

Coupling numerical simulation codes and space environment databases thanks to SPASE

IHDEA meeting– October 2023

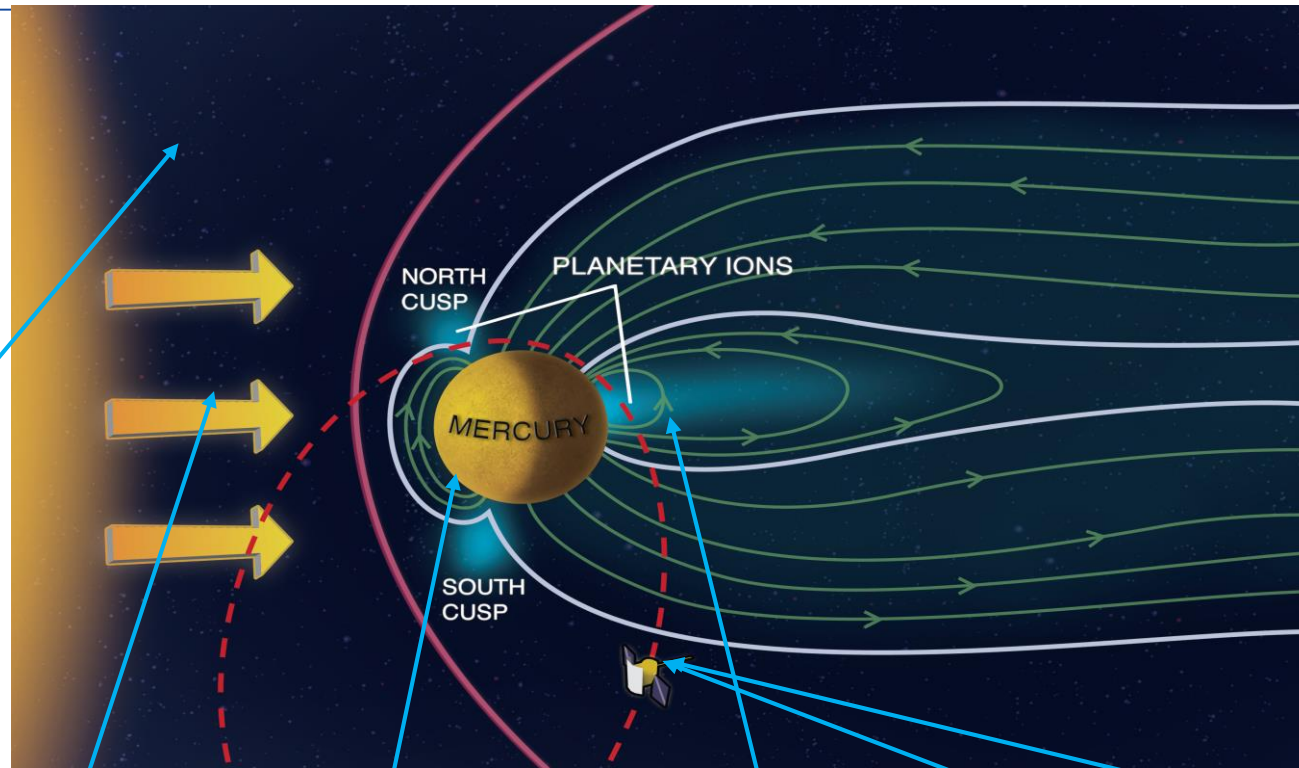
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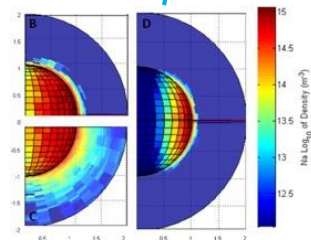
Context: The Sun Planet Digital Environment work package of the Europlanet 2024 Research Infrastructure



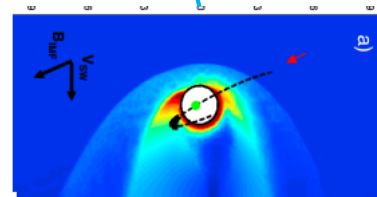
Solar Wind measurement



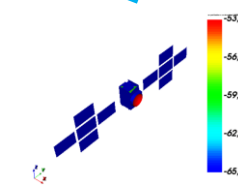
Solar Wind propagation



Exosphere modelling



Magnetosphere modelling

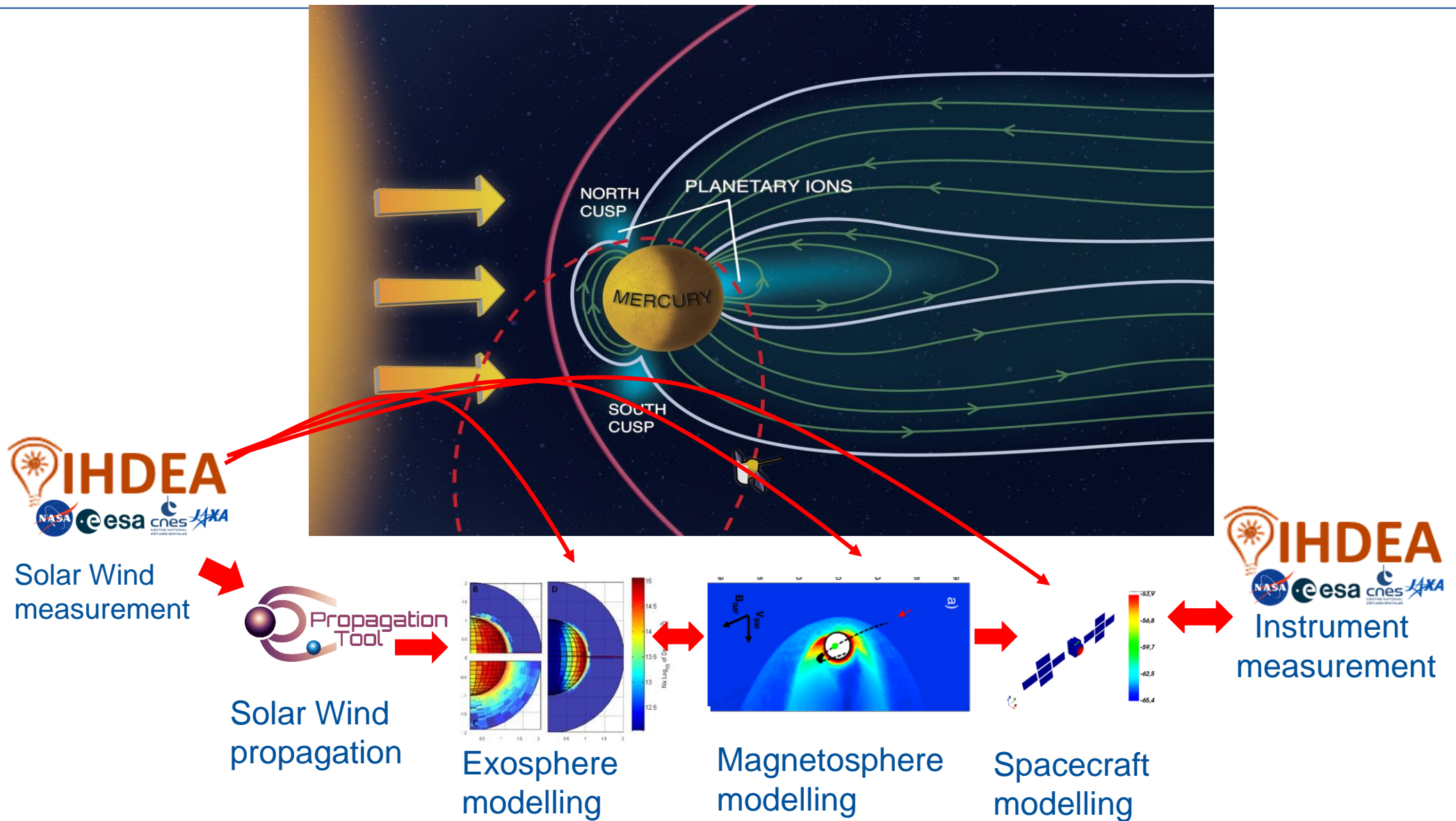


Spacecraft modelling

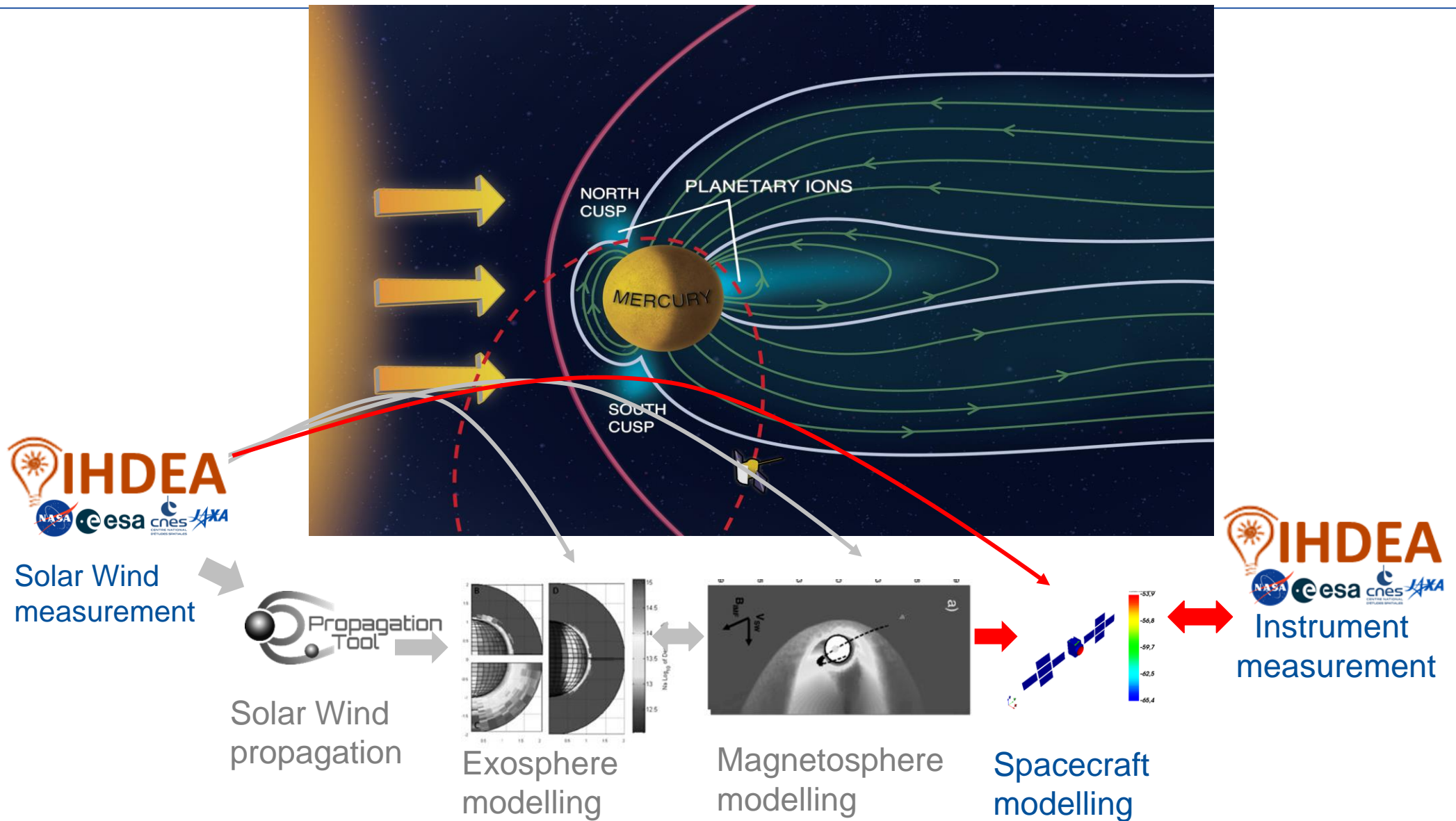


Instrument measurement

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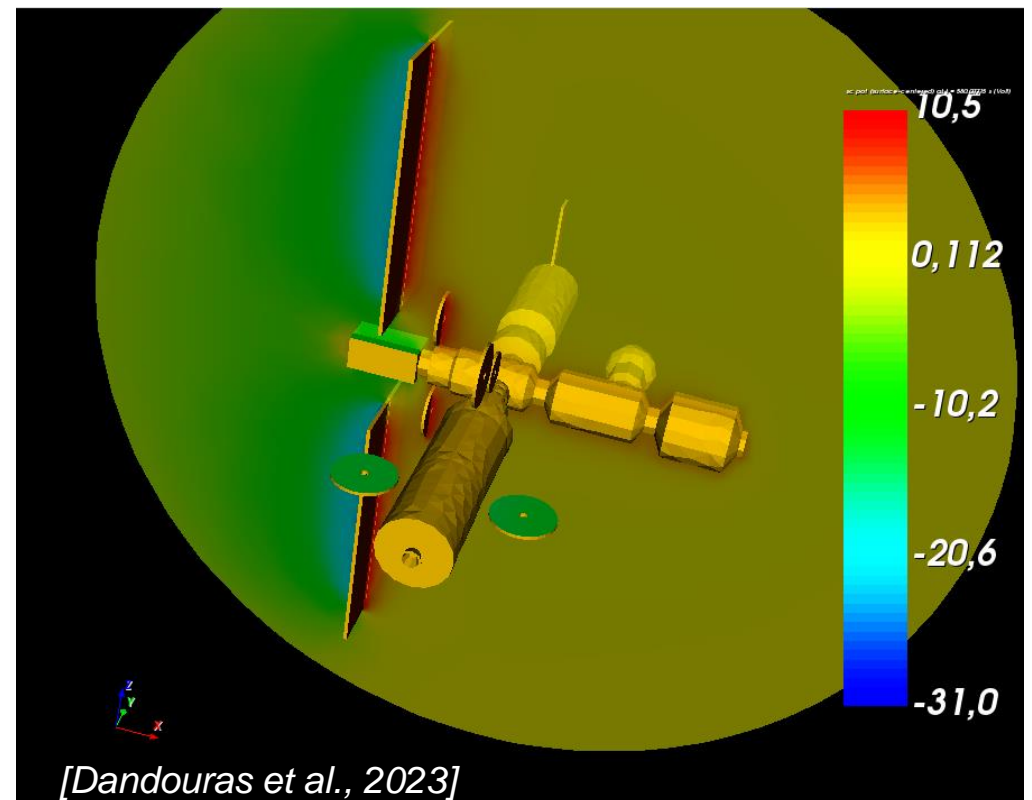


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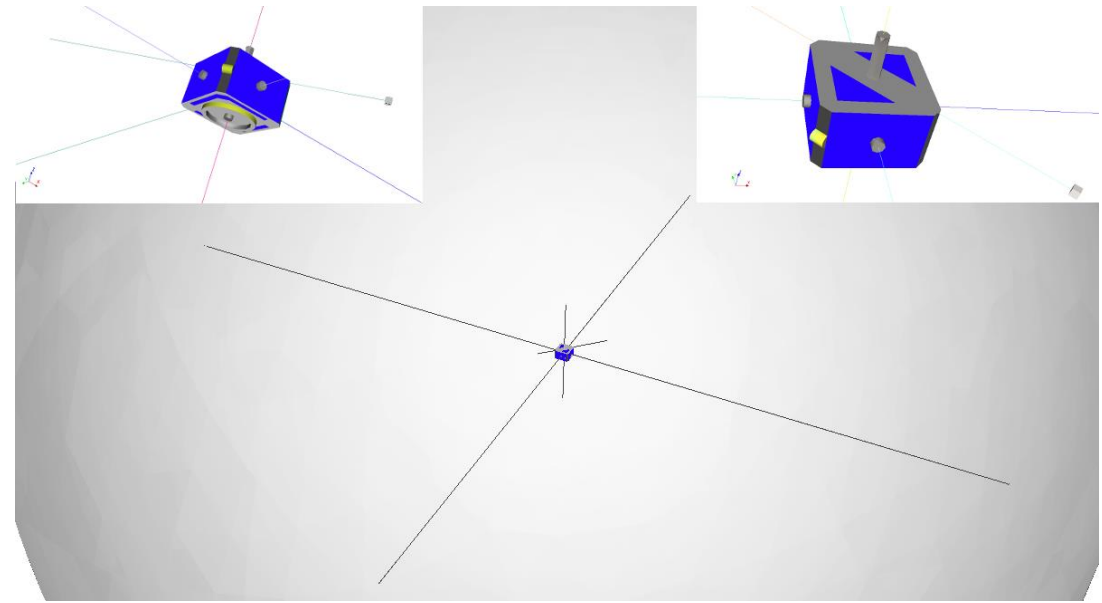
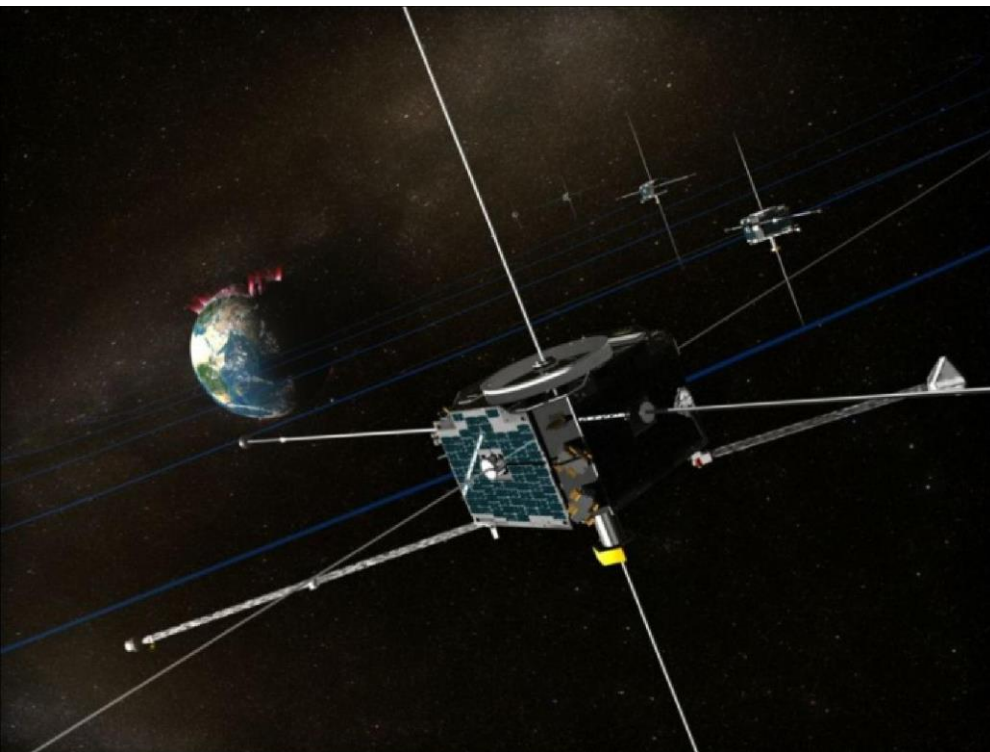
Context: The Spacecraft-Plasma Interaction Software (SPIS)

- Simulates the charge state and the plasma environment of spacecraft
geometry + materials + plasma conditions → *charge state + local plasma environment*
- Multi-physics (plasma, radiations, dusts, contamination, erosion,...), i.e. multiple sub-models
- Open-source, developed by ONERA and Artenum,
with support of ESA and CNES
- Originally used by industrials for platform
electrostatic risk assessment
- More and more used for charging impact on science
instruments, pre-calibration and data analysis



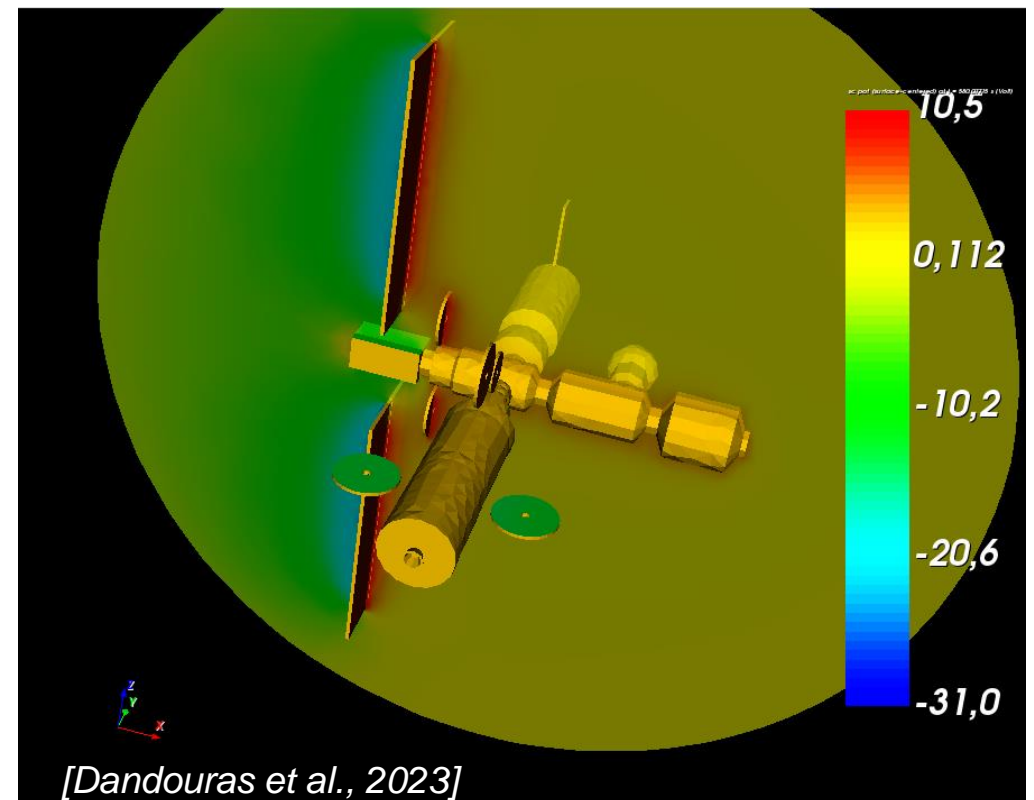
Context: Simulation of THEMIS-B

- To illustrate the new capabilities of SPIS, we perform a simulation of the THEMIS-B spacecraft
- The NASA THEMIS (Time History of Events and Macroscale Interactions during Substorms) mission was to explore the Earth magnetosphere, providing both temporal and spatial resolution through the use of 5 similar spacecraft
- THEMIS spacecraft is meter-sized with 4 ~20 meters antennae + 2 3 meter antennae. The spacecraft has a full instrument suite to measure environment electromagnetic fields and particle distributions.



Context: The Spacecraft-Plasma Interaction Software (SPIS)

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electrostatic risk assessment
- More and more used for charging impact on science
instruments, pre-calibration and data analysis
- **Can simulate instrumental observations, but needs
accurate environment description as input**



Introduction and Conclusion (in case some fall asleep)

- Multi-physics simulation of science instruments/mission interactions with the environment with SPIS
 - estimate charging levels in actual environments
 - estimates the impact on science instrument (pre-calibration, data inversion...)
- We interface SPIS with SPASE to access instrument measurements databases
 - Use of webservices (AMDA, CDAWeb, Vespa) for registry and data access
 - direct access to HPDE repository for metadata
- We demonstrate:
 - SPASE allows a lot of automated pre-filtering of relevant data with correctly filled metadata
 - Software can easily find and interpret data files from different origin and import the data

but: - **need an API to list and filter HPDE registry content**

- **need an (H)API to get the required data in a standardized way**
- **Metadata are not only meant to put your data in large registry, they can facilitate the life of the people working with your data, allowing their handling by tools following the standards**
- **Tools are not intelligent, the more accurate the metadata, the more powerful can be the tools**

The Space Physics Archive Search and Extract (SPASE)



- Data model (Standardized description) developed for 15+ year by an international alliance
- Targets heliosphere, magnetosphere and plasma environment physics
- Provide a standardized way of describing:
 - which datasets exist, what they are about
 - how they were acquired (mission, instrument, people...)
 - where (not how) to find them, under which format
 - what their content is (meaning, unit, field ID...)
- Human readable AND machine actionable description of the data file content
 - metadata to identify and order/filter the resources
 - metadata keywords to identify the physics meaning of data fields
- **Question:**
 - **Make the tool recognize the fields it can use**
 - **Automated match available / requested data with SPIS I/O ?**

Ingestion of data in SPIS: find the available data (first issue)

- Access all resources registered @ NASA's Heliophysics Data Environment Portal
- No registry API:
 - impossible to list the available data:
downloading and parsing the 16000+ XML files is not a good option!
 - impossible to order the data
relying on the ID parsing (folder like) is not a good option
think at how many hours you lost looking for which folder contains the data you want!
folder ordering unreliability is exactly why data model were invented
do not try to override the SPASE description by defining ResourceID guidelines!
- To overcome these issues, we built on the VESPA portal from Observatoire de Paris to generate a SPASE registry API based on the EPN-TAP standard

Ingestion of data in SPIS: find the available data (first solution)

- To overcome these issues, we built on the VESPA portal from Observatoire de Paris to generate a SPASE registry API based on the EPN-TAP standard
- SPIS uses the webservice API

Refine your search [ADQL Query](#) [Back To Services Results](#)

Main Parameters

Target Name

Target Class

Dataproduct.Type

Instrument.Host.Name

Instrument.Name

Processing.level

Time

Location

Spectral

Illumination

Data Reference

Granule.UID

Granule.GID

Results in service spase_vespa

spase_vespa
Service description to be provided

Column visibility Show all Hide all

Select All in current page Reset Selection

granule_uid	dataproduct_type	granule_gid	obs_id
spase://NASA/NumericalData/THEMIS/B/SST/PT3S	spectrum#catalogue_item#cube	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/SCM/PT0.125S	time_series#catalogue_item	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/MOM/PT3S	catalogue_item#cube	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/HelioWeb/Ephemeris/P1D	time_series#catalogue_item	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/GMOM/PT3S	time_series#catalogue_item#cube	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/Fits/PT3S	time_series#catalogue_item	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/FFT/PT0.0556S	spectrum#catalogue_item	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/GBK/PT4S	spectrum#time_series#catalogue_item	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/ESA/PT3S	catalogue_item#cube	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/ESA.FGM/PT96S	time_series#catalogue_item#cube	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/Ephemeris/SSCWeb/PT1M	time_series#catalogue_item	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/Ephemeris/PT01M	time_series#catalogue_item	NumericalData	spase://NASA/NumericalData/THE
spase://NASA/NumericalData/THEMIS/B/EFI/PT3S	time_series#catalogue_item	NumericalData	spase://NASA/NumericalData/THE
spase://DLR/NumericalData/THEMIS/B/FGM/PT0.0078125S	time_series#catalogue_item	NumericalData	spase://DLR/NumericalData/THE

Showing 1 to 14 of 14 entries

Ingestion of data in SPIS: find the available data

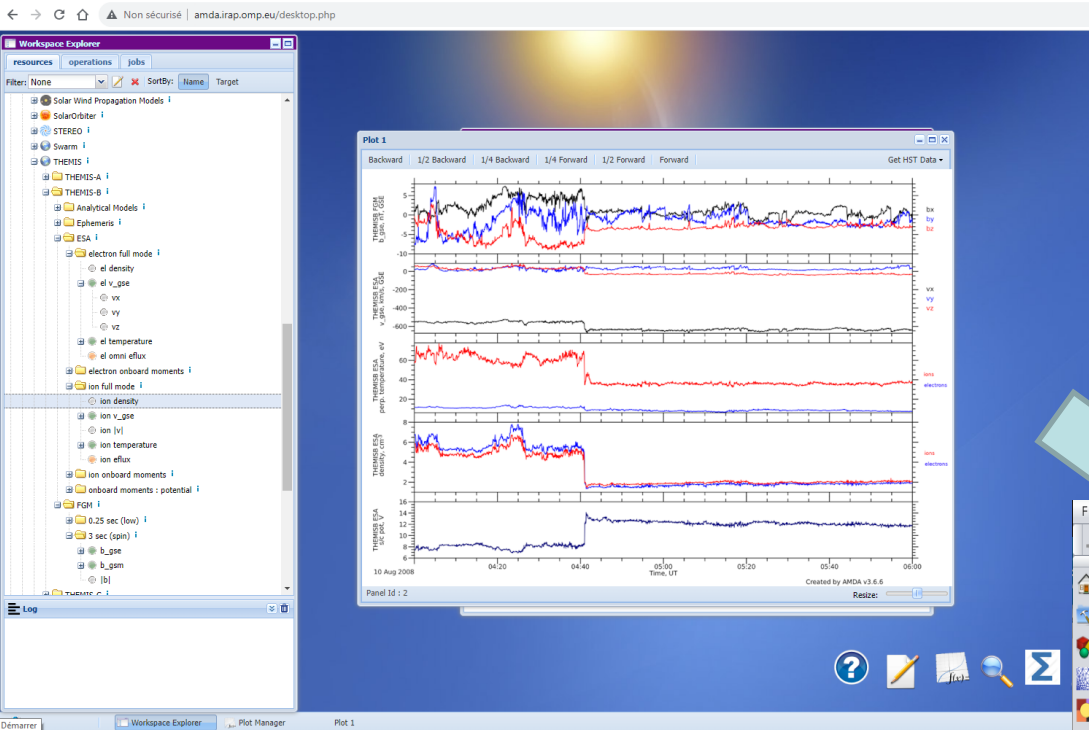
- To overcome these issues, we built on the VESPA portal from Observatoire de Paris to generate a SPASE registry API based on the EPN-TAP standard
- SPIS uses the webservice API to list and order resources, then use hpde.io to get SPASE description

The screenshot displays a web interface for a Virtual Observatory. It is divided into several panels:

- Mission info:** Includes fields for Name, Start, and Duration (72005).
- Environment info:** A tree view showing categories like Environment, electron, ion, and Magnetic.
- Dataset list:** A hierarchical tree view of datasets, with 'THEMIS-B' selected. Sub-datasets include 'ESA', 'electron full mode', 'ion full mode', and 'onboard moments'.
- Dataset info:** Provides detailed information for the selected dataset:
 - THEMIS-B**
Observatory: spase://CNES/Observatory/CDPP-AMDA/THEMIS/ThemisB
Released: 2011-02-23T22:23:40Z
 - Description:** A detailed paragraph describing the THEMIS mission's objectives, phases (Dawn, Tail, Dusk), and instruments.
 - Acknowledgement:** National Aeronautics and Space Administration/United States
 - Contents:** Lists Observatory Group IDs: THEMIS and ARTEMIS.
 - Location:** Lists various regions like Earth, Magnetosphere, and Heliosphere.
 - Operating Span:** Provides start dates and notes for different mission phases.

Ingestion of data in SPIS: select the datasets of interest

- Use Virtual Observatory tools to identify period of interest (here THEMIS-B on Aug. 10th, 2008 4AM)
- Report mission, date and duration in SPIS
- Existing datasets are displayed
- Then, which data field should be used?



The screenshot shows the Virtual Observatory interface. It is divided into several panels: 'Mission info' (Name: THEMIS/THEMIS-B, Start: 2008-08-10T04:00:00Z, Duration: 72005), 'Environment info' (listing Environment, electron, ion, etc.), 'Dataset list' (showing a tree view of datasets like 'electron full mode', 'ion full mode', and 'FGM'), and 'Dataset info' (providing details for selected datasets, including instruments like 'FGM' and output parameters like 'b_gse (thb_bs)' and 'b_gsm (thb_bs_gsm)').

Ingestion of data in SPIS: find and select data of interest

Data fields/ SPIS inputs description

- SPASE <NumericalData> describe the content of datasets:

- with a type (Particle, Fields,...)
- with a physics quantity (density, current...)
- with supporting qualifiers (vector/scalar, average/peak...)

Renaming in v2.6.0?

- SPIS <SimulationModel> defines environment inputs

- Particles:
 - Density (*Quantity: NumberDensity*)
 - Velocity (*Quantity: Velocity ; Qualifiers: Vector*)
 - Temperature (*Quantity: Temperature*)
- Field:
 - Electric (*Quantity: Electric ; Qualifiers: Vector*)
 - Magnetic (*Quantity: Magnetic ; Qualifiers: Vector*)
- Positional (for use with simulated environment)

- Data Content description

- Name
- Key
- Quantity
- Qualifier
- Unit
- Type

- Simulation input description

- Name
- Label
- Quantity
- Qualifier
- Unit

Ingestion of data in SPIS: find and select data of interest

Data fields/ SPIS inputs comparison

- How to compare output parameters and input properties?
 - List pertinent fields
 - Pair them when possible → no equivalent of type!
 - Weight the comparable pairs
 - Quantity must be identical
 - Unit must be convertible
 - Qualifier must match as much as possible
 - Name matching is not reliable
 - Key matching even less (*unless further specifications*)
 - Even though Qualifier comparison may not be perfect match, dimension information may be important and/or required (*Scalar, Vector, Tensor, ...*)
 - Value Range can be matched if specified (*MinValue, MaxValue*)
 - **Exact matching cannot be ensured, user final inspection required anyway.**
- Data Content description
 - Name
 - Key
 - Quantity
 - Qualifier
 - Unit
 - **Type**
 - Simulation input description
 - Name
 - Label
 - Quantity
 - Qualifier
 - Unit

Ingestion of data in SPIS: find and select data of interest

Select SPIS model based on available data

- SPIS is multi-physics / multi-models and modular

- each model described by a <SimulationModel>
- use AssociationType::PartOf to define submodels
- use AssociationType::DeriveFrom to define submodels extension

PopulationModel part of SPIS

MaxwellianPopulation derive from Population Model

- Models may require different input (detailed in SimulationModel::InputProperties)

- Model selection by user, but SPIS can help by checking which models can be set given the available inputs (in development)

- Data Content description

- Name
- Key
- Quantity
- Qualifier
- Unit
- Type

- Simulation input description

- Name
- Label
- Quantity
- Qualifier
- Unit

Ingestion of data in SPIS: find and select data of interest

THEMIS examples

- Magnetic Field example:
 - SPIS search for a data description defined as a Field, magnetic qualified as a vector (SPIS is 3D)
 - Two possible matches found for Themis FGM
 - **Magnetic field magnitude discarded (not a vector)**

The screenshot displays the SPIS Virtual Observatory interface. The 'Mission info' panel shows the mission name 'THEMIS/THEMIS-B', start time '2008-08-10T04:00:00Z', and duration '7200S'. The 'Environment info' panel lists various data categories like 'electron', 'ion', and 'Magnetic'. The 'Dataset list' panel shows a tree structure with 'THEMIS/THEMIS-B' expanded to show 'ESA' and 'FGM' sub-categories. The 'Dataset info' panel provides details for selected datasets, including 'b_gse (thb_bs)' and 'b_gsm (thb_bs_gsm)', both described as 'Vector Magnetic in nT'. The 'Contacts' panel lists 'Dr. Uli Auster' as the Technical Contact. The interface includes a menu bar (File, Tools, Views, Help, Developer) and a toolbar with various icons. At the bottom, there are logos for 'eur PLANET 2024' and 'Connections: Research Infrastructure'.

Ingestion of data in SPIS: find and select data of interest

THEMIS examples

- Particle example:

- density, velocity and temperature found... for which population?
- SPASE allows some simple description (e-, H+, α , ions, dusts....)
- SPIS ask the user to attribute the data to a population, with a pre-election based on SPASE

The screenshot displays the SPIS interface for data ingestion. It features several panels: 'Mission info' (Name: THEMIS/THEMIS-B, Start: [empty], Duration: 7200S), 'Environment info' (listing Environment, electron, electron2, ion, ion2, Electric, Magnetic, Positional, SCVelocity), 'Dataset list' (showing a tree structure with Dataset, AMDA, THEMIS/THEMIS-B, ESA, and various data modes like 'electron full mode', 'electron onboard moments', etc.), and 'Dataset info' (showing 'Observed Region: Earth. Magnetosphere', 'Related Resources', 'Instruments', 'Output Parameters', and 'Contacts'). A dialog box titled 'Attribute data to a population' is open, showing a list of populations: 'electron', 'electron2', 'ion', and 'ion2'. The 'electron' option is selected, and a green checkmark is visible next to the 'density (thb_n_peem)' parameter in the 'Dataset info' panel.

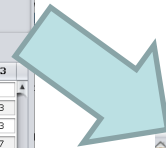
- Once selected, the data must be imported.
- Many ways of accessing the data
- SPASE give many hints as of HOW to get the data (AccessInformation)
 - But the actual request to service is not described
 - The tool needs to know each providers/gateway formalism to get the data
 - HAPI is a solution for time series
- SPIS implements interfaces to AMDA and CDAWeb for data request

Import the data and run

- Once selected, the data can be imported to SPIS which knows from SPASE who to ask and how
- The imported data are used for the simulation, in which they can be monitored

The screenshot shows the 'Global parameters' window in the Virtual Observatory software. It features a table of parameters with columns for Name, Type, Value, Unit, and Description. A 'Metadata' window is open over the table, showing a grid of data series (Series 0 to Series 3) with values in various units like [s], [eV], and [m/s].

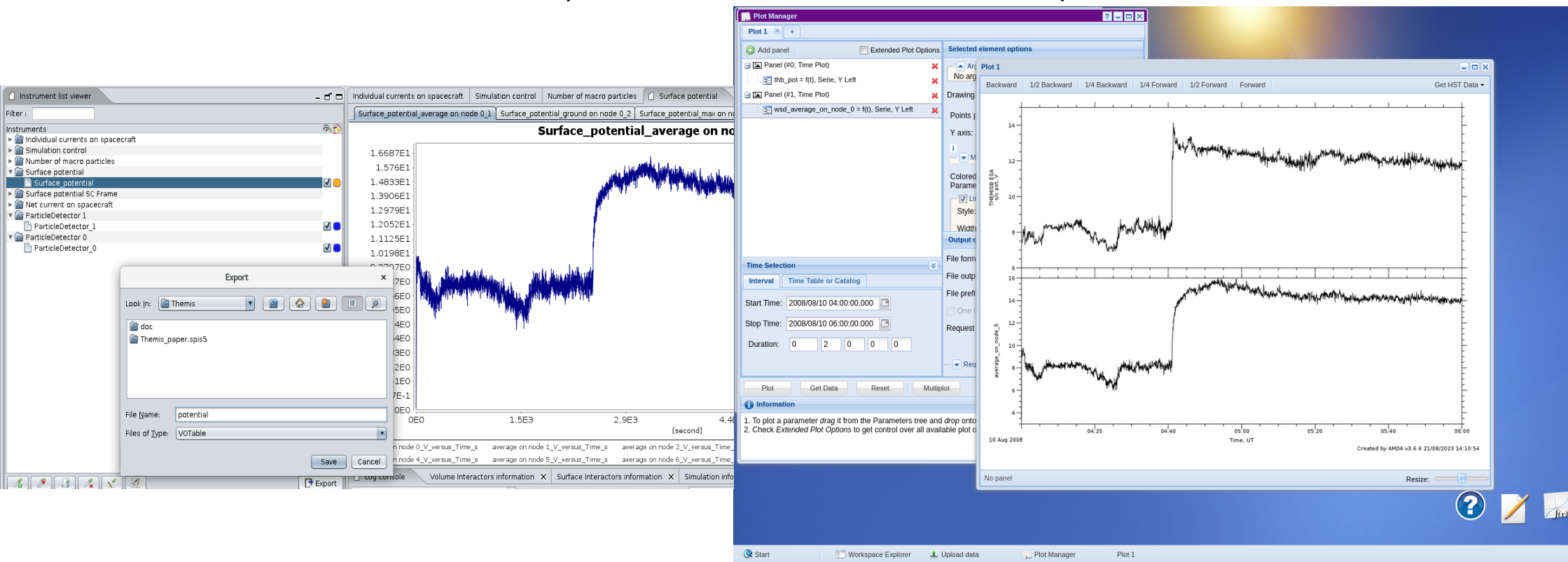
Name	Type	Value	Unit	Description
avPartNbPerCell	double	2.0	None	
B	series		nT	
BFielditerativePusher	int	0	None	
btPartNbPerSurf	int	20	None	
chargeDepositDuringIntegrationFlag	int	0	[]	
elec1DensTable	series		cm-3	
elec1TempTable	series		av	
electronDensity	double	1000000.0	[m-3]	
electronDensity2	double	0.0	[#/m3]	
electronDensityCutoff	double	0.0	[m-3]	
electronDistrib	String		KineticMaxwellBoltzmannVolDistrib	
electronDistrib2	String		PICVolDistrib	
electronDt	double	1.0E-6	[s]	
electronDt2	double	1.0E-6	[s]	
electronDuration	double	1.0E-6	[s]	
electronDuration2	double	1.0E-6	[s]	
electronTemperature	double	1.0	[eV]	
electronTemperature2	double	100.0	[eV]	
electronVx	double	0.0	[m/s]	
electronVx2	double	0.0	[m/s]	
electronVy	double	0.0	[m/s]	
electronVy2	double	0.0	[m/s]	
electronVz	double	0.0	[m/s]	
electronVz2	double	0.0	[m/s]	
environmentType	String		TimeDependentSCVelocity	
ExtendedPopNbr	int	0	None	
ionDensity	double	1000000.0	[m-3]	
ionDensity2	double	0.0	[#/m3]	
ionDistrib	String		PICVolDistribUpdatable	
ionDistrib2	String		PICVolDistrib	
ionDt	double	1.0E-4	[s]	
ionDt2	double	1.0E-4	[s]	
ionDuration	double	1.0E-4	[s]	



The screenshot shows the 'Simulation control' window. A 'Density sensor' plot displays potential values over time (0E0 to 7.5E3 seconds). An 'Export' dialog box is open, showing the file name 'potential' and the file type 'VOTable'. The simulation progress bar indicates 100% completion.

Import, run and export

- Once selected, the data can be imported to SPIS which knows from SPASE who to ask and how
- The imported data are used for the simulation, in which they can be monitored
- Some instruments results can be exported in VOTable with SPASE description for use in databases, tools



Conclusion

- Multi-physics simulation of science instruments/mission interactions with the environment with SPIS
 - estimate charging levels in actual environments
 - estimates the impact on science instrument (pre-calibration, data inversion...)
- We interface SPIS with SPASE to access instrument measurements databases
 - Use of webservices (AMDA, CDAWeb, Vespa) for registry and data access
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