Use of Spenvis and Web resources in the Space Weather Class at KU Leuven

Giovanni Lapenta

Centrum voor Plasma-Astrofysica

Katholieke Universiteit Leuven, Belgium

KATHOLIEKE UNIVERSITEIT
LEUVEN

B-KUL-G0B32A Space Weather – AIMS:

KATHOLIEKE UNIVERSITEIT LEUVEN

- To provide an overview of the current observational data on space weather;

- To provide insight in the basic physics of of space weather;

- To provide an overview of the current state-of-the-art modeling and forecasting activities for selected aspects of space weather, e.g. CME initiation and IP CME evolution, gradual SPE events, etc.

- To explore the effects of space weather on humans and on technology in space and on the ground.

Web page for the class

KATHOLIEKE UNIVERSITEIT LEUVEN

- perswww.kuleuven.be/~u0052182/teaching.html

Class material: Space Weather

Syllabus in wiki format

1. Lecture 1 (HTML)
2. Lecture 2 (HTML)
3. Lecture 3 (HTML)
4. Lecture 4 (PDF)
5. Lecture 5 (PDF)
6. Lecture 6 (PDF)
7. Lecture 7 - notes (PDF)
8. Lecture 7 - slides (PDF)
9. Lecture 8 (PDF)
10. Lecture 9-12 (see Toledo)
11. Lecture 13 (PDF)

Homework

1. Homework 1 (PDF)
2. Homework 2 (PDF)
3. Homework 3 (PDF)
4. Homework 4 (PDF)

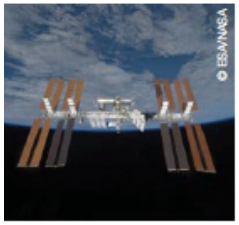
Class offered to:

- Master in Mathematics
- Master in Astrophysics
- Erasmus
- MaNaMa in Space Studies

POC: POC Wiskunde

UNIVERSITEIT GENT

KATHOLIEKE UNIVERSITEIT LEUVEN



Master of Space studies

INTERUNIVERSITY PROGRAMME

Faculty of Science
Faculty of Engineering
Faculty of Medicine
Faculty of Law

Topics covered

MASTER OF SPACE STUDIES	60
COURSE	CREDITS
Mandatory courses	**23**
• Questions in Space Sciences	3
• Space Law and Space Policy	3
• Space Project Management	5
• Space Sciences and Exploration	3
• Life Sciences and Biology in Space	3
• Orbital Mechanics and Mission Design	3
• Spacecraft Design and Instrumentation	3
Major subject	**22**
Students have to choose courses amounting to 22 credits from the list below and (for a maximum of 6 credits) from other Master's programmes at the universities of Gent and Leuven. Students with a Master's degree in the Humanities and Social Sciences are expected to choose these courses from list A below. Students with a Master's degree in Science, Engineering and Technology or Biomedical Sciences are expected to choose these courses from lists B and/or C.	
A Space Law, Policy, Business and Management	
- The Law of International Organizations	6
- Introduction to Management and Strategy	4
- Space Business and Management	4
- Advanced Topics in Space Law and Space Policy	4
- Product Development and Innovation	4
B Space Sciences	
- Space Weather	4
- Advanced Topics in Life Sciences in Space	4
- Astrophysics from Space	4
- Remote Sensing of the Atmosphere	4
- Synchrotron Radiation Research in Earth and Planetary Sciences	4
- Plant Biology in Space: Life Support System Applications	4
- Global Change Monitoring and Coastal Processes	3
C Space Technology and Applications	
- Space Geodesy, Geophysics and Earth Observation	4
- Satellite and Space Communications	4
- Spacionics Systems Design	3
- Spacecraft Technology and Space Environment	5
- Reliability of Space Systems	4
- Robotics	4
- Image Analysis and Understanding	6
Master's thesis	**15**

Master in Astrophysics and Master in Math

KATHOLIEKE UNIVERSITEIT LEUVEN

MASTER OF ASTRONOMY AND ASTROPHYSICS	120 studiepunten
COURSE	CREDITS
Compulsory courses	**54**
• Observational Techniques in Astronomy	6
• Research Projects I	3
• Binary Stars	6
• Theory of Nucleosynthesis	3
• Star Formation	6
• Interstellar Matter	6
• Physics of Planets	6
• Asteroseismology	6
• Specialised Topics in Astronomical Techniques	6
Students must choose two of the courses below.	
• Stellar Structure Models	3
• Research Projects II	3
• Research Projects III	4
Elective courses	**36**
Students choose electives comprising at least 36 credits, either from the list below or from specialized courses included in other Master's programmes, particularly physical applied mathematics (Plasma Astrophysics) courses from the Master of Mathematics and physics courses from the Master of Physics.	
• The Milky Way Galaxy	6
• Relativity	6
• Dynamics of Stellar Systems (UGent)	6
• Theoretical Seismology	6
• Capita selecta in Astronomy and Astrophysics	6
• Planetary Systems	6
• Computational Methods for Astrophysical Applications	6
Master's thesis	**30**

MASTER OF MATHEMATICS
(120 credits)

Introductory and General Section (30 credits)

In this section the student has to take courses from the K.U.Leuven curriculum adding up to 30 credits. These courses can be introductory and/or may be of general non-mathematical nature (e.g. dutch course). The programme director advises each student individually so that package of courses in this section is optimally tailored to the student's specific situation and needs. The chosen package has to be approved by the programme director.

Options (60 credits)

The student chooses one of the two options.

1. Option Pure Mathematics

The student chooses for (at least) 60 credits from the subgroups according to the rules specified in each subgroup.

- **Core Courses** (at least two courses, choice)
- **Deepening Courses** (at least two courses, choice)
- **Exchange Courses** (at least one course, choice)
- **Advanced Courses** (at least one course, choice)
- **Research Seminars** (one seminar, choice being determined by the domain of the master thesis)
- **Elective Master Courses**
  (The student can choose up to three courses (max. 18 credits) from the option Applied Mathematics or from the Dutch master program)

2. Option Applied Mathematics

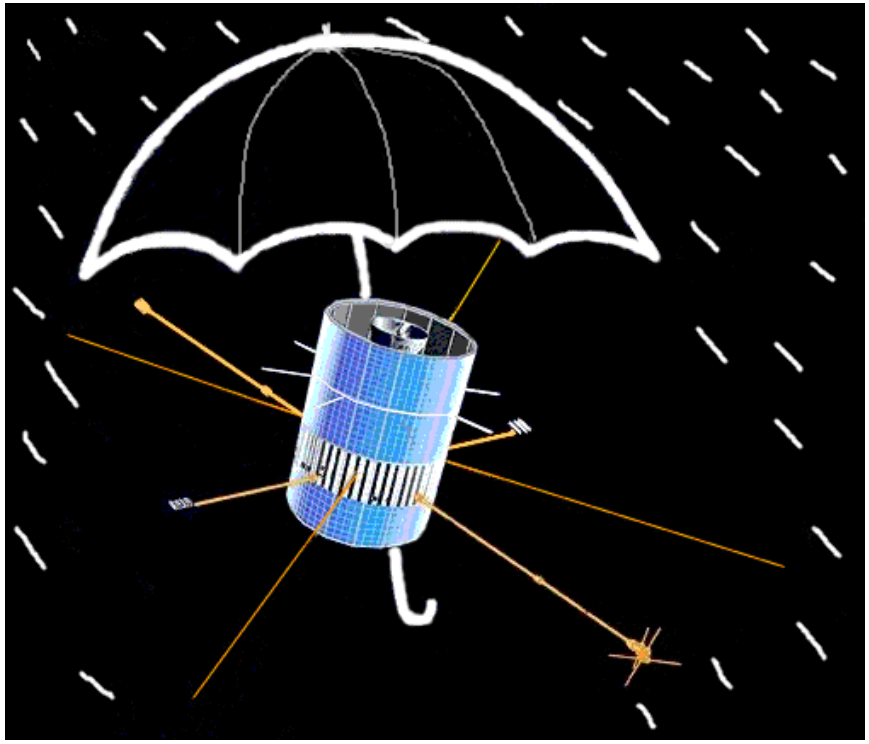
The student chooses for (at least) 60 credits from the subgroups according to the rules specified in each subgroup.

- **Physical Applied Mathematics** (at least three courses, choice)
- **Numerical Mathematics** (at least one course, choice)
- **Probability and Statiscs** (at least two courses, choice)
- **Exchange courses** (the student can choose one course)
- **Advanced Courses** (at least one course, choice)
- **Resaerch Seminars** (one seminar, choice being determined by the domain of the master thesis)
- **Elective Master Courses**
  (The student can choose up to three courses (max. 18 credits) from the option Pure Mathematics or from the Dutch master program)

Master Thesis (30 credits, compulsory)

Overview of the space weather class

KATHOLIEKE UNIVERSITEIT LEUVEN



- Some students have little math and phyiscs
- Most students do not know what a plasma is
- Or the structure of the solar system plasma
- Need to provide a short background on the "geography", mathematics and physics of space plasmas
- Regular Students: part A - introduction
- Advanced students: part B – project

Overview of the class

KATHOLIEKE UNIVERSITEIT LEUVEN

- Descriptive Part
  1. Sun and Solar Wind
  2. Heliosphere and Magnetosphere
  3. Typical space weather events
  4. High Energy Particles

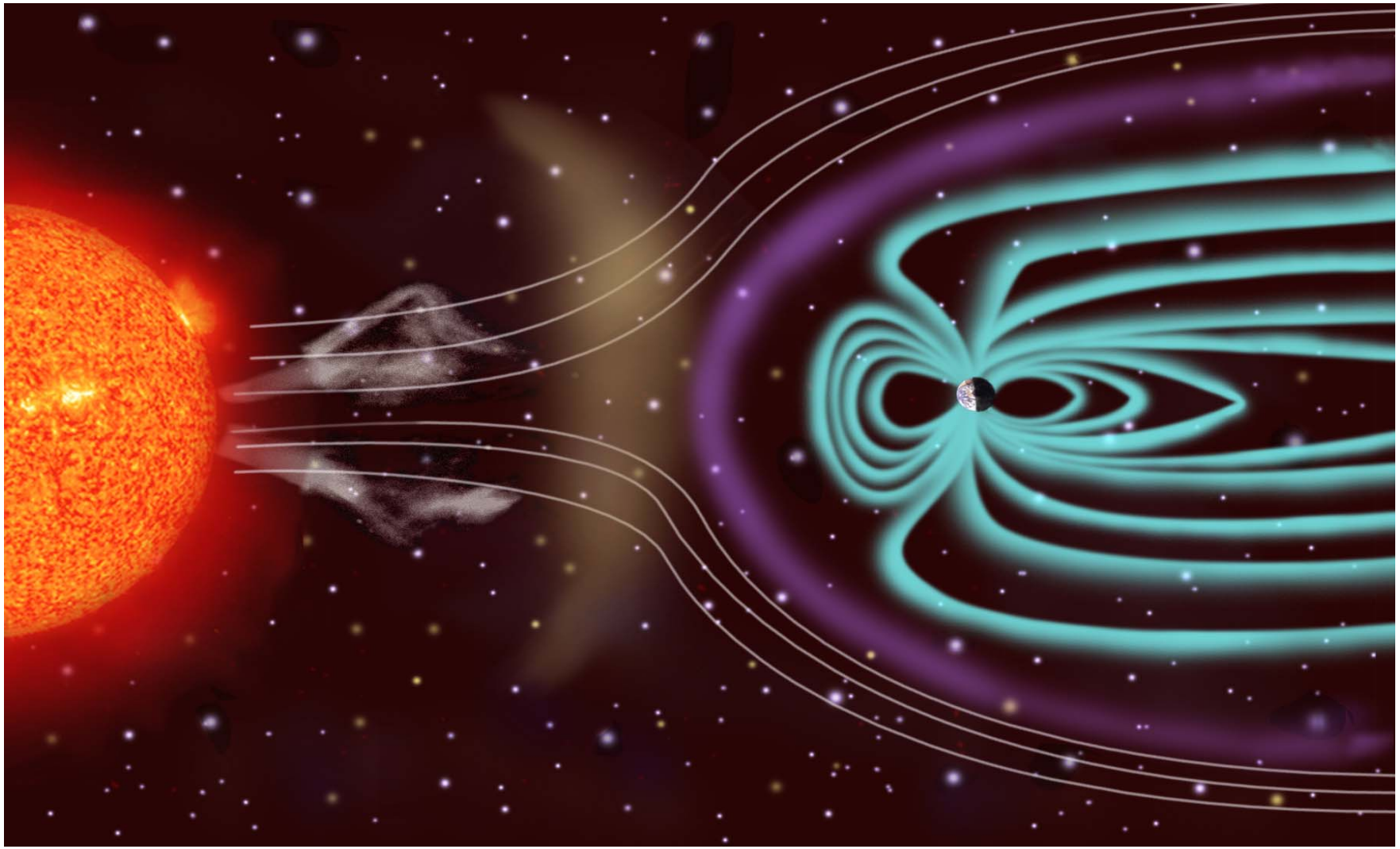
- Application Part
  1. Interaction of particles, fields and radiation with matter
  2. Biological impact of space weather
  3. Technological impact of space weather

- Modeling Part
  - Particles and Fields (ABC of plasma physics)
  - Kinetic approach: microphysics of space weather
  - Fluid approach: macrophysics of space weather

- Guest professors:
  - Johan De Keyser: inner magnetosphere and observations
  - Stefano Markidis: kinetic simulation

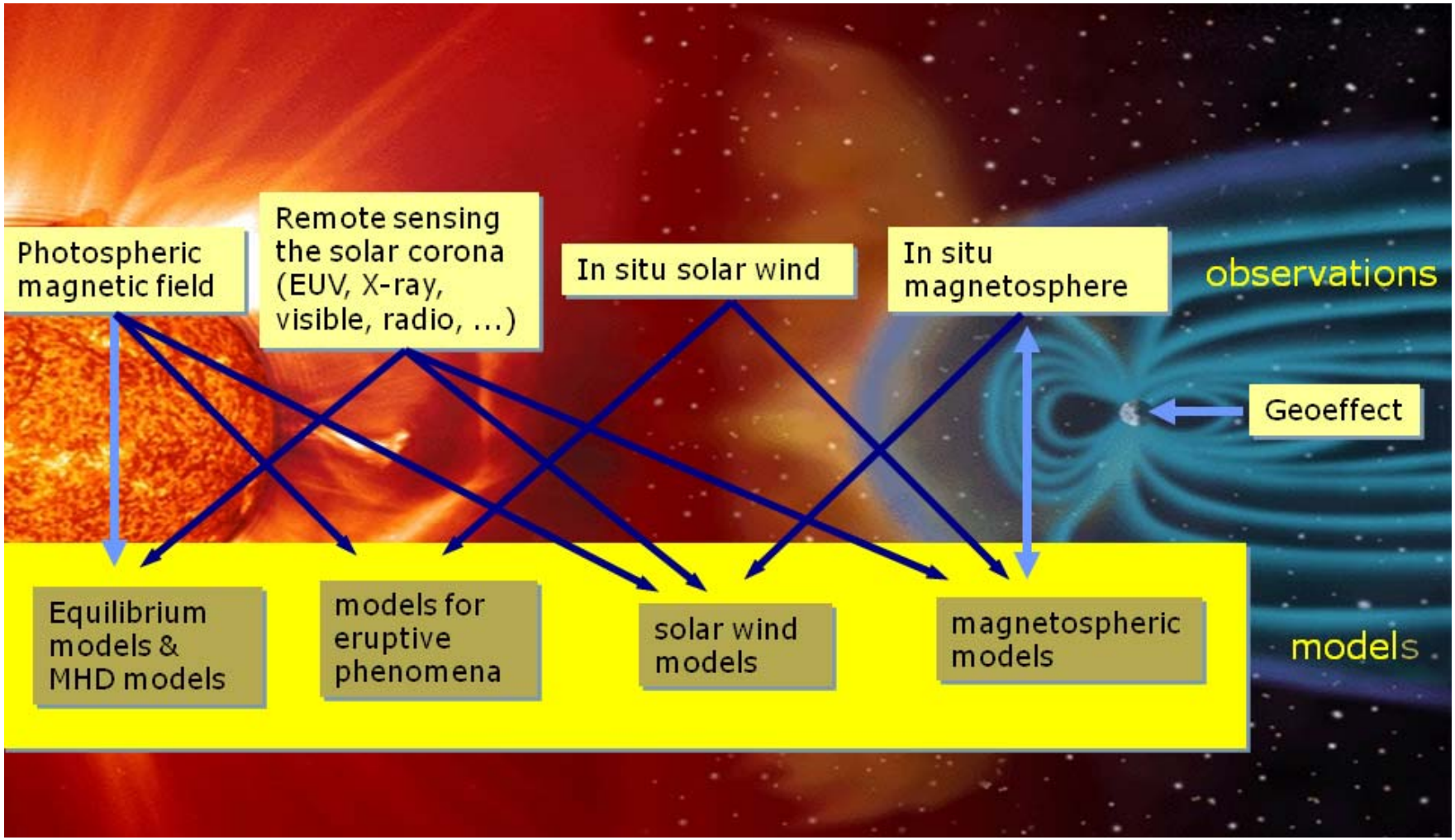
Descriptive part: The Sun-Earth coupling

KATHOLIEKE UNIVERSITEIT LEUVEN

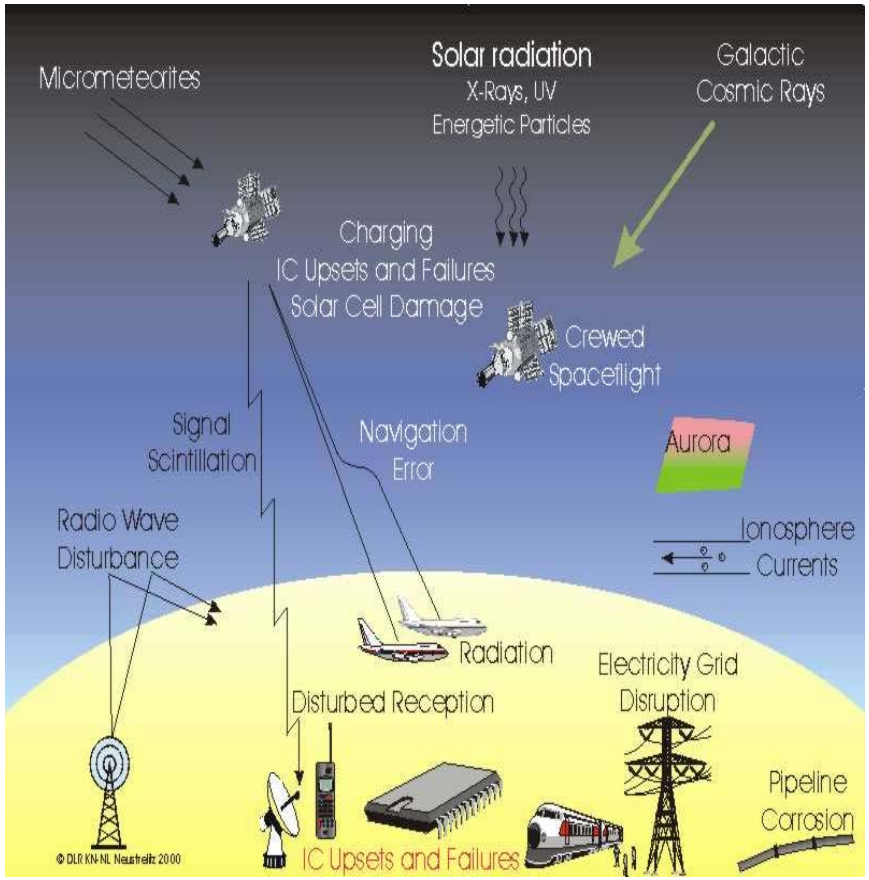


Modelling part: processes to model

KATHOLIEKE UNIVERSITEIT LEUVEN



Effects of space weather



- NASA: Living With a Star, Sun-Earth Connection
- NSF: Cism, Integrated Space Weather Modeling, Geospace Environment Modeling
- NOAA, DOD,…
- Spaceweather.com
- JAPAN: Space Environment & Effects System
- ESA: new initiative SSA, swenet.eu
- In Belgium: ROB, BISA

Descriptive part

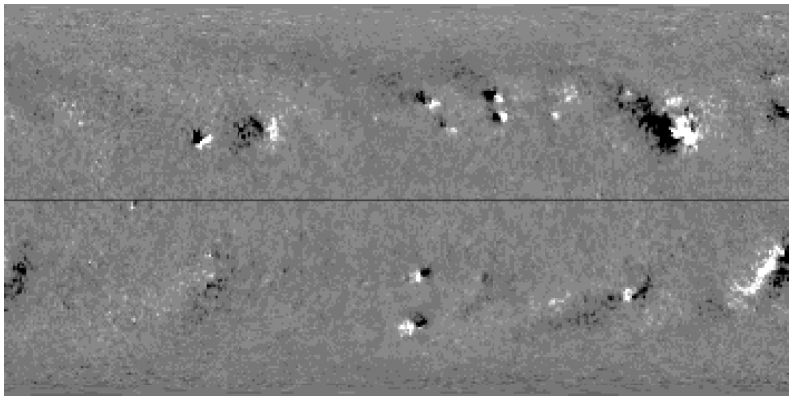
KATHOLIEKE UNIVERSITEIT LEUVEN

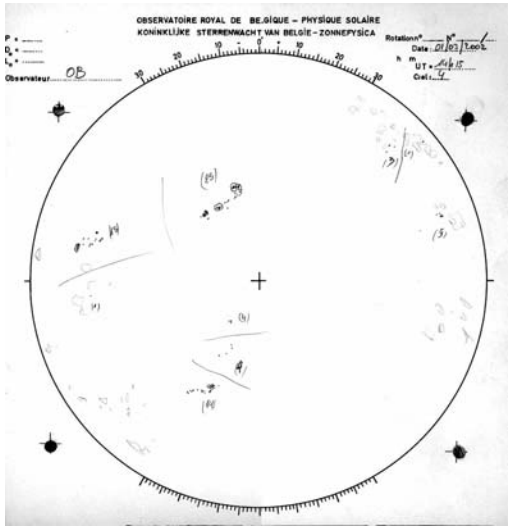
Solar – ground based:

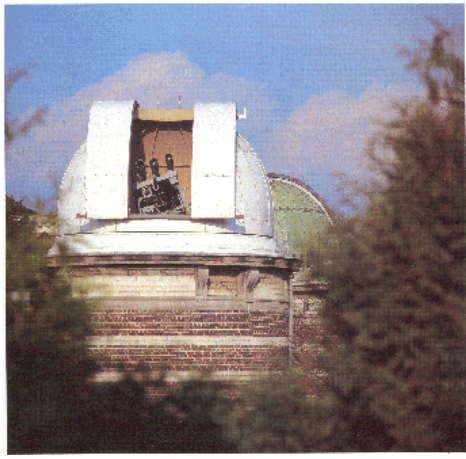
- ROB (Brussel)
- Wilcox Observatory
- Mt Wilson
- GONG

Solar – space based:

- SOHO
- STEREO
- TRACE
- Proba 2
- SDO



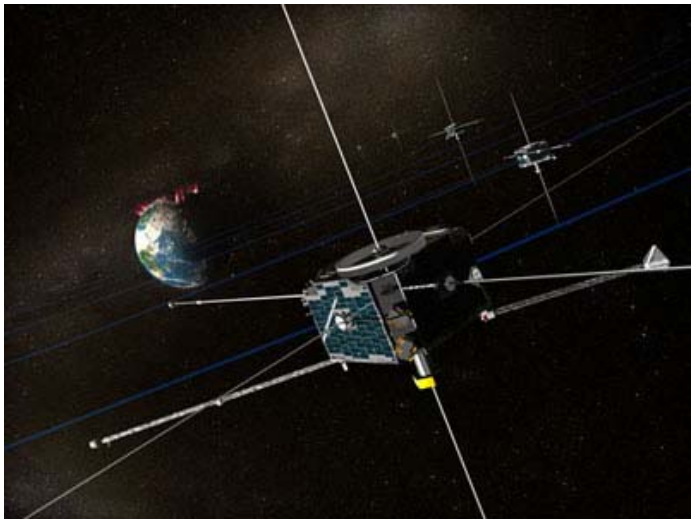


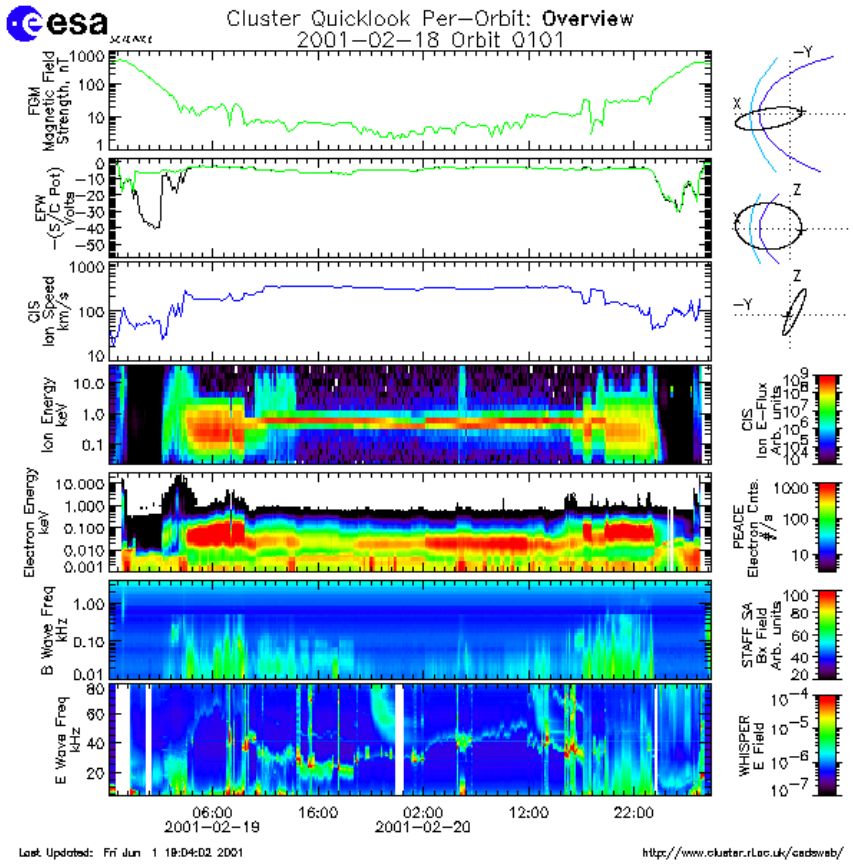


A typical day for Professor David (Berghmans)

Space Missions

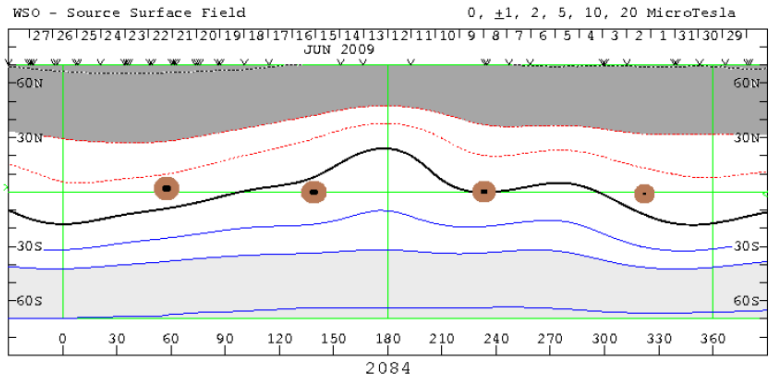
KATHOLIEKE UNIVERSITEIT LEUVEN

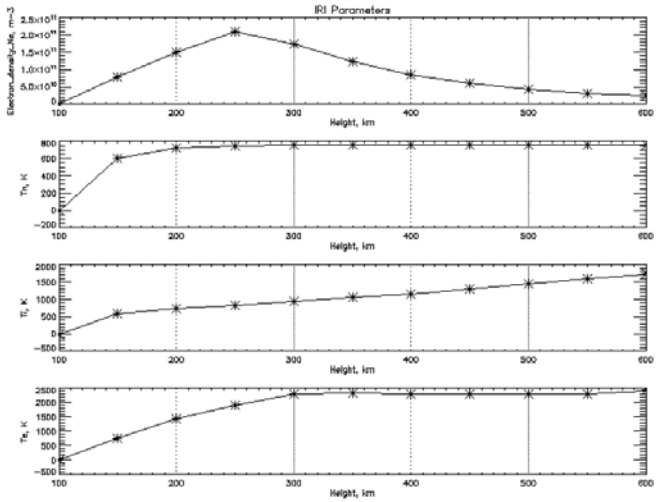




- We cover how to access and use data from probes:
- Themis
- Cluster

Example of Tasks done by the students





- Use web resources and models learned in class to predict solar wind at the Earth in different days. From synaptic maps to comparion with ACE data

- Use web resources to study dependence of ionospheric parameter from day to night and with different indeces of space weather activity

Modeling Part

KATHOLIEKE UNIVERSITEIT LEUVEN

- A PIC code in MATLAB

https://perswww.kuleuven.be/~u0052182/teaching.html

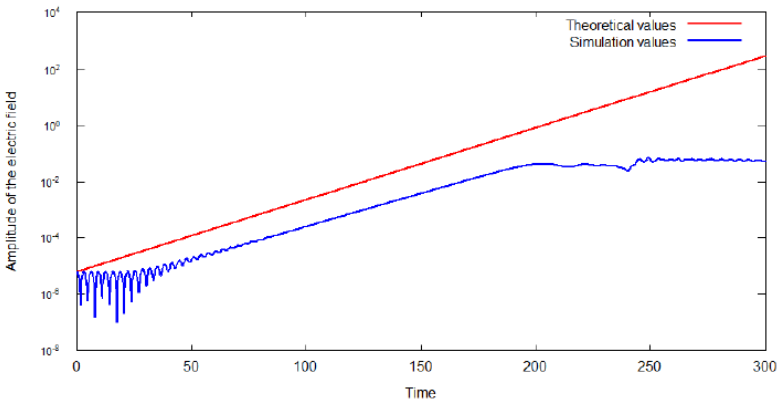
```
L=2*pi;
DT=.5;
NT=200;NTOUT=25;
NG=32;

N=1000;
WP=1;
QM=-1;
V0=0.2;
VT=0.0;

XP1=1;
V1=0.0;
mode=1;

Q=WP^2/(QM*N/L);
rho_back=-Q*N/L;
dx=L/NG;


% 2 Stream instability
xp=linspace(0,L-L/N,N)';
vp=VT*randn(N,1);
pm=[1:N]';pm=1-2*mod(pm,2);
vp=vp+pm.*V0;

% Perturbation
vp=vp+V1*sin(2*pi*xp/L*mode);
xp=xp+XP1*(L/N)*sin(2*pi*xp/L*mode);

p=1:N;p=[p p];
un=ones(NG-1,1);
Poisson=spdiags([un -2*un un],[-1 0 1],NG-1,NG-1);
```

```
for it=1:NT

   % aggiornamento xp

   xp=xp+vp*DT;
   out=(xp<0); xp(out)=xp(out)+L;
   out=(xp>=L);xp(out)=xp(out)-L;

   % proiezione p->g

   g1=floor(xp/dx-.5)+1;g=[g1;g1+1];
   fraz1=1-abs(xp/dx-g1+.5);fraz=[fraz1;1-fraz1];
        out=(g<1);g(out)=g(out)+NG;
        out=(g>NG);g(out)=g(out)-NG;

   mat=sparse(p,g,fraz,N,NG);
   rho=full((Q/dx)*sum(mat))'+rho_back;

   % calcolo del campo

   Phi=Poisson\(-rho(1:NG-1)*dx^2);Phi=[Phi;0];
   Eg=([Phi(NG); Phi(1:NG-1)]-[Phi(2:NG);Phi(1)])/(2*dx);

   % proiezione q->p e aggiornamento velocita'

   vp=vp+mat*QM*Eg*DT;

end
```

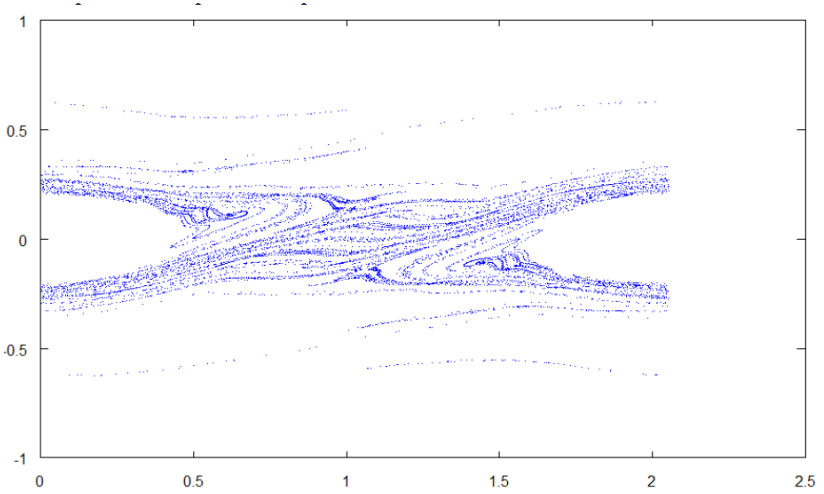
Runs in MATLAB (not free)
Or in OCTAVE (free)

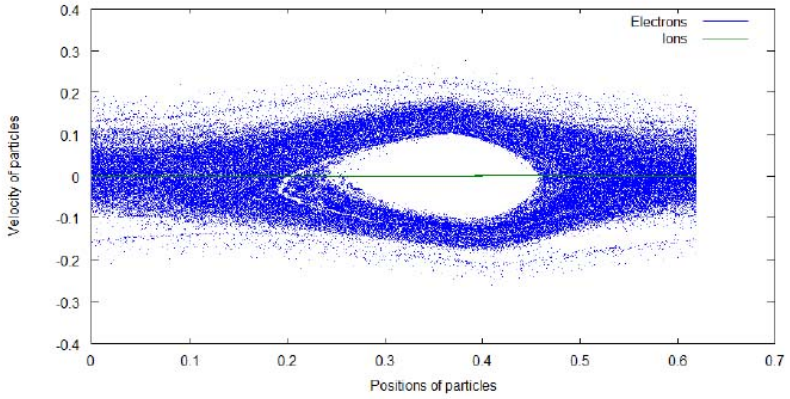
Examples from student projects: relaxation via wave-particle interaction

KATHOLIEKE UNIVERSITEIT LEUVEN



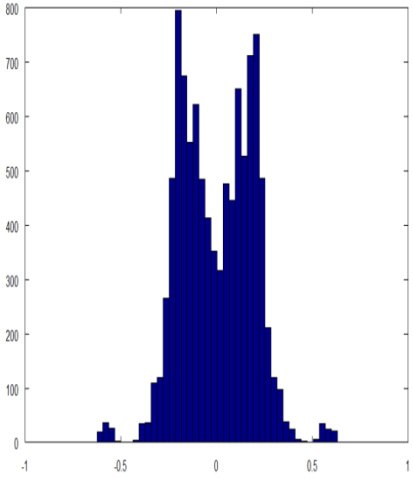
Graph 5: Growth of the electric field





Graph 4: Phase-space plot of the electrons after 300 plasma periods

* Distribution of the particle velocities at a given time:



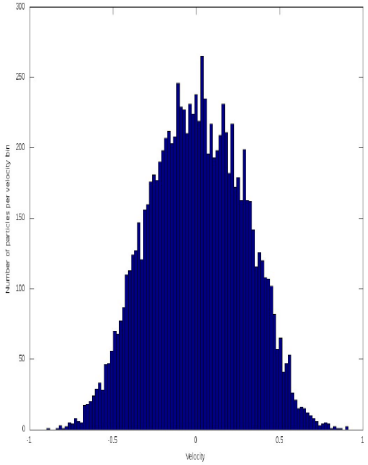


Figure 22: Velocity distribution function at timestep 6000.

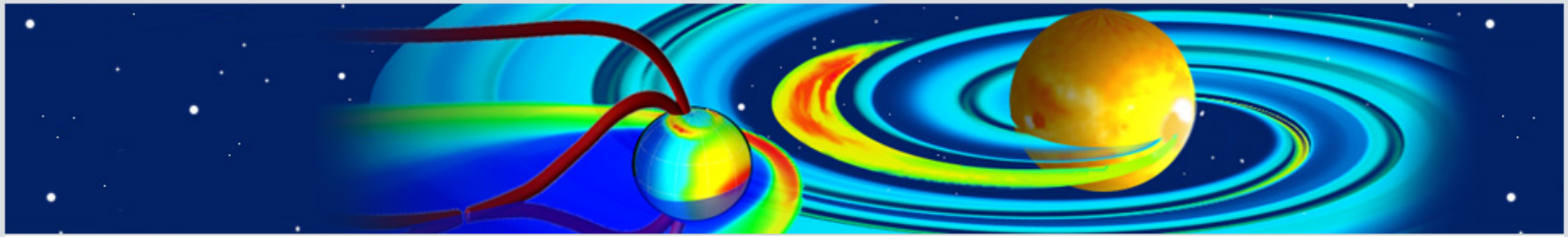
CCMC: http://ccmc.gsfc.nasa.gov/

KATHOLIEKE UNIVERSITEIT LEUVEN

COMMUNITY COORDINATED MODELING CENTER

Related Links | Frequently Asked Questions | Community Feedback | Downloads | Sitemap

About US | Space Weather Models at CCMC | Request A Model Run | View Model Run Results | Instant Run | Experimental Real-Time



CCMC Mission Statement

The CCMC is a multi-agency partnership to enable, support and perform the research and development for next-generation space science and space weather models.

CEDAR ETI Challenge

CCMC is supporting CEDAR Electrodynamics Thermosphere Ionosphere (ETI) Modeling Challenge. The outcome of the preliminary round of model output comparisons will be discussed at the CEDAR 2010 Workshop (June 25, 2010, 10:30 - 12:30). To participate in this fist round of the Challenge please submit your model results using CCMC on-line **submission interface** prior to June 1st, 2010.

Find out more

CCMC Services

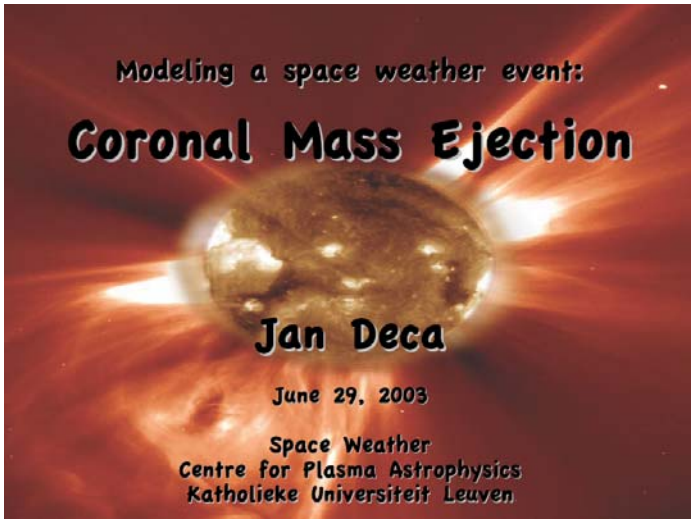
- We provide, to the scientific community, access to modern space research models
- We test and evaluate models
- We support Space Weather forecasters
- We support space science education

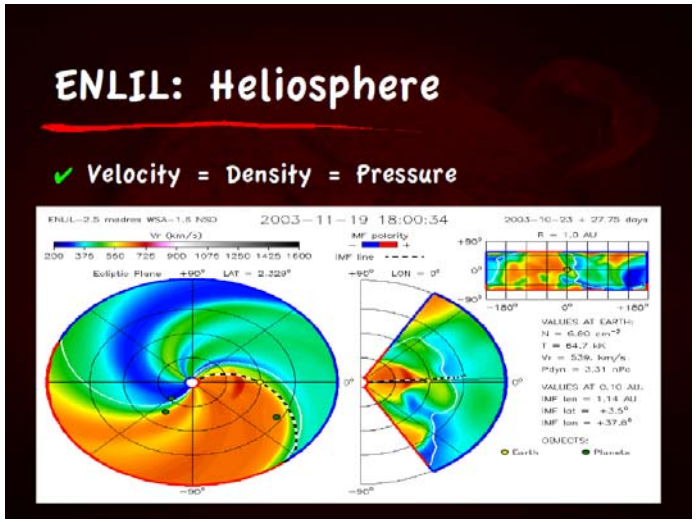
Latest Additions to the CCMC Services

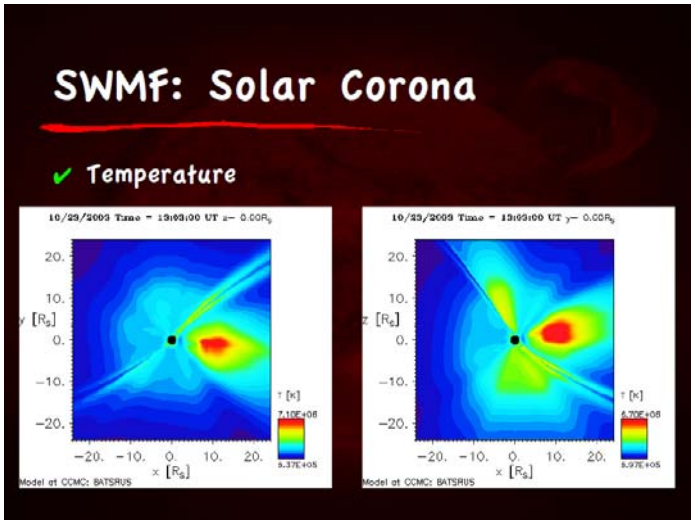
- **Integrated Space Weather Analysis System** is a web-based dissemination system for NASA-relevant space weather information.
- **Space Weather Awareness at NASA** space weather information portal.
- **LWS Supported Tools and Methods**
- **Kameleon software**: model output from different

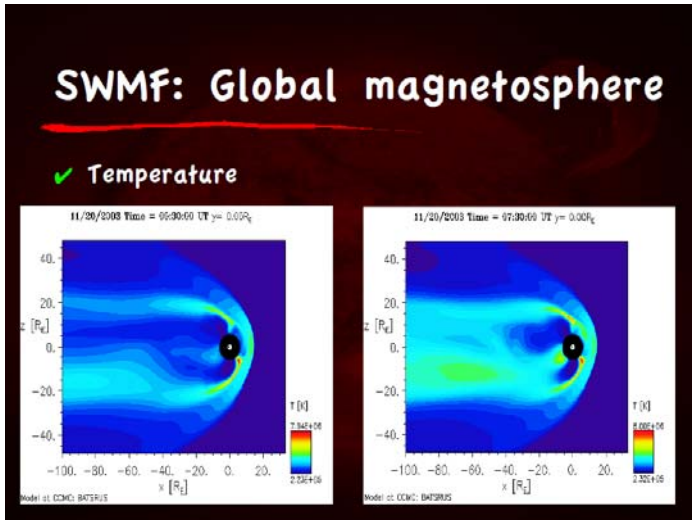
Sample of one project based on CCMC

KATHOLIEKE UNIVERSITEIT LEUVEN









Tasks relative to effects of space weather

KATHOLIEKE UNIVERSITEIT LEUVEN

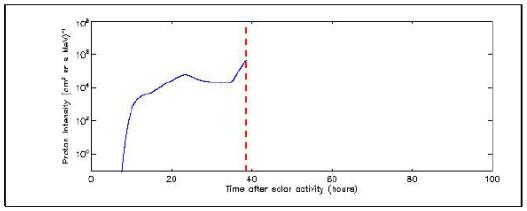


Figure 6: The intensity of 125 eV protons after the solar activity.

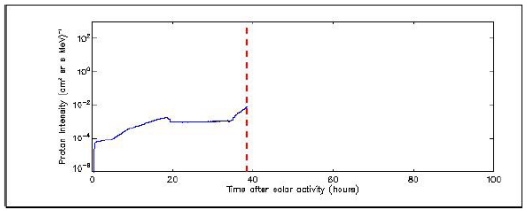
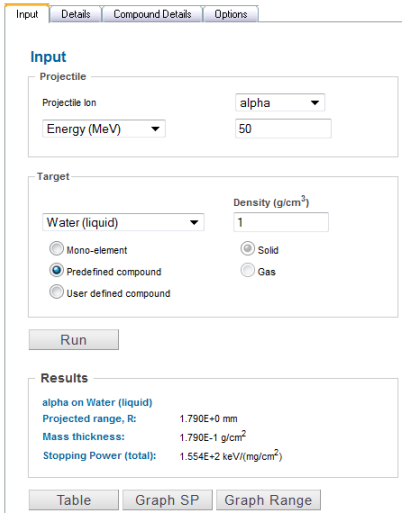


Figure 7: The intensity of 64 MeV protons after the solar activity.



- Use SOLPENCO to study tha propagation of high energy particles
- Determine fluences, time delays for different energies

- Use models to predict range of high energy particles in matter and compare then with the simulations off the NUCLEONICA web site.

Use of Spenvis by the Students: desing a mission

KATHOLIEKE UNIVERSITEIT LEUVEN

Mission segment 1:

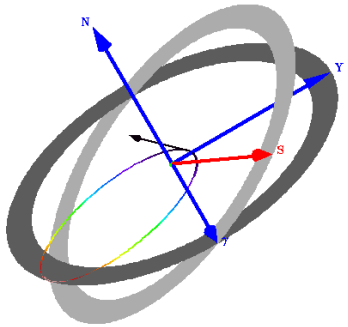
Orbit type:	general
Apogee:	36000.00 km
Perigee:	450.00 km
Inclination:	28.50°
R. A. Ascending Node:	179.75°
Argument of Perigee:	0.00°
True Anomaly:	0.00°
Period:	10.66 hrs
Number of orbits:	1.00
Duration:	0.44 days
Orbit start:	01/01/2010 00:00: 0.0
Orbit end:	01/01/2010 10:39:48.9
Segment end:	01/01/2011 00:00: 0.0
Segment length:	365.00 days
Semi latus rectum:	11750.39 km
Semi major axis:	24596.00 km
Eccentricity:	0.72
Mean motion:	14.14 rad/day
Integration step:	0.50°

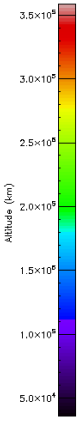
Time intervals

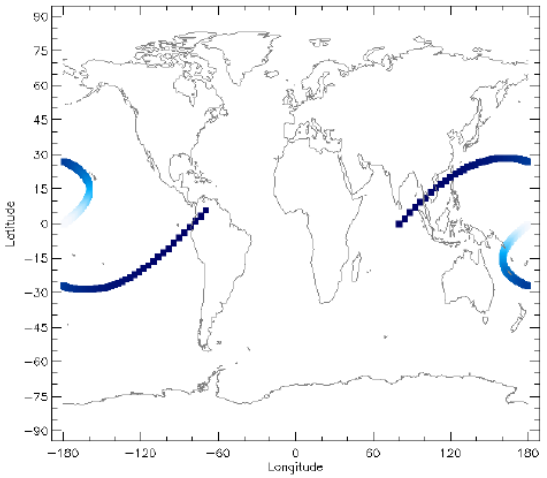
60.0 s below 20000.0 km

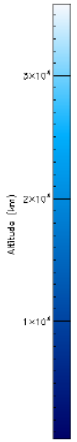
240.0 s between 20000.0 km and 80000.0 km

3600.0 s above 80000.0 km



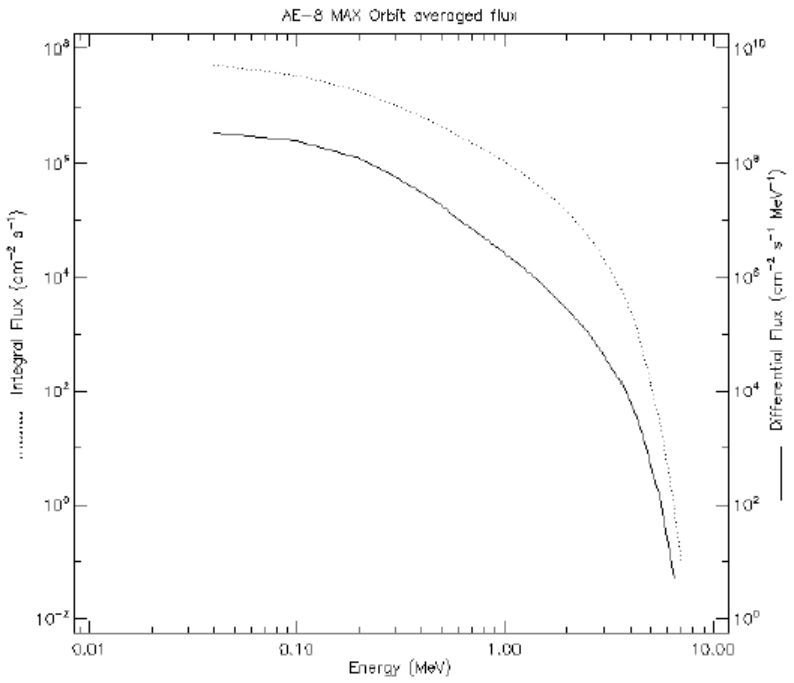


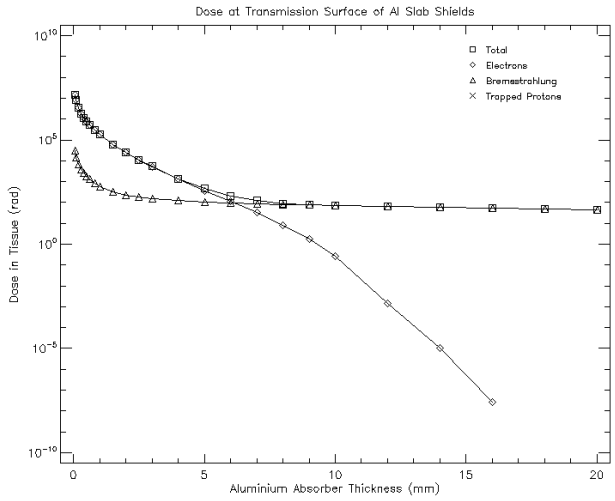




Use of Spenvis by the students: radiation dose

KATHOLIEKE UNIVERSITEIT LEUVEN





- Obtain the spectrum from the models in Spenvis
- Measure the penetration
- Evaluate dose and risk of cancer to personnel
- Determine thickness of Al to reduce the dose below a prescribed limit

Satellite charging with Spenvis

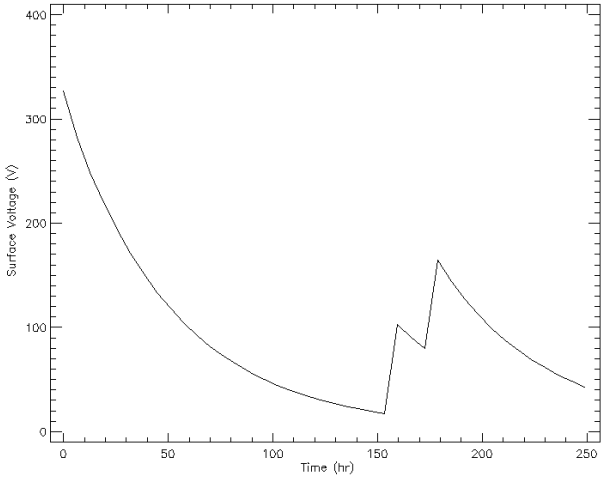
KATHOLIEKE UNIVERSITEIT LEUVEN

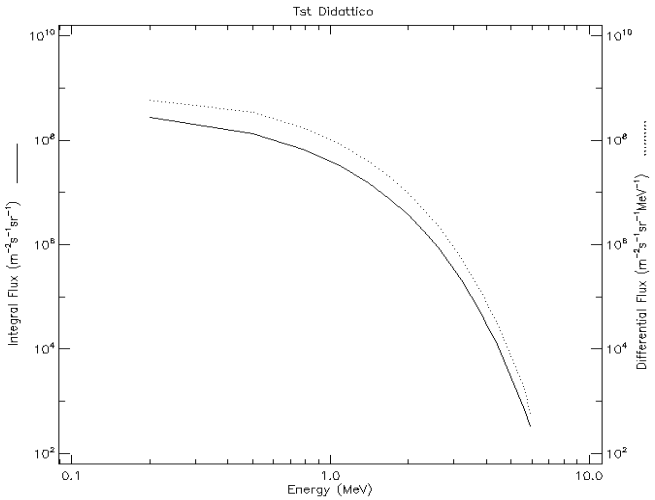
Electron environment: evaluate the FLUMIC model over a spacecraft orbit

Geometry and materials. Caution: the default values for the dielectric material parameters are given for reference only. The results of the simulation critically depend on the values of the input parameters.

Geometry: cylindrical	
Field of view: 90.0 deg	
Dielectric: teflon	**Conductors**
Thickness [cm]: 0.1	**Shield:** gold
Temperature [K]: 298.0	**Thickness [cm]:** 0.1
Density [g cm^{-3}]: 2.17	**Core:** aluminium
Conductivity [Ohm^{-1}m^{-1}]: 1.0E-16	**Radius [cm]:** 0.1
Dielectric constant: 2.15	
Breakdown el. field [V m^{-1}]: 1.0E7	
RIC dose rate factor k_p: 2.0E-14	
***Delta*:** 0.7	
Activation energy [eV]: 0.0	
Grounded at one surface :	
inner surface	

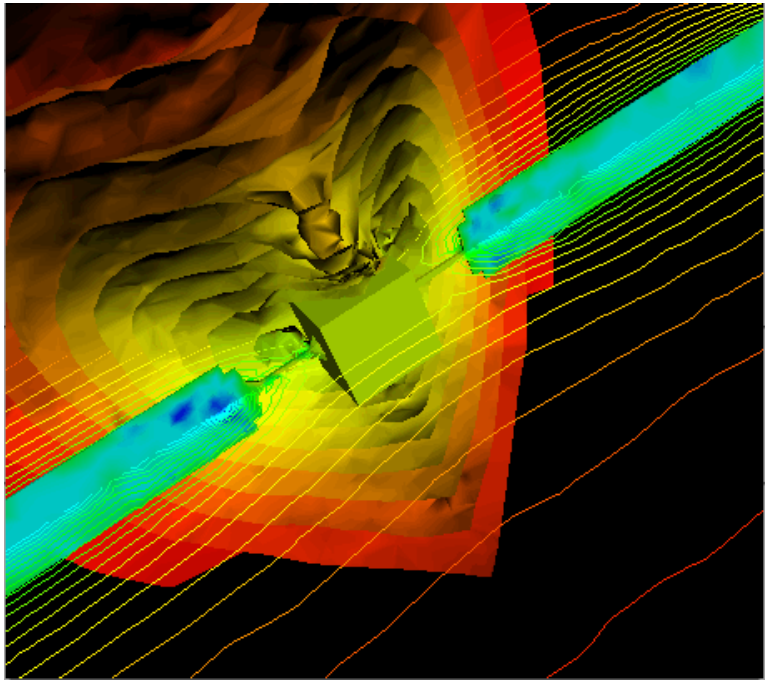
Reset Run





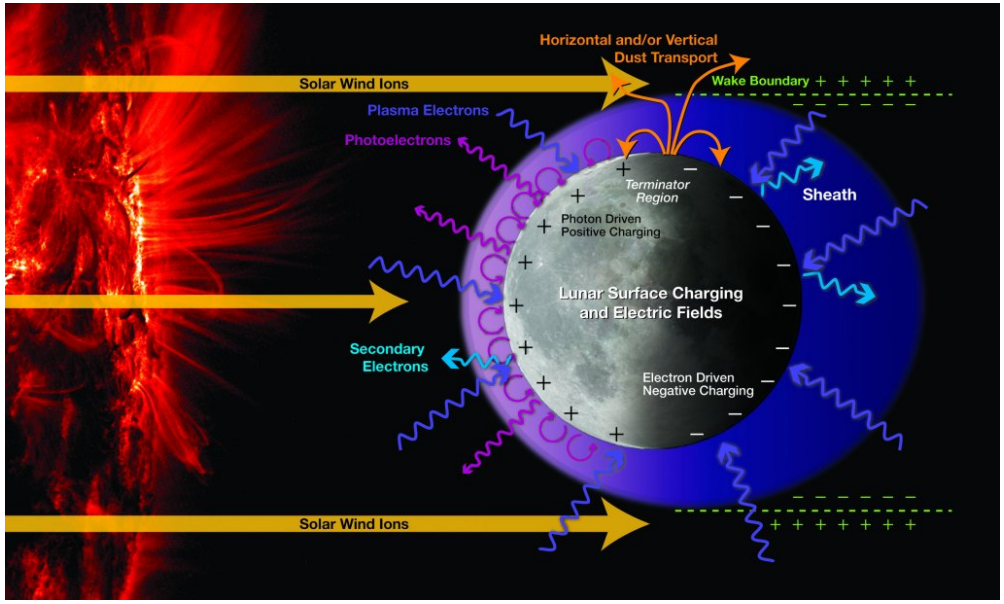
Plasma Simulation in Space

KATHOLIEKE UNIVERSITEIT LEUVEN



ESA Spine Program

(SPACECRAFT PLASMA INTERACTIONS NETWORK IN EUROPE)



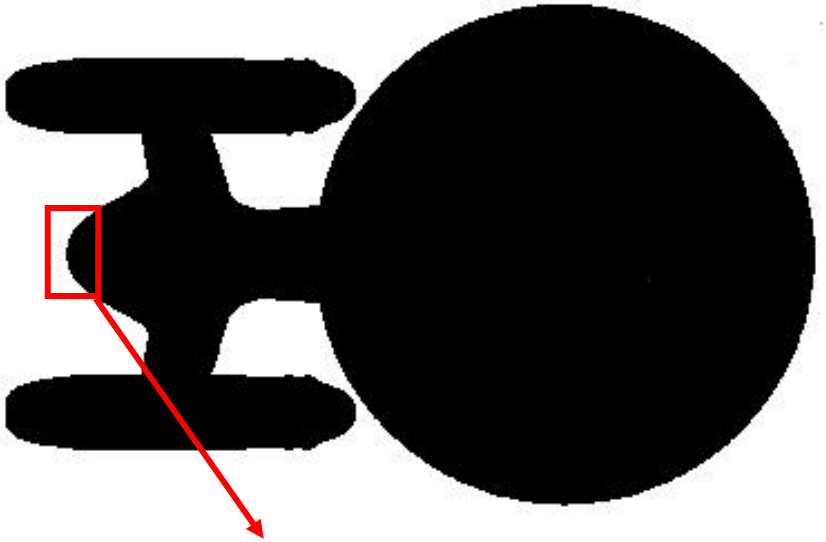
Lunar Science Institute in Boulder

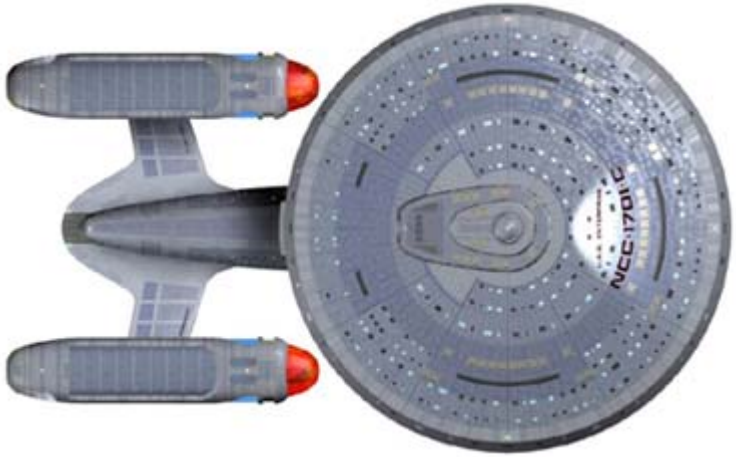
Charging: The DEMOCRITUS Code

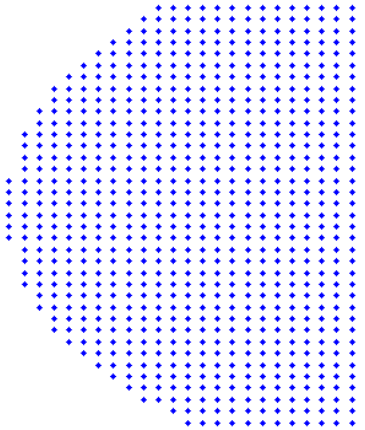
KATHOLIEKE UNIVERSITEIT LEUVEN

Model Features

- Model of the Enterprise
- Simulations with our code Democritus
  http://code.google.com/p/democritus/



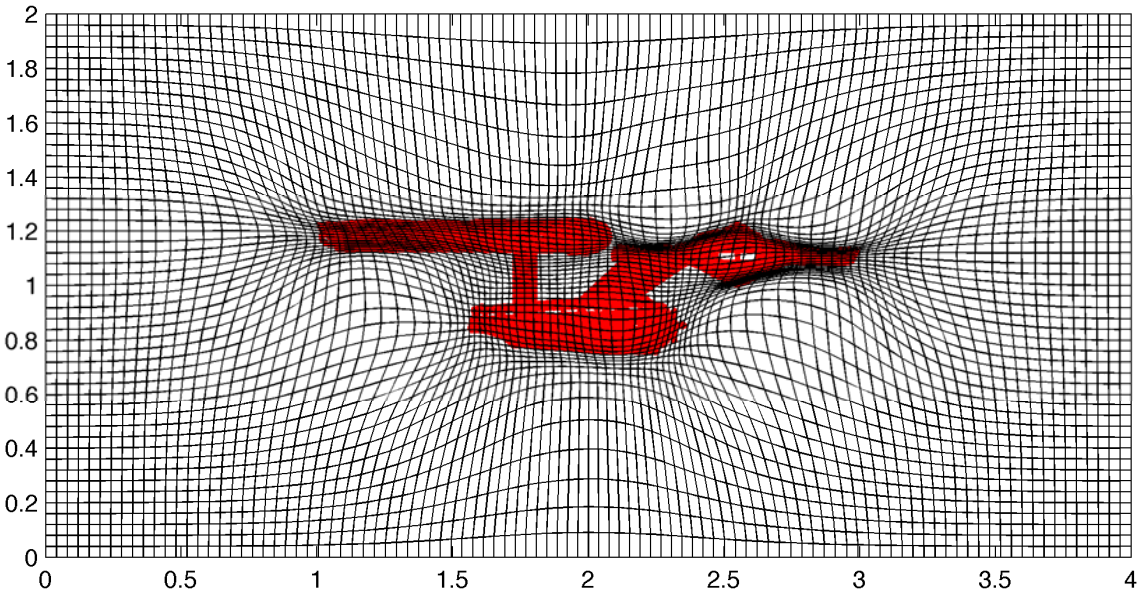




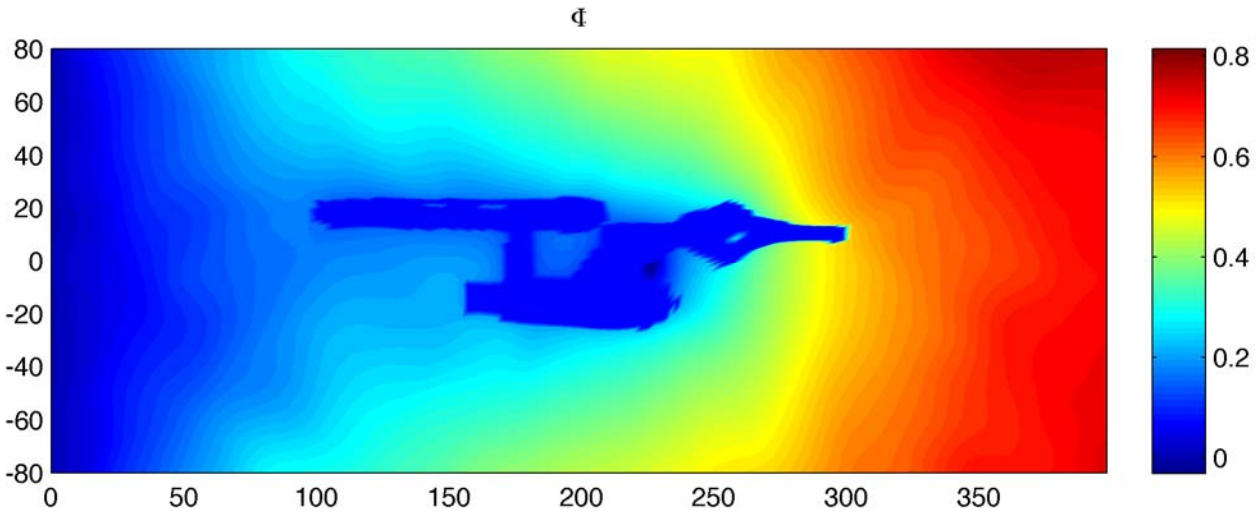
DEMOCRITUS (2D) and CELESTE (3D) available on **google codes**

Charging in a flowing plasma

KATHOLIEKE UNIVERSITEIT LEUVEN

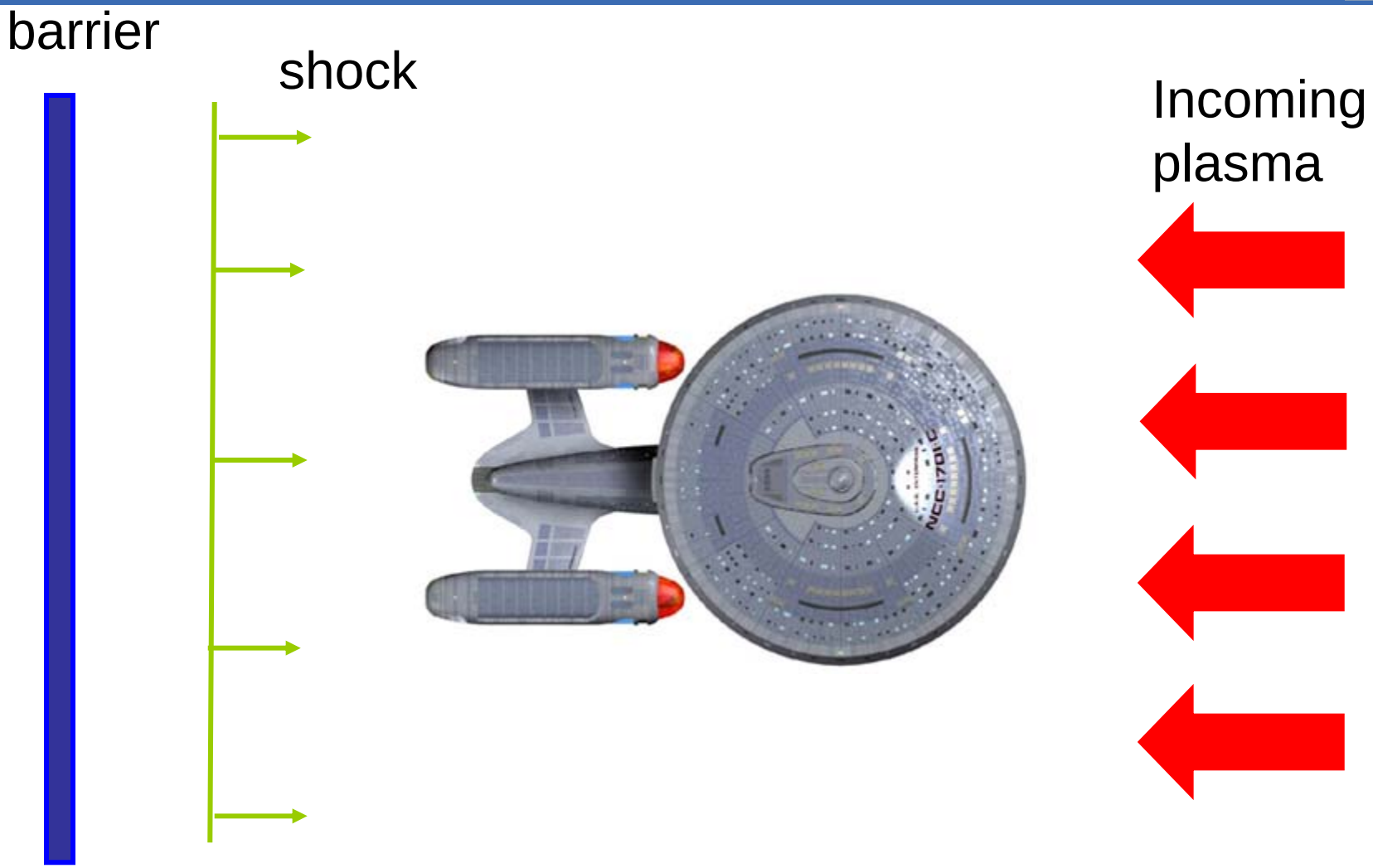


Adaptive Grids



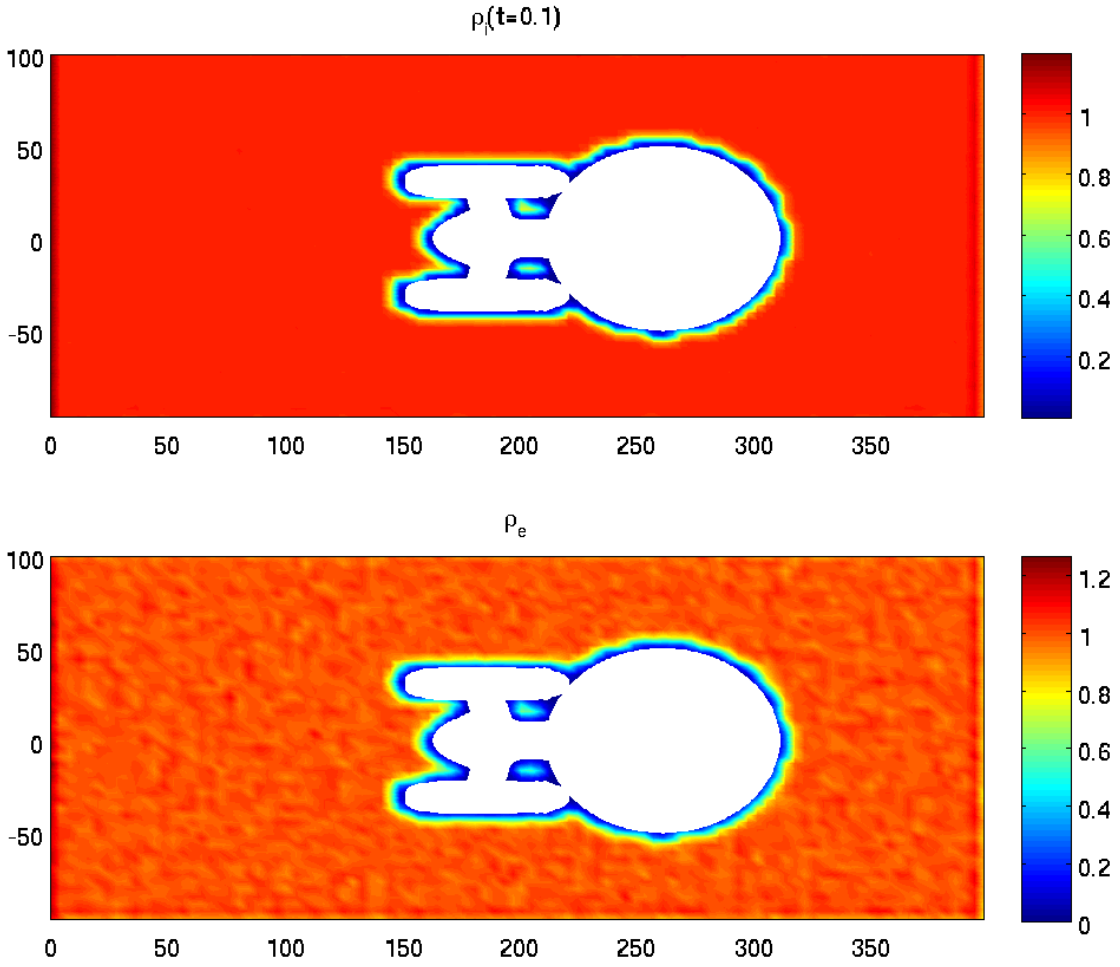
Plasma flow

A shock hitting the Enterprise



Plasma arriving from the right, hits barrier on the left and causes a shock traveling forward.

Example: Enterprise hit by a shock

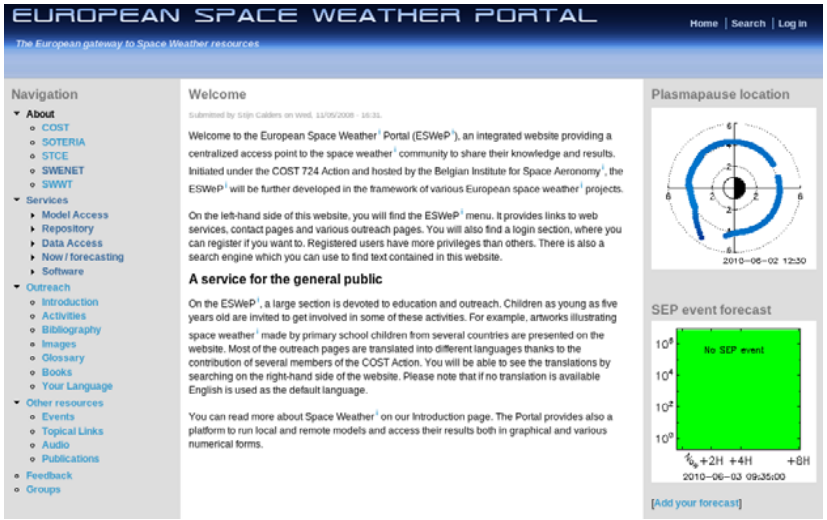


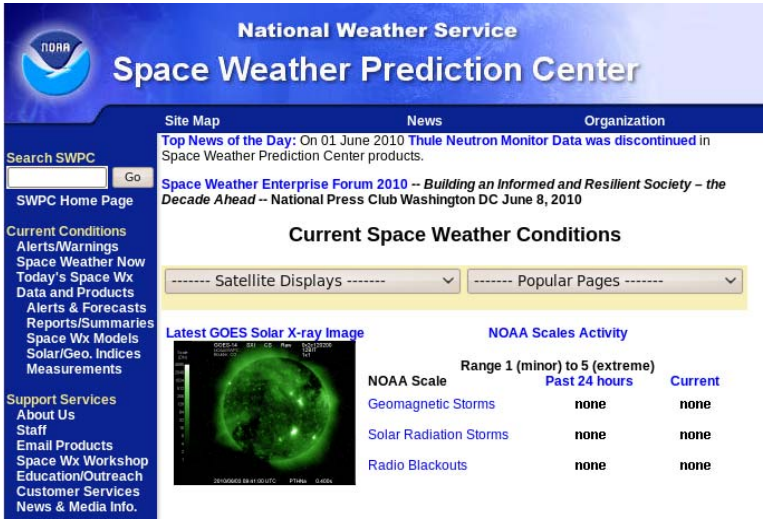
Ion (top) and Electron (bottom) density

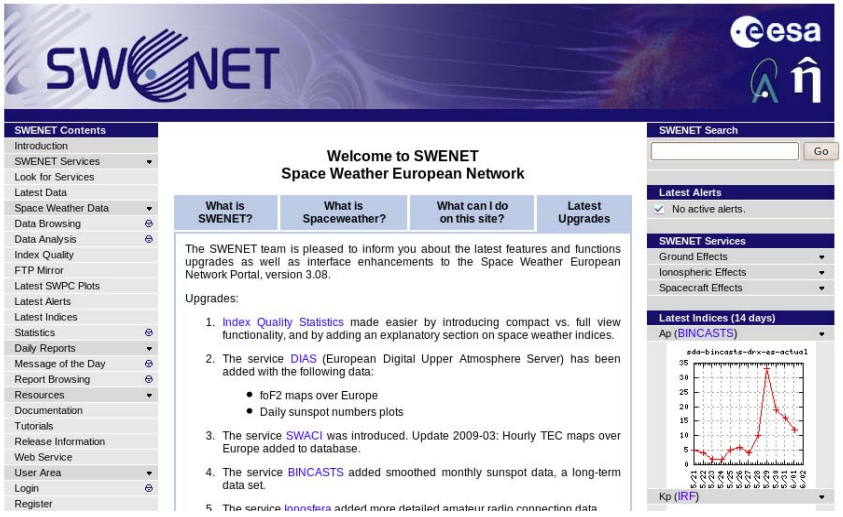
Use of Space weather resources

KATHOLIEKE UNIVERSITEIT LEUVEN

Training on the use of the space-weather resources.







SOLAR-TERRESTRIAL INVESTIGATIONS AND ARCHIVES

- Funded by the EC in FP7 –Space Science
- Coordinator: G. Lapenta, CPA
- Fcous on data and its interpretation:

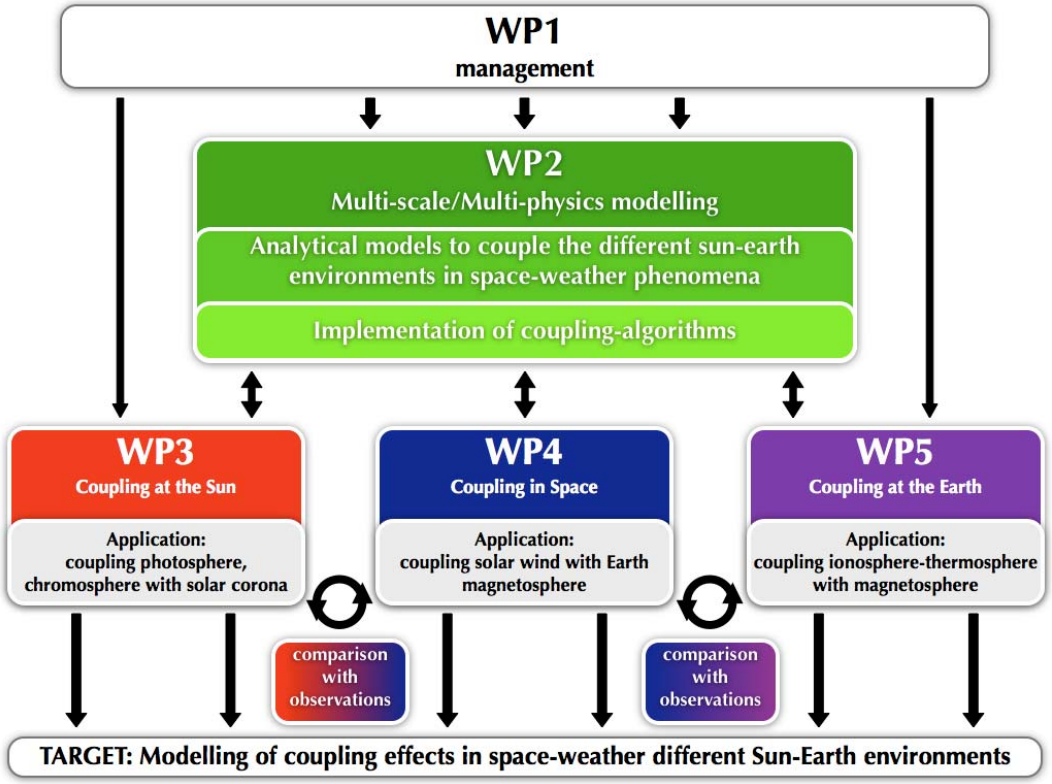
1. Photosphere
2. Chromosphere/Corona
3. Heliosphere/Terrestrial effects
4. Irradiance

www.soteria-space.eu

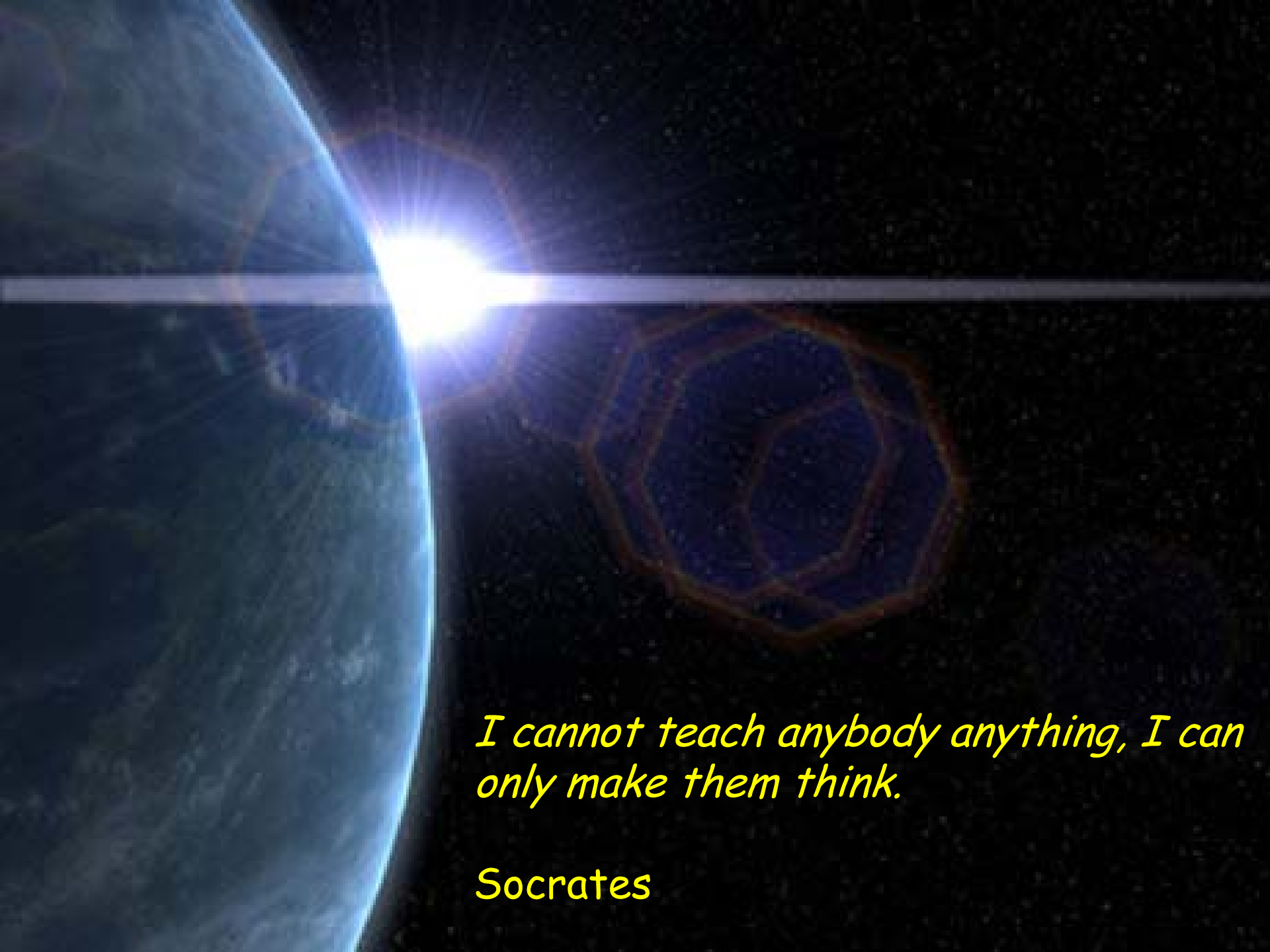
Participant Number	Participant short name	Participant organisation name	Country
1 (coordinator)	KU Leuven	Katholieke Universiteit Leuven	Belgium
2	UNIGRAZ	Universitaet Graz	Austria
3	PMOD-WRC	Pyhsikalisch-Meteoroligisches Observatorium Davos and World Radiation Center	Switzerland
4	KO	Konkoly Observatory	Hungary
5	CNRS LPCE & LP	Centre National de la Recherche Scientifique	France
6	ROB/SIDC	Koninklijke Sterrenwacht van Belgie	Belgium
7	OBSPARIS	Observatoire de Paris	France
8	SRC-PAS	Space Research Centre, Polish Academy of Sciences	Poland
9	MTA-KFKI-RMKI	MTA-KFKI-RMKI Research Institute for Particle and Nuclear Physics	Hungary
10	DTU	Technical University of Denmark	Denmark
11	UOulu	University of Oulu	Finland
12	UGOE	Georg-August-Universität Göttingen Stiftung Öffentlichen Rechts	Germany
13	HVAR	Hvar Observatory, Faculty of Geodesy, University of Zagreb	Croatia
14	NOVELTIS	Noveltis Sas	France
15	FIAN	P.N. Lebedev Physical Institute	Russia
16	IEEA	Informatique Electromagnetisme Electronique Analyse numérique	France

SWIFF:New FP7 project on space weather modelling

KATHOLIEKE UNIVERSITEIT LEUVEN



Participant short name	Participant organisation name	Country
KU Leuven	Katholieke Universiteit Leuven	Belgium
BISA	Belgian Institute for Space Aeronomy	Belgium
UNIPI	Università di Pisa	Italy
UCPH	Københavns Universitet	Denmark
OATO	Astronomical Observatory Turin - Istituto Nazionale di Astrofisica	Italy
ASI	Astronomical Institute, Academy of Sciences of the Czech Republic	Czech Republic
USTAN	University of St Andrews	Scotland, UK


I cannot teach anybody anything, I can only make them think.
Socrates

EXTRA SLIDES

KATHOLIEKE UNIVERSITEIT
LEUVEN

Summary of Student's projects - Modelling

KATHOLIEKE UNIVERSITEIT LEUVEN

- Seven stundents did a PIC study of streaming instabilities in 2010 (space weather class)
- Three students studied relativistic acceleration with the PIC code in 2009 (astronomy endprojects)

- One student of astronomy is using the PIC code for acceleration by wave-particle interaction (thesis)
- One student of mathematics is usng the PIC code for the study of electron holes in the magnetosphere (thesis)
- One student of physics is using the PIC code for the study of solar system formation (thesis)