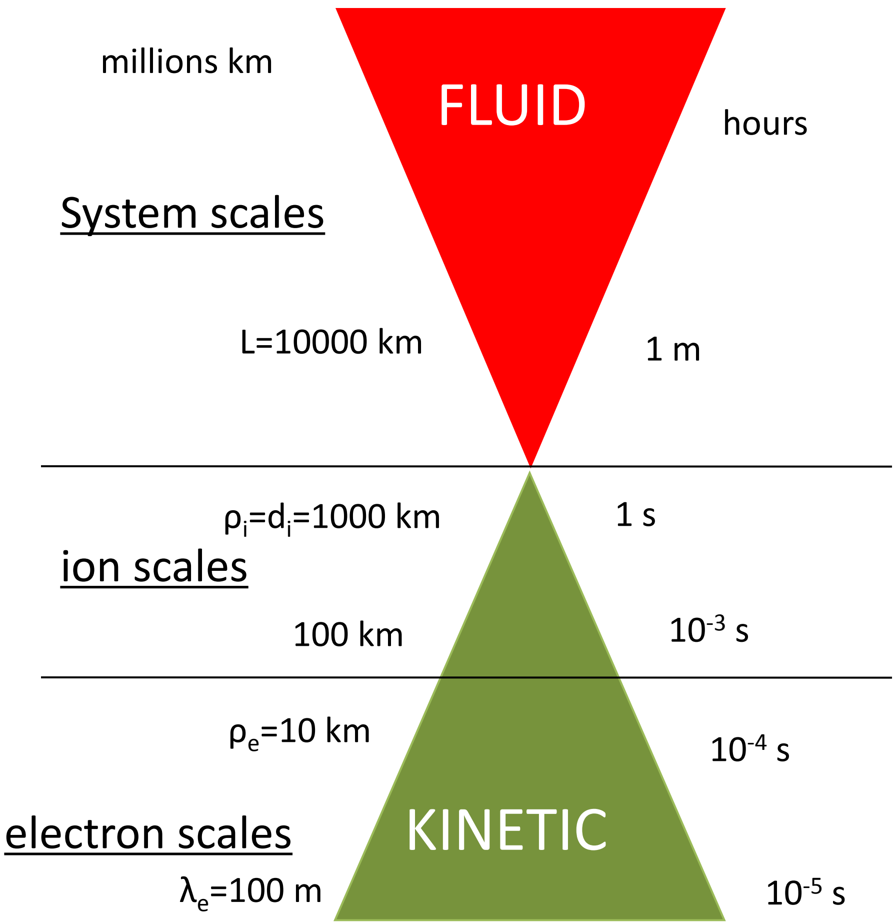


Motion of charged particles with magnetic field.

Fluid approach: study local averages (density, average speed, temperature,….)

$$n(\mathbf{x}, t), \mathbf{U}(\mathbf{x}, t), T(\mathbf{x}, t)$$

Different physics models at different scales



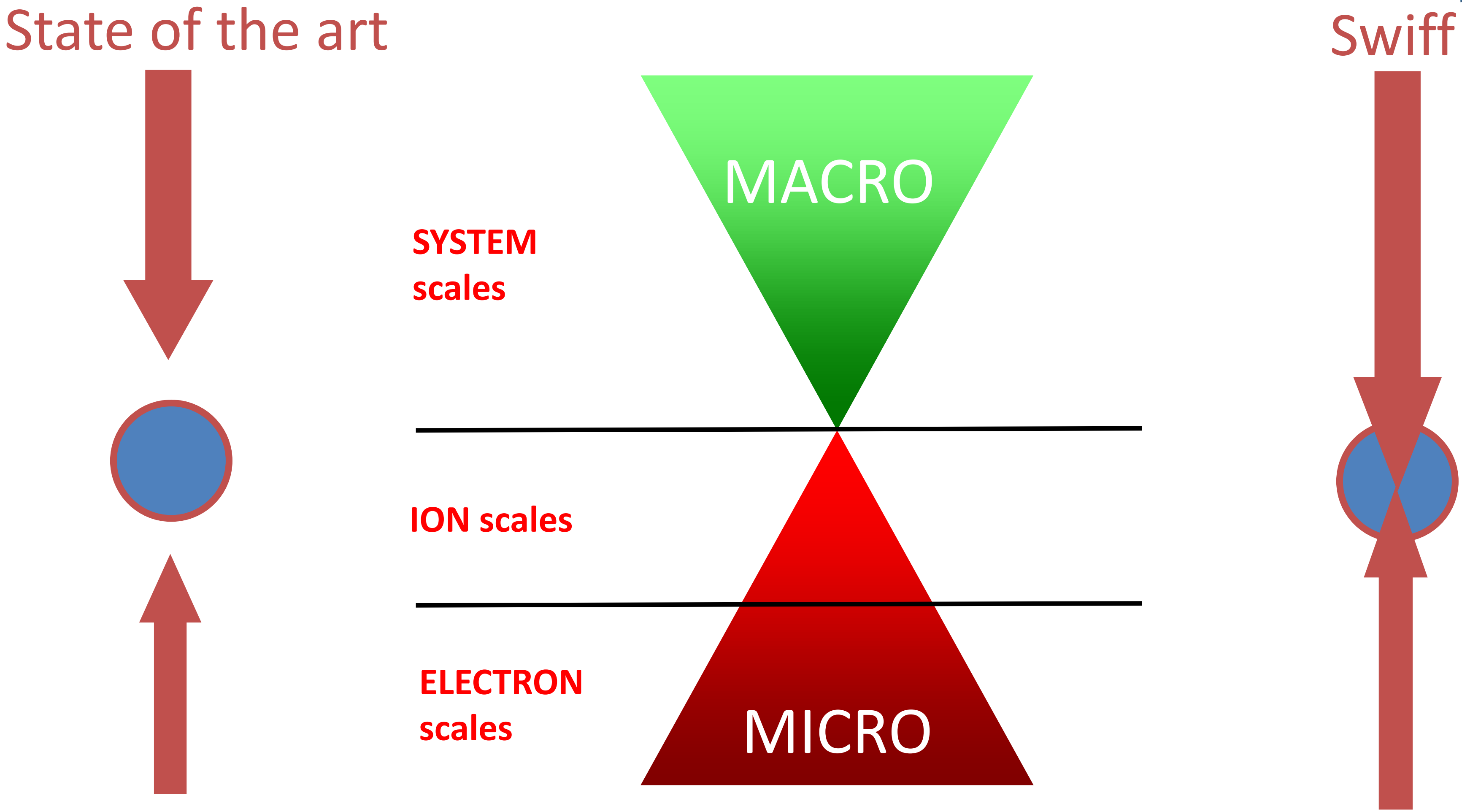
Fluid models

- computation effort manageable even at large scales
- miss the small scale physics
- adjustable parameters reduce the predictive value

Kinetic models

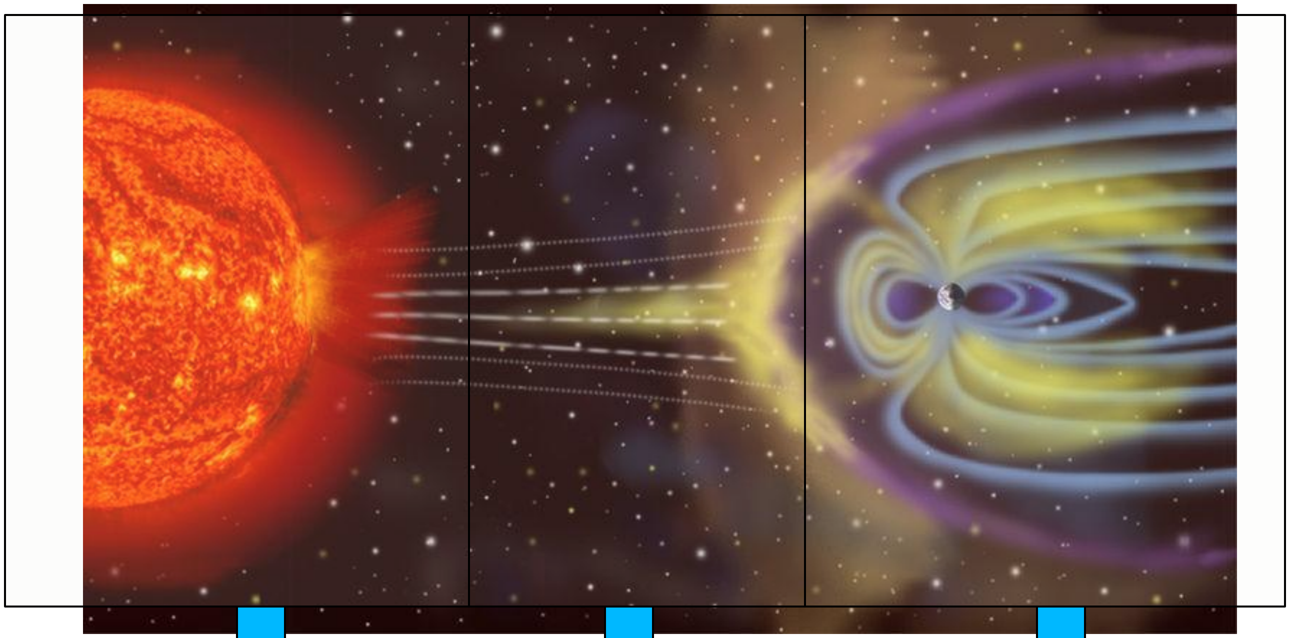
- first principles: include all physics, in particular what we do not yet understand
- surprisingly simple to conceive and implement in computers
- not economical at large scale

Multiscale – Multiphysics – Our Goals



SWIFF allows to bridge the micro-macro gap by increasing size and resolution by the needed 3 orders of magnitude

Horizontal integration – Multiphsyics challenge



WP3: couling at the Sun (Nordlund)

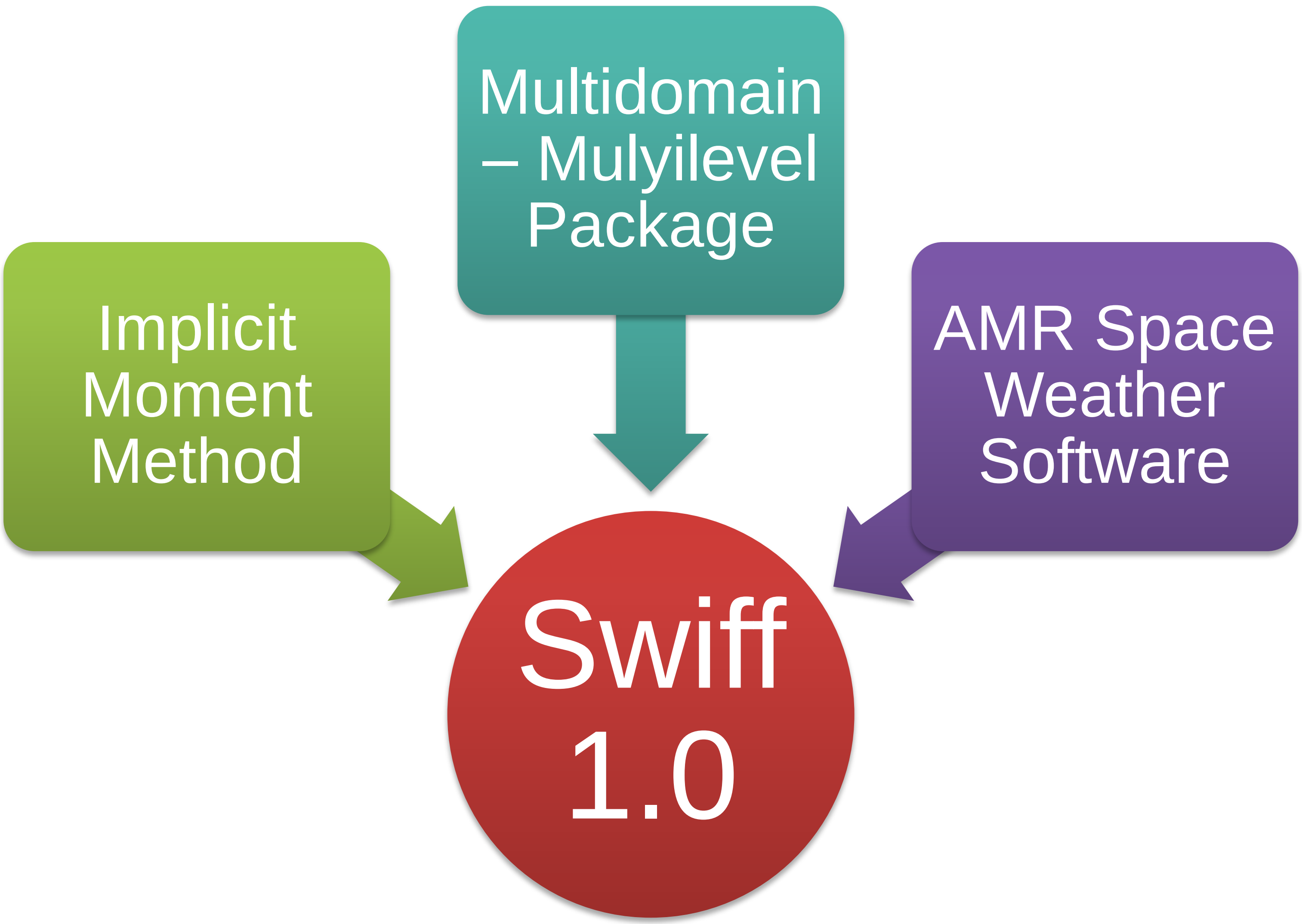
WP4: coupling in space (Califano)

WP5: coupling at the Earth (Pierrard)

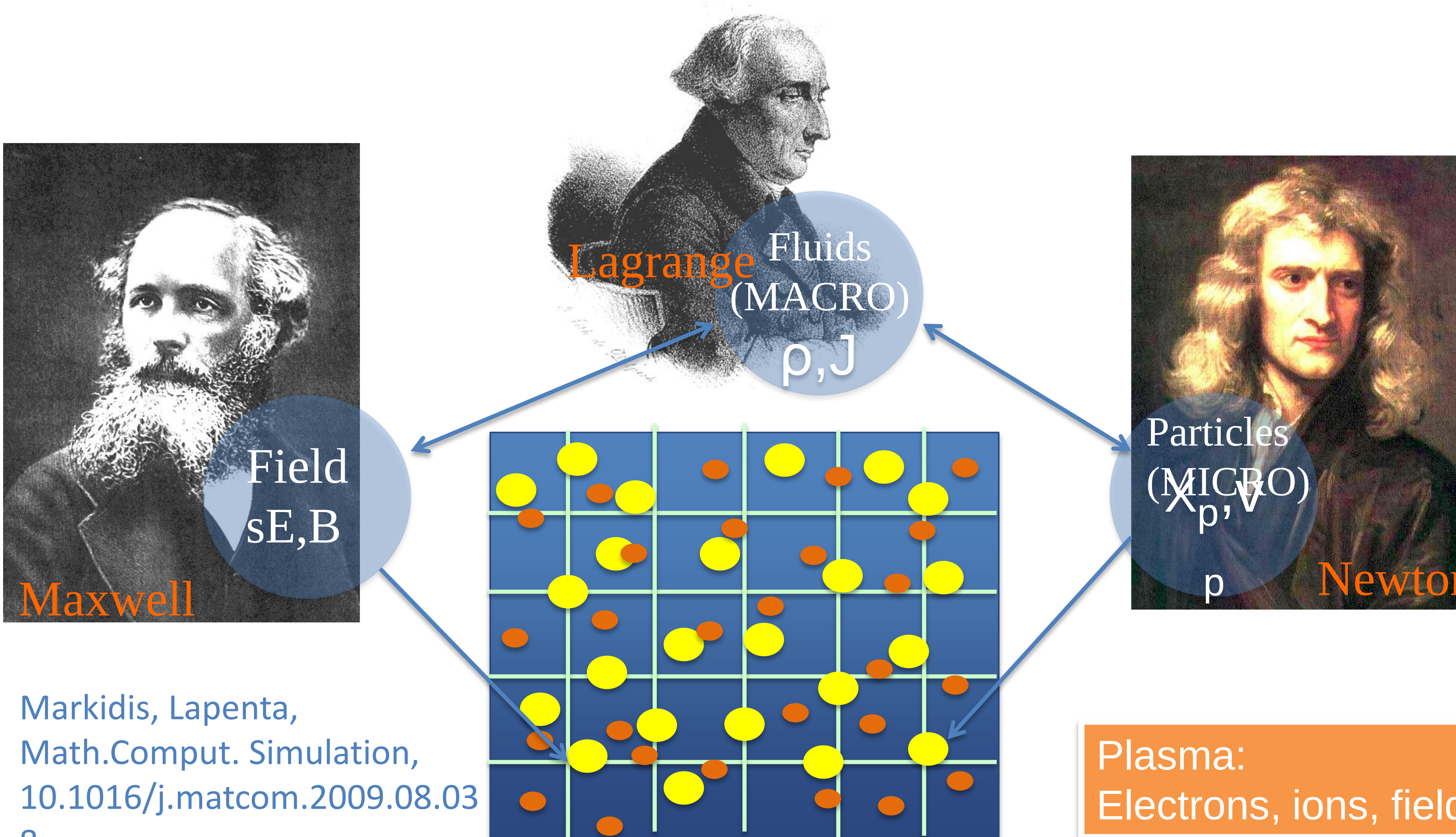
WP1/6: Management and Dissemination (Lapenta)

WP2: Mathematical Models (Keppens)

Swiff 1: First release of our software tools



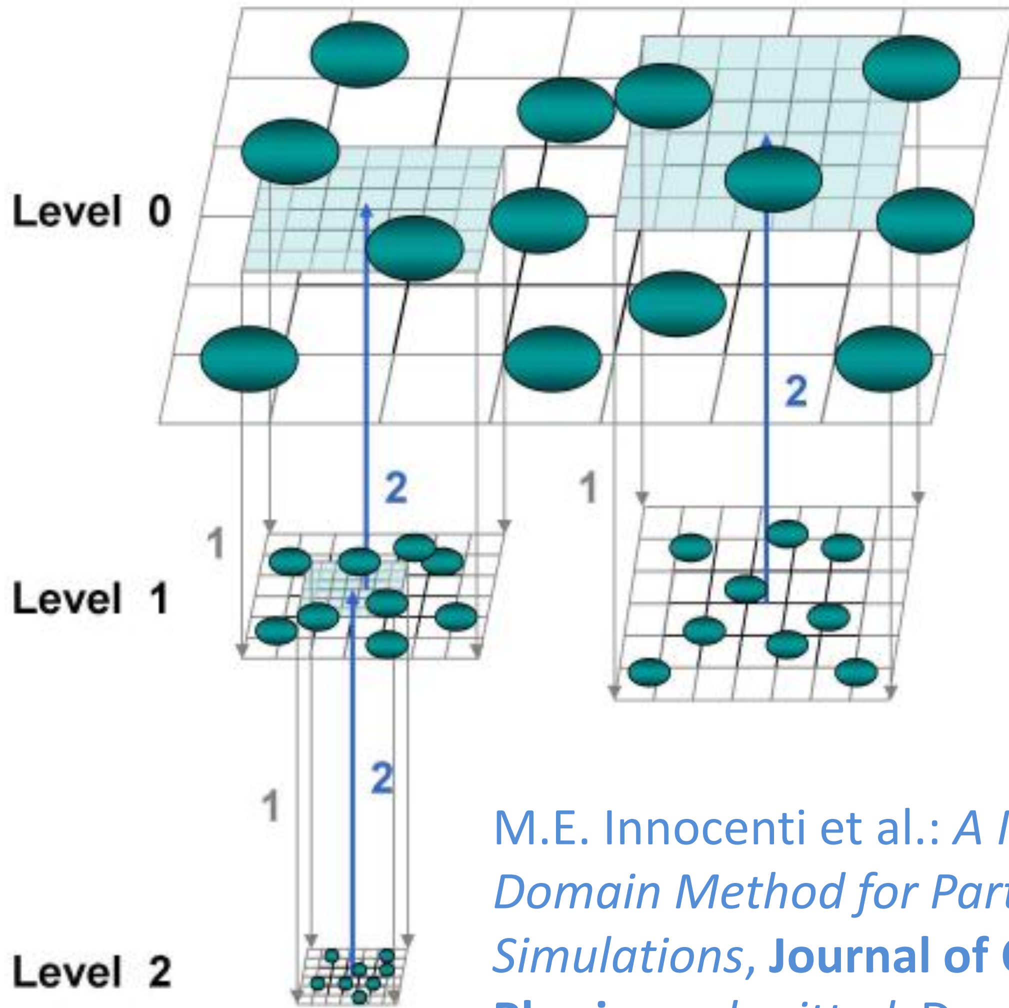
Swiff 1.0: Muliphysics with implicit moment method: FLUID to KINETIC



Markidis, Lapenta, Math.Comput. Simulation, 10.1016/j.matcom.2009.08.038

Plasma:
Electrons, ions, field

Swiff 1.0: MultiLevel – MultiDomain Approach



M.E. Innocenti et al.: *A Multi Level Multi Domain Method for Particle In Cell Plasma Simulations*, **Journal of Computational Physics**, *submitted*, Dec. 2011, http://arxiv.org/abs/1201.6208.

Advantages of the Implicit Approach

Explicit stability constraints

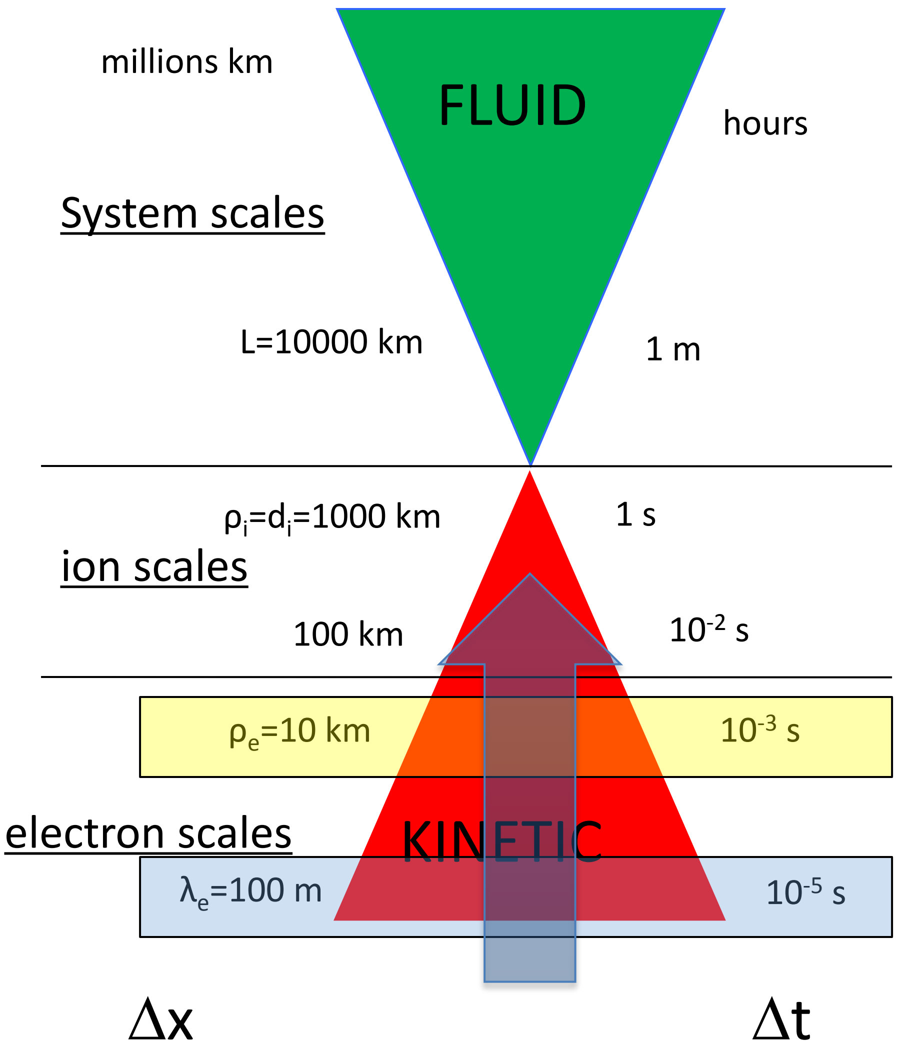
$$\omega_{fastest}\Delta t < 2$$

$$\Delta x < \lambda_{smallest}$$

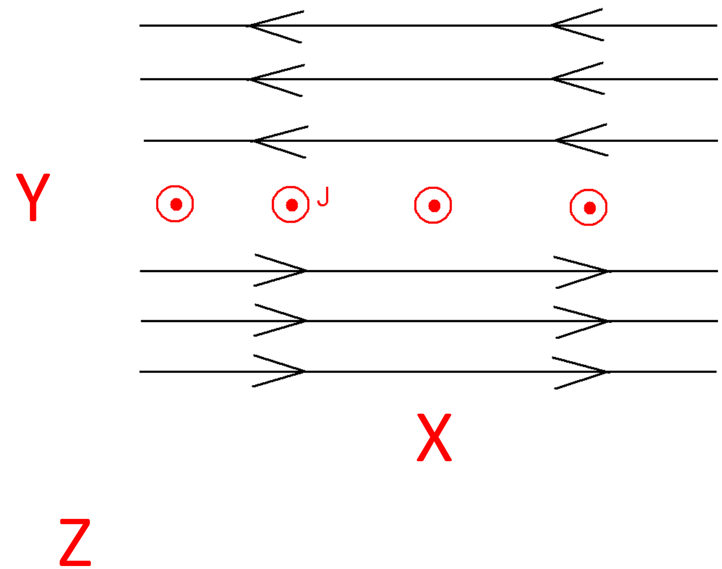
$$c\Delta t < \Delta x$$

Implicit stability constraints

$$\frac{\Delta t\,\omega_{fastest}}{\Delta x / \lambda_{smallest}} < 1$$



Example of Applocation to WP4: simulations of the Earth magntotail

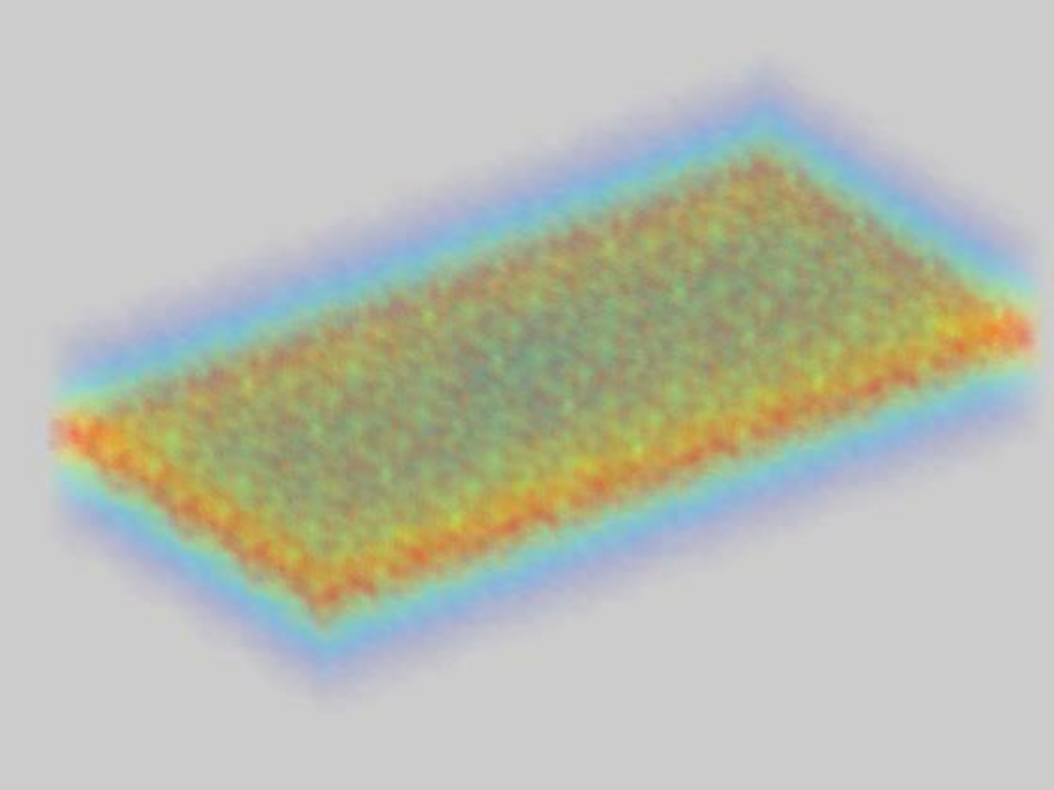


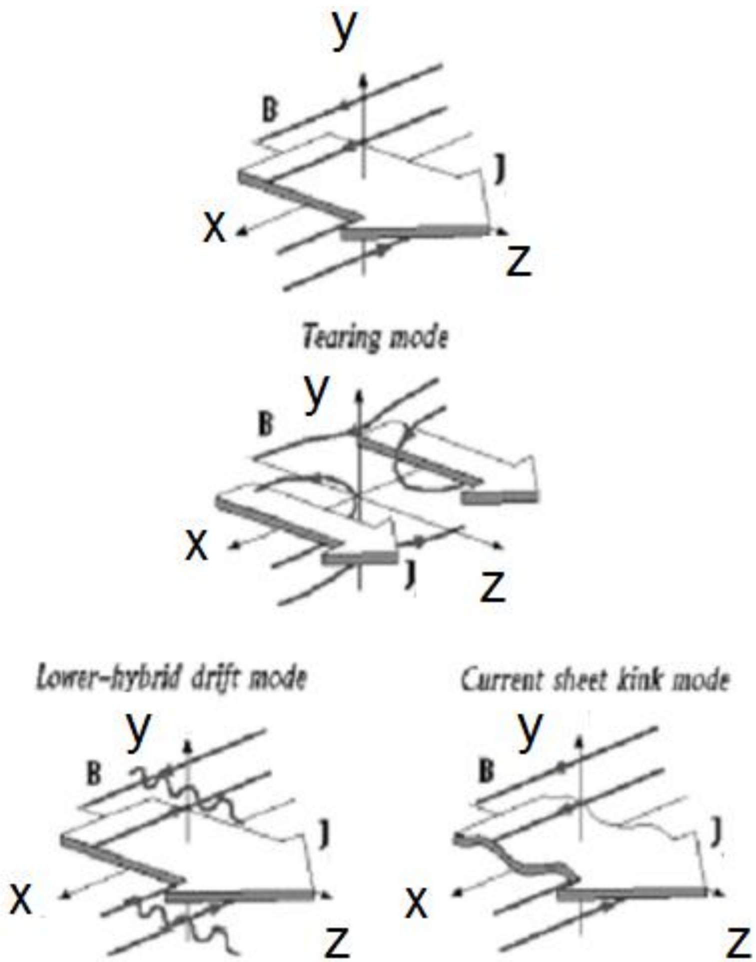
$$\mathbf{B} = B_0 \tanh(y/L)\hat{\mathbf{x}} + B_g\hat{\mathbf{z}}$$

$$p = p_b + p_0 \operatorname{sech}^2(y/L)$$

$$b = \frac{p}{B^2/8\pi} \rightarrow b(z=0) = \frac{p_b + p_0}{B_g^2/8\pi}$$

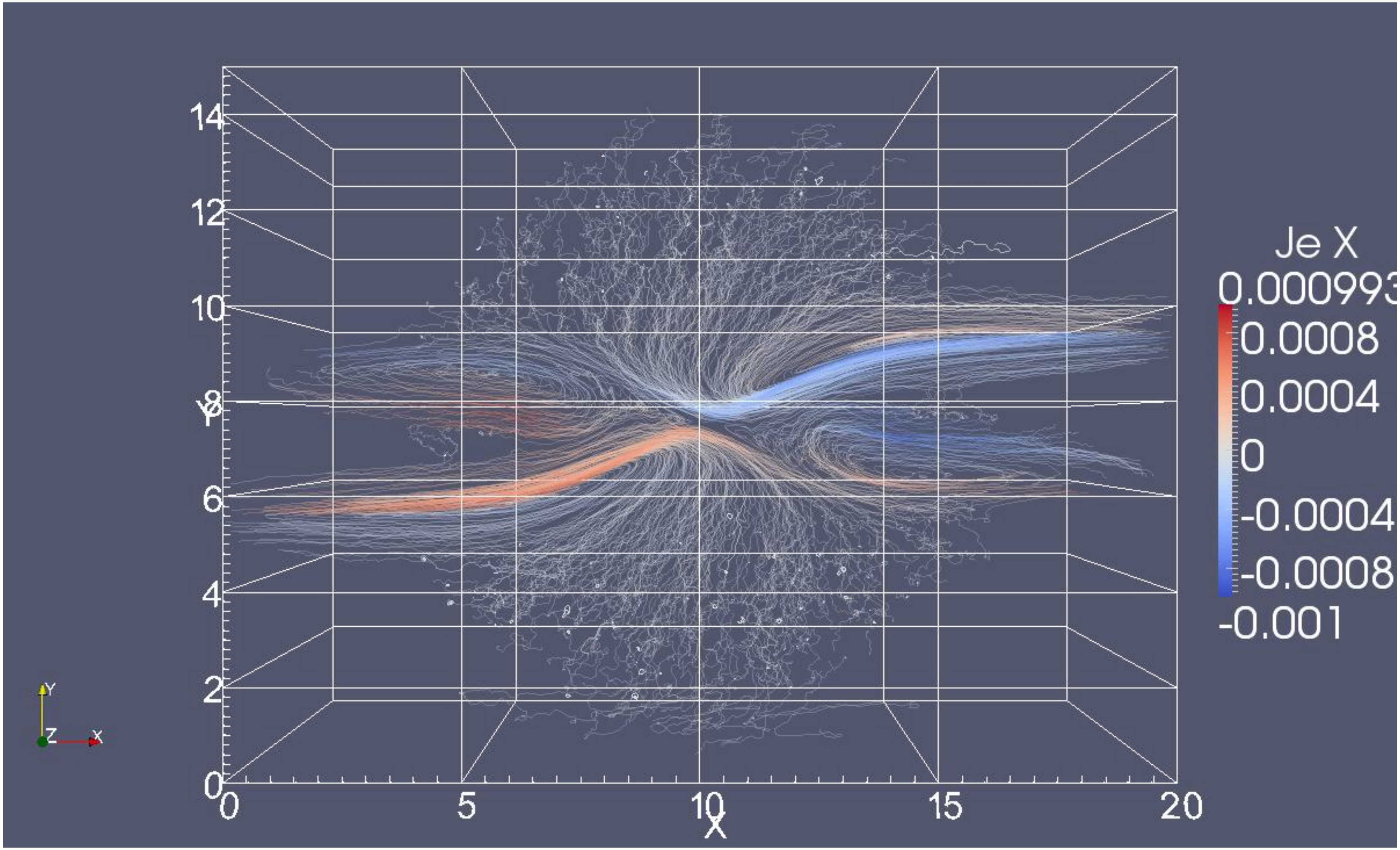
3D evolution: micro-macro coupling



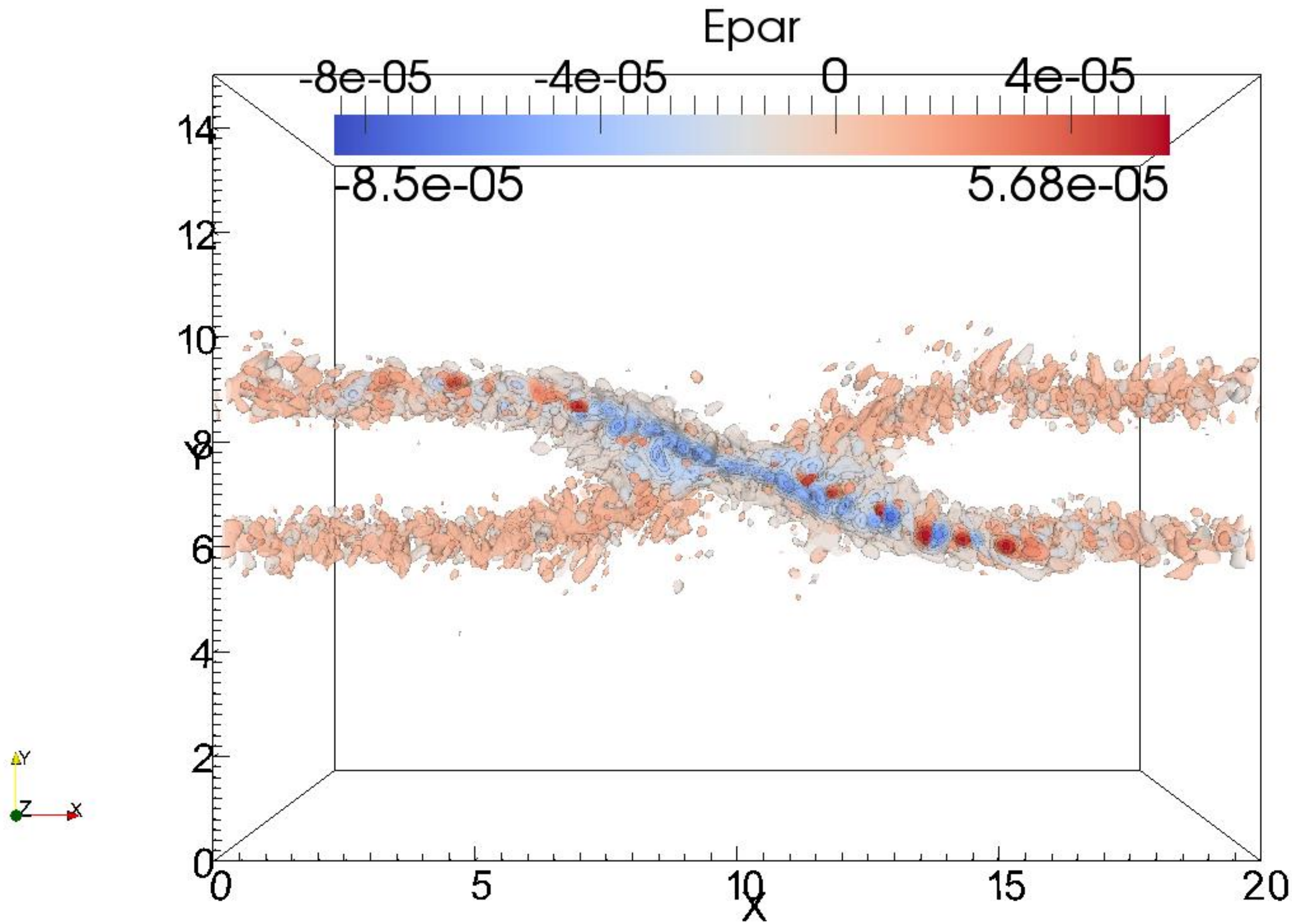


Lapenta, JCP, 2012
Several publications in 2011, 2012
Deliverable 2.1

The reconnection jets are deflected



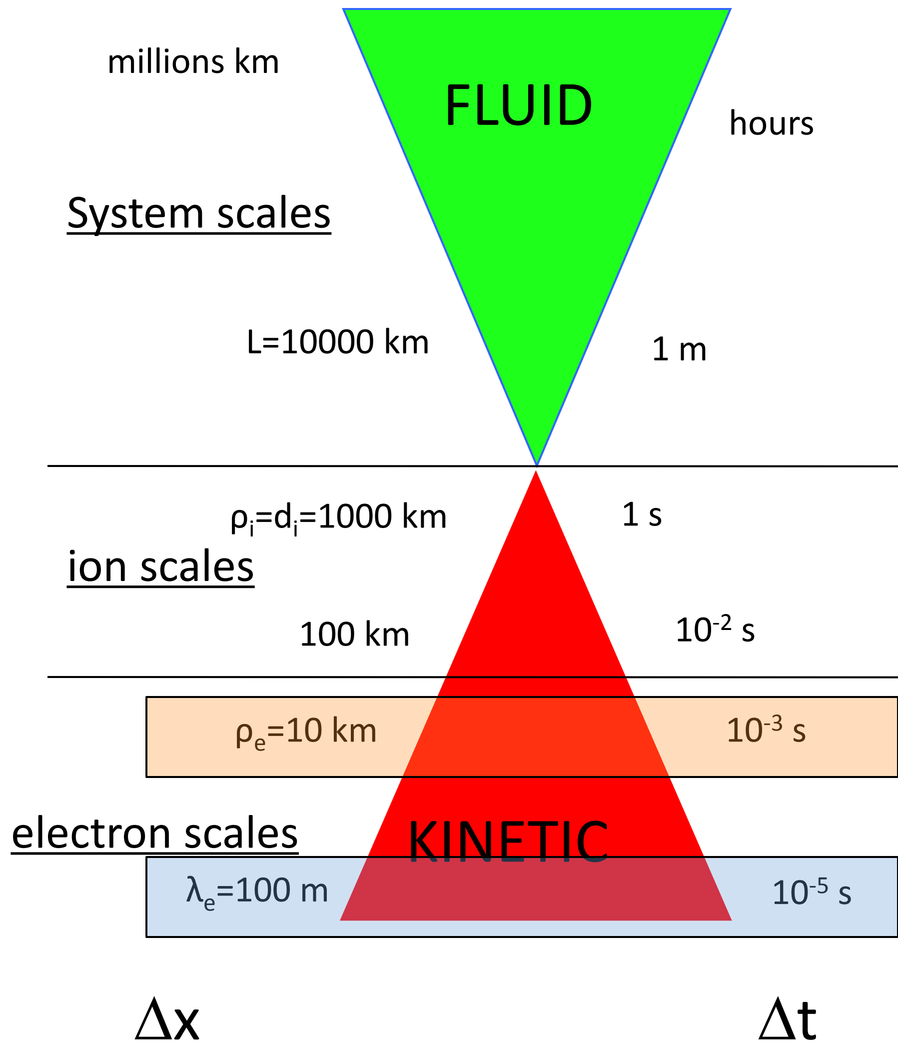
Strong electron flows cause micro-structures



Advances provided by SWIFF: pre vs post SWIFF

	Explicit-Pre SWIFF	Implicit-Post Swiff	Gain
Dx	λ_{De}=100 m	d_e=10 Km	100
Dy	λ_{De}=100 m	d_e=10 Km	100
Dz	λ_{De}=100 m	d_e=10 Km	100
Dt	$\omega_{pe}\Delta t$=0.1 or 10^{-5}s	$\omega_{pe}\Delta t$=100 or 10^{-3}s	1000
Tot			10^9

A SWIFF run that takes **1 day** would take: **2,800,000 years** with previous explicit codes



Co-Design and space weather at KU Leven

Space Science projects

Soteria

- First ever EC-FP7 funded project on space weather
- Started 2008
- End this year
- Cordinator: G. Lapenta

Swiff

- FP7 project on the space weather call
- To run till 2014
- Cordinator: G. Lapenta

eHeroes

- FP7 project
- From the 2011 call
- Kick-off in Rome in March 2012
- To run till 2015
- Cordinator: G. Lapenta

HPC projects

- DEEP
- Intel Exascience Lab
- Hybrid Computing

KATHOLIEKE UNIVERSITEIT LEUVEN

SPACECAST

CASSIS

MMS NASA

esa space situational awareness

ExaScience Lab Intel Labs Europe EXASCALE COMPUTING

Intel Exascience Lab
exascience.com

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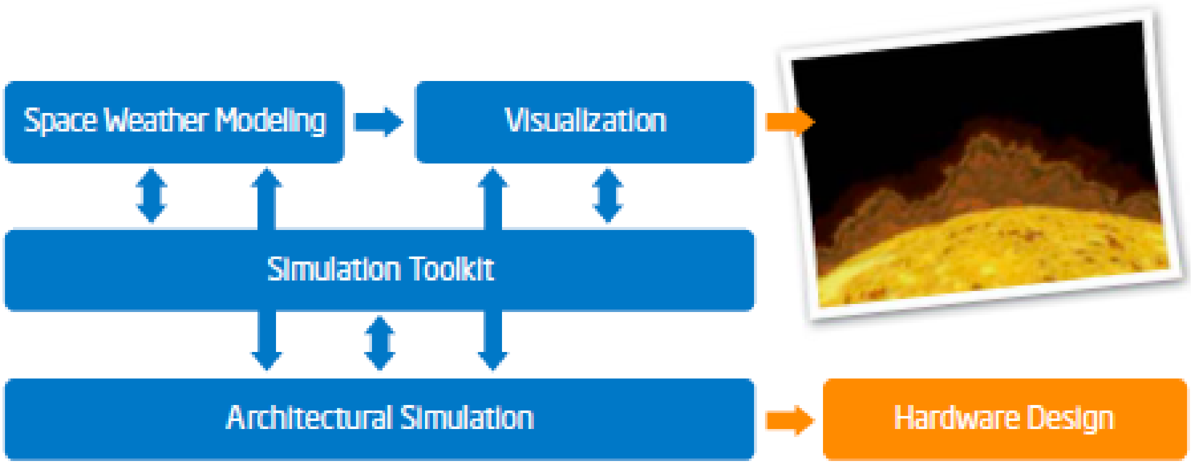
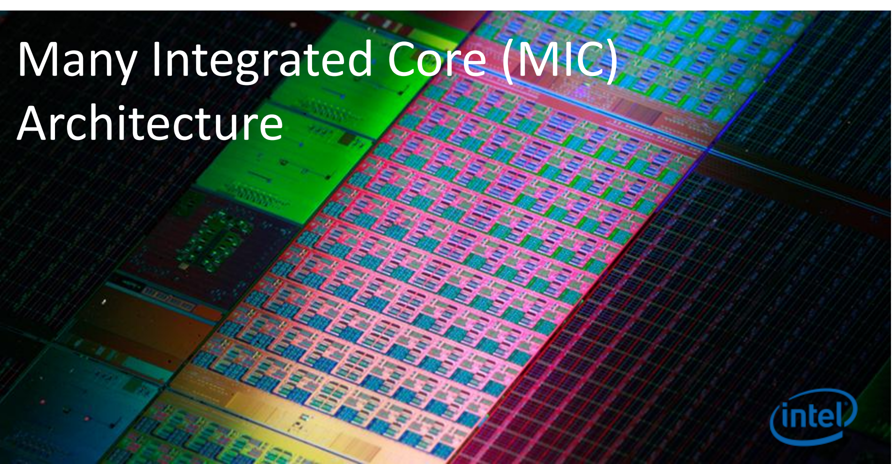
EXASCALE COMPUTING



DEEP Project
deep-project.eu

Job: postdoc to develop and test implicit PIC on MICs

Dynamical Exascale Entry Platfor
Coordinator: Thomas Lippert ,
Forschungszentrum Juelich GmbH



Towards Exascale with application to:

- Detailed brain simulation
- Space Weather
- Climate simulation
- Computational fluid engineering
- High temperature superconductivity
- Seismic imaging

Space Weather and Exascale Computing

Development of implicit PIC for GPU-based HPC

- Porting iPIC3D to nvidea GPUs using CUDA
- Redesign of the algorithm for hybrid architecture – Strong synergy with DEEP and Intel MICs.
- Adding collisions for conditions typical of some space systems (ionosphere and photosphere for example) and of laboratory plasmas

Job: phD student to develop and test implicit PIC on GPUs