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# Joining the yellow hub: uses of the Simple Application Messaging Protocol in Space Physics analysis tools

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## ABSTRACT

The interest for data communication between analysis tools in planetary sciences and space physics is illustrated in this paper via several examples of the uses of SAMP. The Simple Application Messaging Protocol is developed in the frame of the IVOA from an earlier protocol called PLASTIC. SAMP enables easy communication and interoperability between astronomy software, stand-alone and web-based; it is now increasingly adopted by the planetary sciences and space physics community. Its attractiveness is based, on one hand, on the use of common file formats for exchange and, on the other hand, on established messaging models. Examples of uses at the CDPP and elsewhere are presented. The CDPP (Centre de Données de la Physique des Plasmas, <http://cdpp.eu/>), the French data center for plasma physics, is engaged for more than a decade in the archiving and dissemination of data products from space missions and ground observatories. Besides these activities, the CDPP developed services like AMDA (Automated Multi Dataset Analysis, <http://amda.cdpp.eu/>) which enables in depth analysis of large amount of data through dedicated functionalities such as: visualization, conditional search, cataloguing, etc. Besides AMDA, the 3DView (<http://3dview.cdpp.eu/>) tool provides immersive visualisations and is further developed to include simulation and observational data. These tools and their interactions with each other, notably via SAMP, are presented via science cases of interest to planetary sciences and space physics communities.

Keywords: space physics, planetary sciences, virtual observatory, interoperability standards, analysis tools, scientific exploitation

## INTRODUCTION

With the growing amount of data from both observational and modeling origins, data centres are forced to develop and ease data access and scientific exploitation. This goes through user friendly data bases but also through the procurement of dedicated tools which are the key to optimal science return. In planetary sciences and space physics the study of a particular object (e.g. planets, moons, comets, solar wind,  $\dot{\gamma}$ ) is seldom performed using a single dataset; on the contrary it is indeed through the combination of multiple dataset of heterogeneous origins that new insight can be gained. However designing a single analysis tool holding all functionalities to tackle this large variety of data would be unreachable; more reasonably and efficiently, the current trend is to couple or interoperate specifically designed tools. Data communication between these tools or software then remained the key to have such an organization working on the large scale. This is the frame of common protocols to which IVOA (International Virtual Observatory Alliance) has long been committed.

In this paper we show how one of these IVOA protocols, the Simple Application Messaging Protocol or SAMP, has been efficiently used outside its originating community (astronomy) to address science cases applied to space physics. The focus is therefore not on the specificity of the protocol, but rather its practical use, to show how it enables easy data communication between tools. We take advantage of such uses at the French Plasma Physics Data Centre (CDPP), but also companion tools, to present adequate science cases. Further technical information on SAMP may be obtained directly from IVOA <http://www.ivoa.net/documents/SAMP/>. The paper starts by shortly presenting the CDPP tools involved, continues with a short note on SAMP, before proceeding to the science cases.

## CDPP: A SHORT PRESENTATION

### CDPP and interoperability

Since its creation by CNRS and CNES in 1998, the French Plasma Physics Data Centre (CDPP) has a continuous strategy to develop analysis tools for the wider space physics community. If data distribution and scientific tool development are at the core of CDPP activities, they will not reach their goal if they were not entangled in an international web of efforts. Several consortia indeed aim at unifying data description (or data model) and data communication (or protocols) in order to assemble interoperable bricks of services. The main actors are namely: IVOA (<http://www.ivoa.net/>) in the general astronomy field, IPDA (<http://planetarydata.org/>) where planetary sciences issues are discussed between space agency, SPASE (<http://www.spase-group.org/>) in the space physics field. At the French level ASOV (<http://www.france-vo.org/>) coordinates the national effort.

In the recent year European FP7 projects have given an important frame for designing and implementing new standard and protocols.

In Europlanet-RI, the CDPP team participated with the VO-Paris team to the development of PSR-DM (Planetary Science Resource Data Model) and EPN-TAP (Europlanet-Table Access Protocol), both based upon IVOA standards. These data model and protocol are now used to share more and more datasets in the domain of planetary sciences (*Erard et al., 2014a,b*), using IVOA existing standards and infrastructure. At the same time, AMDA has turned SAMP compatible which enabled its connection to external tools such as Aladin, Topcat and query databases such as APIS (<http://lesia.obspm.fr/apis/>); this is demonstrated here in science cases section. Tutorials (as video or manual) of how this interplay can be performed are also available on the CDPP tutorial page.

In IMPEX (see a detailed project description at <http://impex-fp7.oeaw.ac.at/>) the CDPP participated to the development of a simulation data model together with the LATMOS (documents are available at <http://impex-fp7.oeaw.ac.at/documentation.html>). This model, which is a SPASE extension, enables to

describe simulation and analytical model results in a common way which is a prerequisite to build interoperable services on heterogeneous databases.

The following Figure presents how CDDP databases and tools are interlinked and connect to the outside world. Some of these value added services and databases are discussed in the next pages.

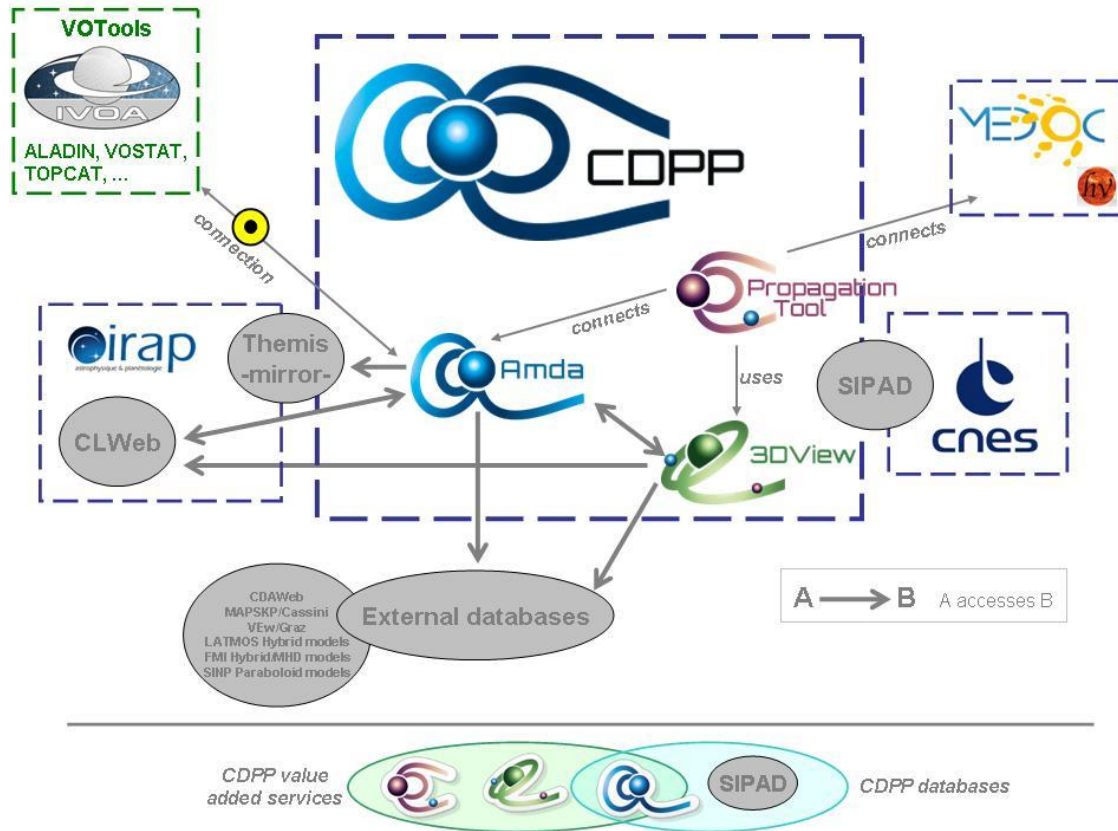


Figure 1: CDDP is an ensemble of databases and services in interoperable connection with external centres and tools.

## Tools at CDDP

Since 2006 and the development of the AMDA tool, CDDP followed its strategy to increase data exploitation. It led to the development of several tools both internally and by the means of close cooperation between CDDP researchers and SME.

**AMDA:** <http://amda.cdpp.eu/>

AMDA is developed at CDDP since 2006 (*Jacquey et al., 2010, Génot et al., 2010*). Its initial aim was to provide visualization capabilities to Earth magnetosphere data. Quickly it was enriched by a data mining tool and the functionality for the user to define its own physical parameters. The central philosophy is that the user manipulates parameters and does not directly manipulate files. The tool therefore acts both as a data base and a tool as its data holding has been progressively increased to include those from a wide variety of heliophysics missions. Recently in the frame of the FP7 IMPEX project access to simulation and model data has been also provided via AMDA.

AMDA can be connected to a SAMP hub in order to easily exchange files (in VOTable or CDF formats) with other analysis tools.

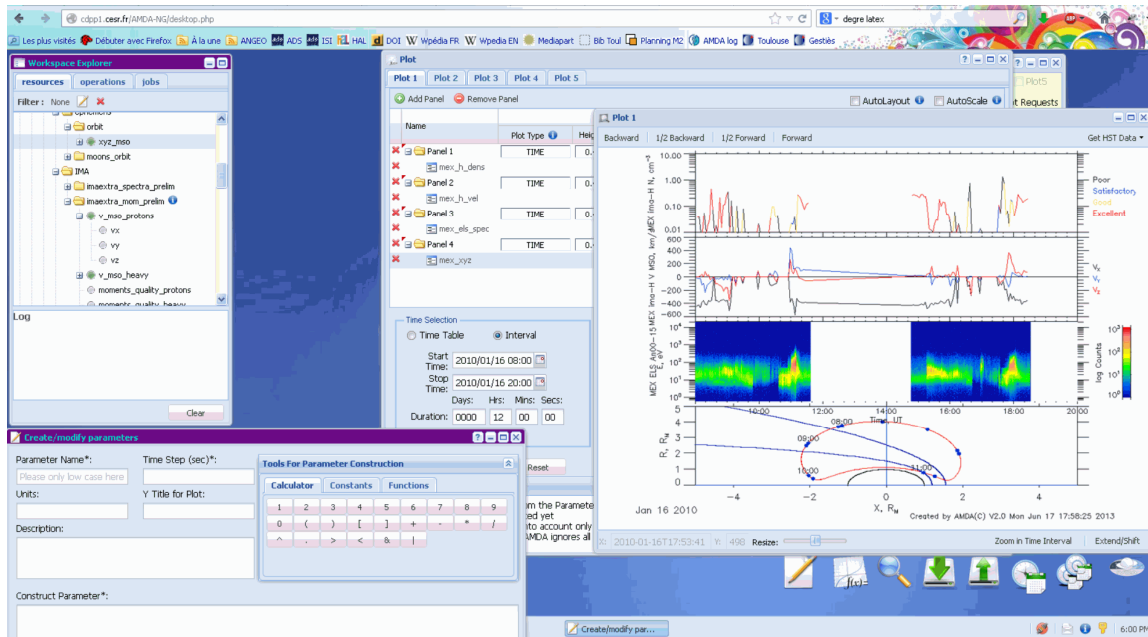


Figure 2: the AMDA interface as of end 2013. It is based on the concept of desktop in the browser using ExtJS framework. The data tree is exposed on the left part, activities (plotting, data mining, time table management, ...) are proposed on the bottom right and corresponding interfaces appear in the central part of the browser.

## Data in AMDA

The AMDA database mostly consists in time series (scalar, vector, spectra) in homogeneous format to ease exploitation. Moreover data from other space physics centres are accessible via interoperable means:

- CDAWEB at GSFC, NASA (a large collection of data from space physics missions),
- the European mirror data centre for MAPSKP/Cassini data at IRAP (key plasma parameters from the Cassini mission),
- the European mirror data centre for NASA/Themis data at IRAP (a five-spacecraft mission to study the magnetosphere),
- the Venus Express MAG database at IWF, Graz, Austria (the magnetometer instrument onboard the Venus orbiter).

Via these various centres and its own holding, CDDP renders accessible space plasma data from the ionospheric domain to the heliospheric domain also including planetary sciences; in this last domain it should be noted that the FP7 Europlanet-RI project enabled the ingestion of more than 300 new datasets in AMDA, mostly from NASA/PDS. Thanks to the FP7 IMPEX project the CDDP recently widened its data offer by providing modeling results: magnetic field models at planets (from SINP, Russia) and hybrid/MHD codes for solar wind/planet interactions (from LATMOS and FMI).

**3Dview:** <http://3dview.cdpp.eu/>

3D orbit visualisation in maneuverable scenes is the main objective of 3DView. All celestial objects from the Solar System are included together with most of scientific spacecraft. Recently in the frame of the FP7 IMPEX project access to observation, simulation and model data has been also provided. This tool is developed by the SME GFIö under CNRS contract and CNES license.

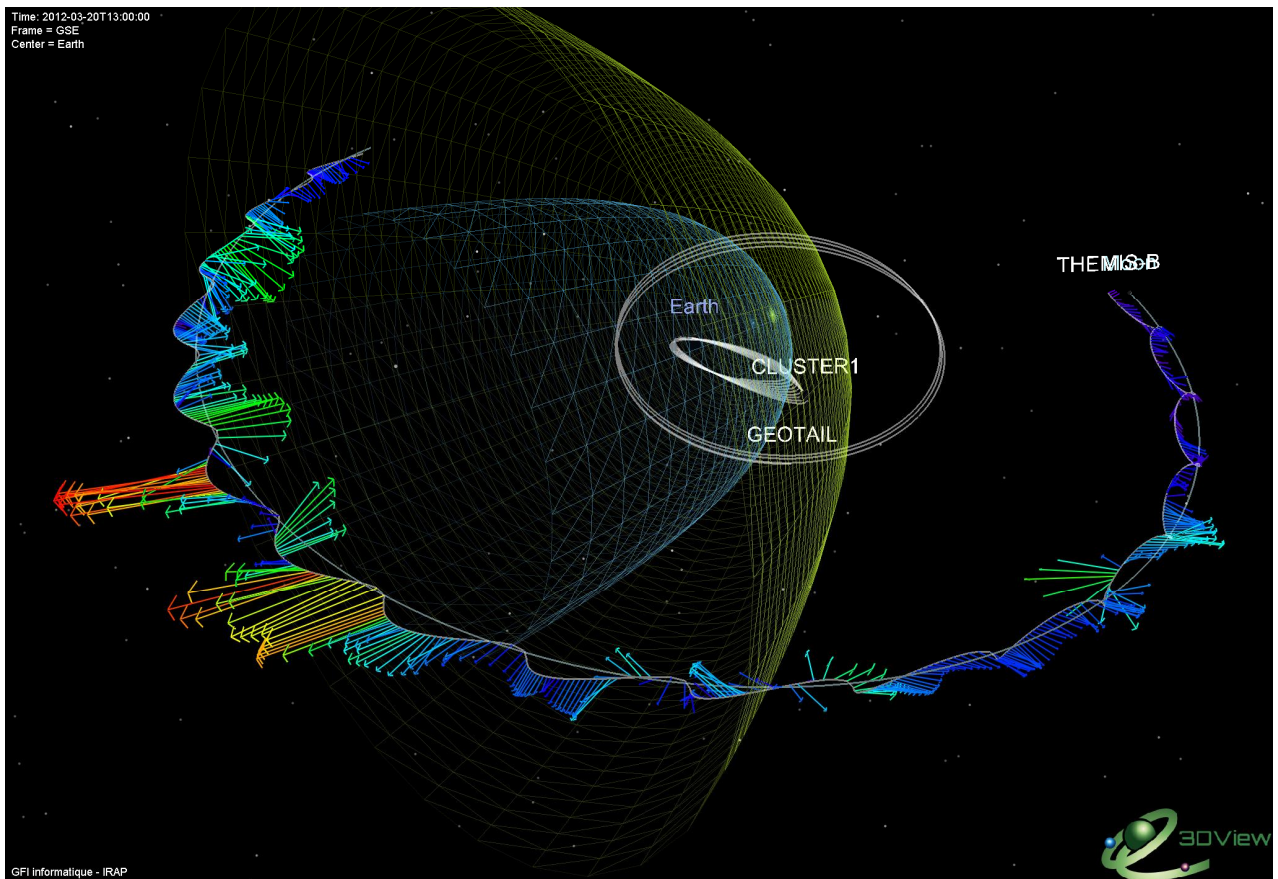


Figure 3: 3Dview scene illustrating about 20 days of the trajectories of the spacecraft Themis B orbiting the Moon along its passing through the solar Wind, the bow shock (green surface), the magnetopause (blue surface) and the distant magnetotail. The measured magnetic field vectors are shown as arrows with the length and colour coding the magnitude of the field in GSE coordinate system. Current sheet flapping is evidenced in the tail and perturbations are observed at frontier crossings. Themis in-situ data are obtained via web service access to the AMDA database (right window). Cluster 1 and Geotail orbits are also shown.

**TREPS:** <http://treps.cdpp.eu/>

This tool provides a friendly web interface to 3DView web services offering coordinate transformation. Original files can be loaded from the user disk, and URL or via SAMP. Numerous data and time formats are dealt with for both the source and target data. The user can choose from a large list of planetary coordinate systems to transform from and toward, including: GSE, GSM, JSO, JSM, KSO, KSM, MSO, VSO, LSE, 67PCG\_EME,  $\hat{i}$


## CONNECTING TOOLS: SAMP APPLICATIONS IN SPACE SCIENCE TOOLS

Besides CDPP tools a crowd of space physics tools are nowadays joining the interoperability and Virtual Observatory paradigm, following the pioneering astronomy-led software such as Aladin or Topcat.

If these tools commonly take advantages of web services for data communication, there is also a growing use of the communication protocol SAMP (<http://www.ivoa.net/documents/SAMP/>), developed by IVOA from its predecessor PLASTIC (Taylor et al., 2006). One of the goals behind SAMP is to ease data broadcast between tools without building a strong link between them (as web services do).

The purpose of the next section is to show how this protocol, initially designed for astronomy

applications, is successfully employed for plasma and planetary sciences uses. In order to understand this attractiveness, let us first present the basis of this protocol (the dedicated IVOA page is a reference document; see also <http://wiki.ivoa.net/twiki/bin/view/IVOA/SampPapers>).

Basically, the protocol is based on the creation of a hub through which data files in common format can transit from one stand-alone or web-based application to another. When a hub is formed it is symbolized by the  logo, usually visible on the desktop bar of your computer. Usually space physicists tend to launch an instance of the Topcat tool to create the tool, even if they do not use it for their application (see for instance the Science Case 1 below).

The semantics of messages exchanged between SAMP clients are defined by MTypes (Message Type). Although VOTable is the standard way to convey tabular data with SAMP (from the IVOA recommendations), it should be noted that it is also possible to transmit FITS file, and more recently also CDF files, now a standard format in the space physics community. This stems from the fact that most of existing MTypes were initially defined in astrophysical context, and thus not usable in the case of space physics or planetary sciences; it follows that specific communities tend to define their own MTypes. For CDF a specific MType has been defined which is useful when both ends of the communication understand CDF, or when transformation to VOTable would not be convenient. The list of known Mtypes is maintained informally by the IVOA, and can be obtained from <http://www.ivoa.net/samp/>.

## SCIENCE CASES

### Science case 1: magnetic field in GSE/LSE coordinate systems in the Moon environment

#### Description

The user wants to visualize magnetic field data (vectors) acquired around the Moon in a Moon-centered scene. He knows that such data exist on AMDA and wants to use 3DView for the 3D rendering.

Tools involved: AMDA, 3DView, TREPS

#### Procedure

The user goes to the database of the AMDA tool (Figure 4) and selects magnetic field data in the Moon environment obtained by the NASA/Themis mission; however in AMDA these data are only available in Earth-centered coordinates (GSE), as this mission was initially targeting Earth sub-storms physics; in a later phase of the mission, two of its probes (Themis B & C) have been later gravitationally captured by the Moon, thus reorienting the scientific objectives (a project called Artemis), but not how the database is built. The user first plots the data for the interval of interest and then thinks to use the coordinate transformation service, TREPS, to perform an operation between the original GSE system and the final LSE system in which he/she wants to display the data. The user hits the Get Data button. A download interface appears in which he/she can choose the time format, the structure of the file, í ; actually the default selection is enough for the current purpose. Hitting the download button he/she can choose to send the data to a companion tool instead of getting a file. Here one assumes that a SAMP hub has already been opened (typically the Topcat software is used to launch a local hub on the user's computer) and that AMDA and TREPS are also connected to the hub. In the AMDA interface it is then possible to choose TREPS as a destination tool for the data. Now, in TREPS the GSE coordinate system is chosen as the source system while the target system is set to LSE. The transformation is then easily realized and, if the user correctly defines VOTable as the export format, he/she then has the possibility to send the transformation result via SAMP (Figure 5). The user goes to 3DView, sets up the scene (Moon-centered, in ECLIPJ2000) for the corresponding spacecraft (Themis B for the given interval, a scene). 3Dview must then also be connected to the SAMP hub. Back in TREPS, the user sends the transformed data to 3DView which finally displays the magnetic field vector as colored arrows along the Themis B trajectory (Figure 6).

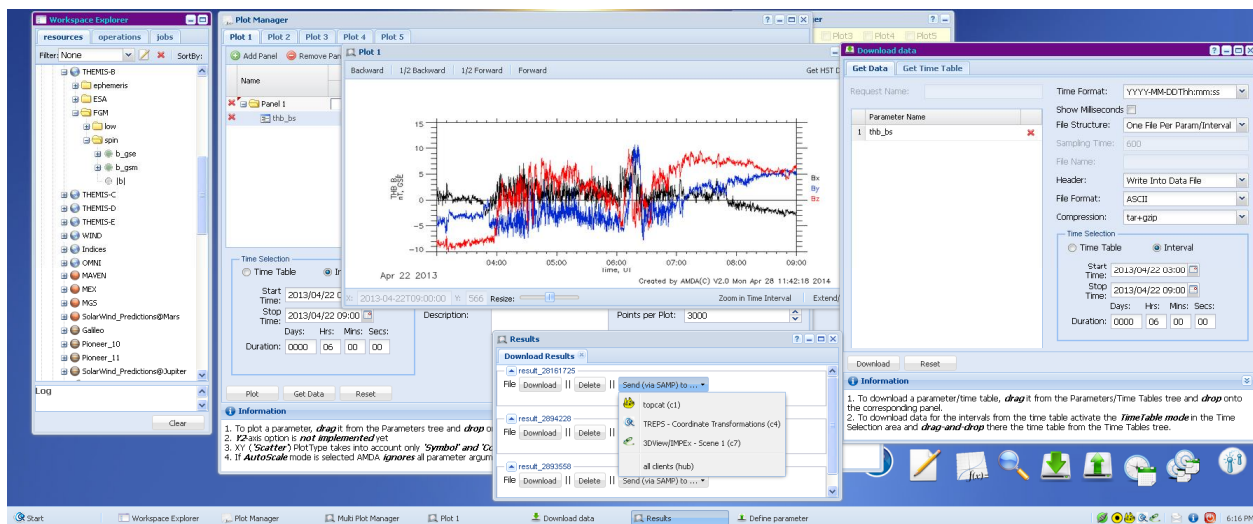



Figure 4: on the AMDA desktop the user has displayed the data tree (left) with THEMIS B data directories, made a plot on the interval of interest (middle part of the image), clicked on the Get Data button to select data to be exported (right part of the image), clicked on the Download button and displayed the different client tools to which he/she can SAMP-send the data (here TREPS and 3DView are seen as possibilities, together with Topcat which was used to create the hub). The desktop bar in AMDA (lower right corner) shows successively a green sign meaning that AMDA is connected to the hub, the SAMP hub logo , and Topcat, TREPS and 3DView logos.

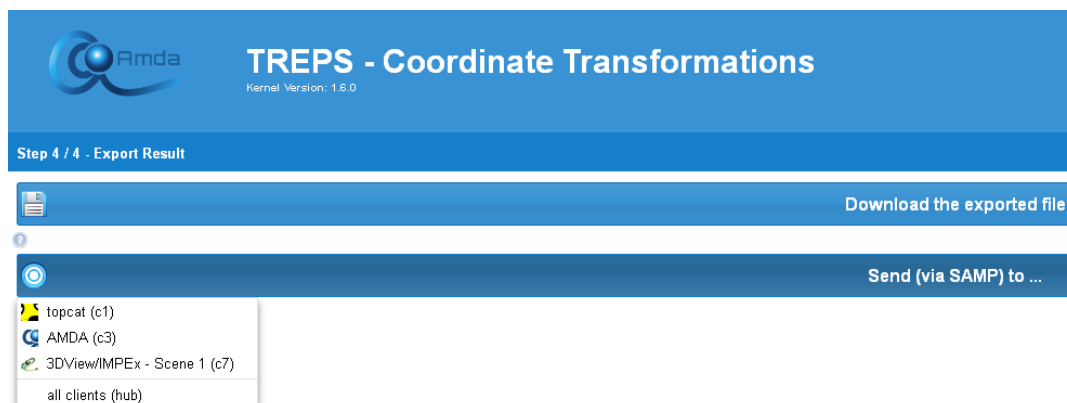


Figure 5: the last step of the transformation performed on TREPS (step 4: export result); the user has now the choice to send the transformed data to 3DView (or eventually back to AMDA).

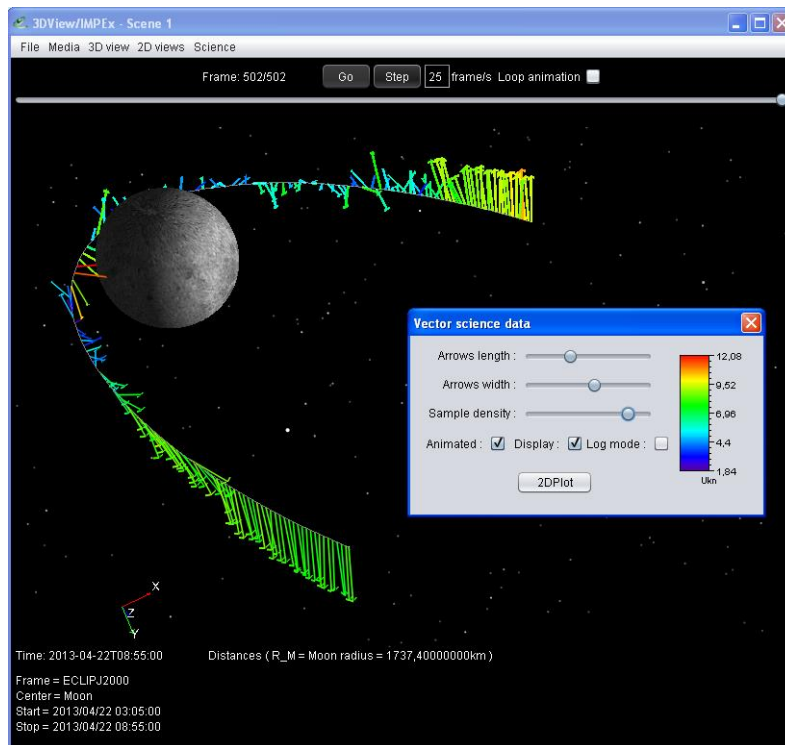


Figure 6: the 3DView scene displaying the Moon, the orbit of THEMIS B during the interval of interest, and the magnetic field in LSE coordinate system shown as arrows (both the colour and the length code the amplitude of the field).

It should be noted that, in this process, the user did not manipulate data files at any time: SAMP first enabled the transfer of data between AMDA and TREPS, and second between TREPS and 3DView. At present this chain is operating only if the VOTable format is used throughout but it will be soon possible to widen this choice (to CDF and netCDF formats for instance in this community).

## Science case 2: comparison of observed and simulated plasma velocity in the Mars environment

### Description

The user wants to compare observations on the Mars environment with numerical simulations in order to get the broader context and/or to validate the numerical model.

Tools involved: LatHyS, AMDA, Topcat

### Procedure

The user goes to the database of the AMDA tool (Figure 7) and selects several Mars Express datasets for plotting such as the proton energy spectrograms and moments together with orbital information on a time interval corresponding to one orbit. He/she chooses to compare these data with simulated data available on the LatHyS (Latmos Hybrid Simulation, <http://impex.latmos.ipsl.fr/LatHyS.htm>) database to reveal the plasma behavior in places adjacent to the specific observations by Mars Express. As LatHyS is a database, containing 1D, 2D, and 3D pre-computed data products, but with no plotting interface, and as AMDA only enables to display time series, the user decides to perform the comparison on a third tool, Topcat, which enables both kinds of plots. Here also it is assumed that Topcat has been opened from the start to initiate the hub; in reality it is not too late to do it now. The procedure to send data to Topcat from AMDA is similar to what has been explained in Science Case 1 (an displayed in Figure 4). On LatHyS (Figure 8) the user has the choice between several simulations of the Martian environment and finally selects a run depending on the solar wind input parameters. He/she connects LatHyS by hitting the appropriate button

on the interface (note that similarly to AMDA LatHyS is a web-based application but can nonetheless be connected to the hub). He/she decides to compare proton velocity in the simulated XZ plane which he/she sends to Topcat. At this stage (Figure 9) Topcat has received two tables: one (IMPEX data) from LatHyS, and one (DDw7qb4q) from AMDA; these particular names are chosen by the sending applications depending on their internal mechanism. Here again all data are conveyed in VOTable. Manipulating Topcat allows to displayed both tables and finally to over-plot 1/ the proton velocity (here the x-component but this can be modified) measured by Mars Express along its trajectory (the velocity amplitude is here coded in color) on 2/ the XZ plane cut of the 3D simulation file of the same quantity. It should be observed that the two plots agree reasonably well (i.e. colors match in the same location) such as to differentiate solar wind from planetary environment plasmas.

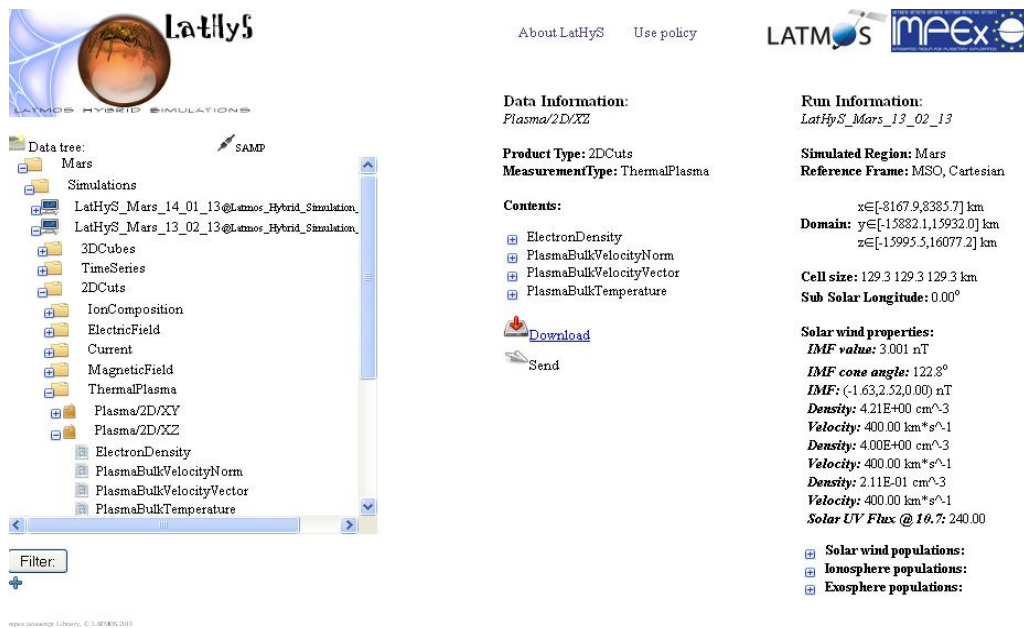


Figure 8: the LatHyS database developed at LATMOS in the frame of European FP7 IMPEX project. Hybrid simulations of planetary environments in interaction with the Solar Wind are accessible as 3D data files, or sampled as plane cuts or along spacecraft trajectories. The SAMP functionality may be activated on the upper left part of the interface and data subsequently sent by hitting the Send button (in the form of a paper plane).

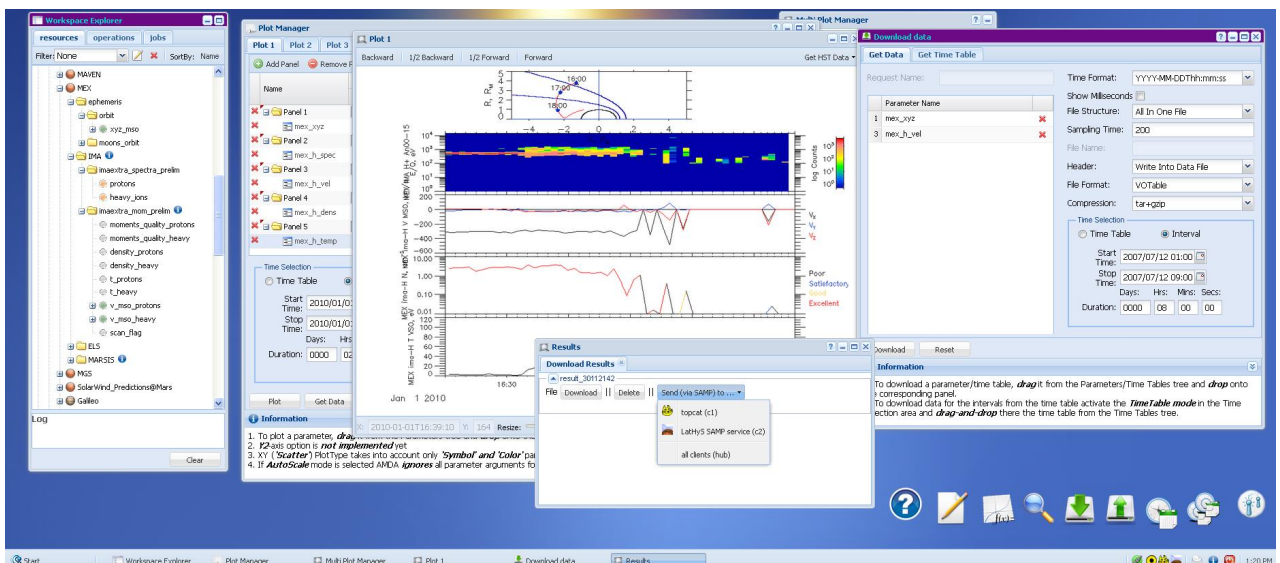


Figure 7: on the AMDA desktop the user has displayed the data tree (left) with Mars Express data directories, made a plot on the interval of interest (middle part of the image), clicked on the **Get Data** button to select data to be exported (right part of the image), clicked on the **Download** button and displayed the different client tools to which he/she can SAMP-send the data (here Topcat and LatHyS are proposed as possibilities).

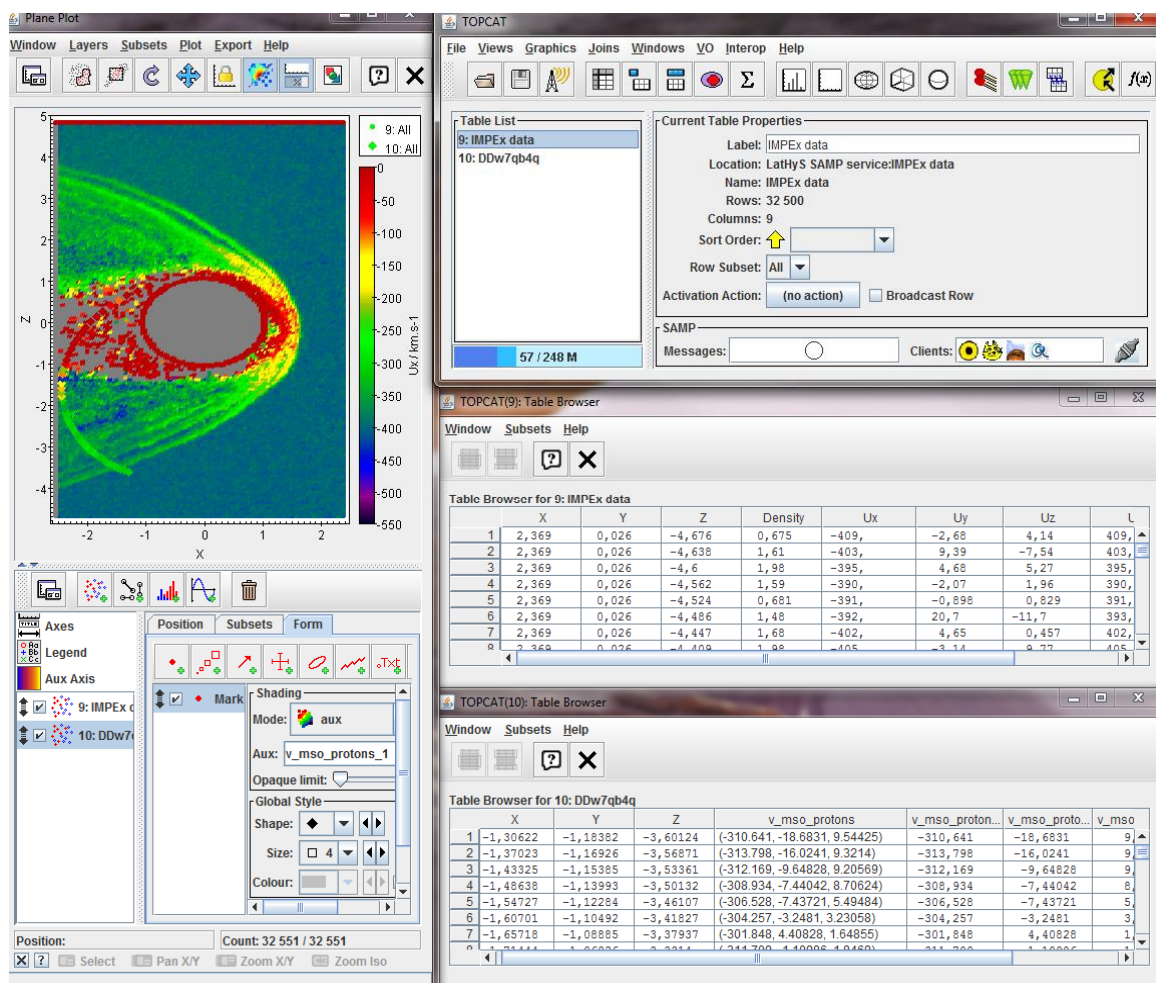


Figure 9: the Topcat interface where data (here the x-component of the proton velocity) from LatHyS (simulated 2D plane cut) and AMDA (observed Mars Express parameter coded in colour along the actual trajectory) are compared. In the **Clients** window (upper right) the SAMP hub logo is visible together with Topcat, LatHyS and AMDA logos.

### Science case 3: imagery of auroral emission at Saturn in conjunction with interplanetary shock observed by Cassini

#### Description

The user wants to compare ultraviolet observations of the auroral emissions of Saturn by the Hubble Space Telescope (HST) with local observations of the solar wind parameters during the cruise phase of Cassini in order to estimate the influence of external conditions on the global dynamics of the magnetosphere of Saturn. The main functionality developed to that purpose in AMDA consists in answering to a request for HST observations between start time and stop time for a given planet name (in our case here Saturn). To this end:

1. HST metadata are first obtained from the MAST server or APIS database using the EPN-TAP protocol in the latter case,
2. Filters are then applied to extract the relevant datasets corresponding to the user request, and an interface enables the user to obtain a first glance (quick-looks) at the relevant HST observations,
3. Communication is finally established with Aladin using SAMP in order to display selected HST

observations (FITS files).

Databases queried: AMDA, MAST (<http://archive.stsci.edu/hst/>), APIS (<http://lesia.obspm.fr/apis/>)

Tools involved: AMDA, Aladin

### Procedure

In AMDA the user selects several Cassini datasets when the spacecraft was, for example, in the solar wind during the month of January 2004 (Figure 10). The  $\delta$ Get HST data button is then clicked (top right corner of the plot window): a new window appears where the user can, on the left part, query two different HST databases  $\delta$  MAST or APIS  $\delta$  and define his/her request by choosing 1/ the target (Jupiter, Saturn or Uranus) and 2/ the time period for the query, eventually extending or shifting the original in-situ data interval; this last option may be useful in order to time shift in-situ observations in the solar wind such as to take into account the distance of the spacecraft to the targeted planet.

The user can then visualize, on the right part of the window, the results of his/her query: HST images are sorted by date and organized in day by day folders. The user can preview HST images by passing the mouse on the dates and select the images he/she wants to download or visualize by ticking the box associated to each date. A detailed scientific description (and metadata) of the HST image can be obtained directly from the MAST or APIS website by clicking on the date. After choosing the relevant HST images, the user can either download them in a zip file or send them to Aladin or any other tools connected via the SAMP protocol (e.g. the astronomical imaging application DS9 <http://ds9.si.edu/>) by clicking the corresponding buttons at the bottom.

The connection to Aladin may be done in two ways (see corresponding buttons on Figure 10). Either an Aladin Web tab is opened with the selected images directly uploaded (as FITS) in the interface; or the selected images are sent via SAMP (also as FITS) to a local Java instance of Aladin. This last case is illustrated on Figure 11. Any other SAMP tools accepting FITS could also receive the images. The extension of the CDPP/AMDA service to astronomical data (HST observations) and IVOA tools (Aladin) therefore opens a new window in our understanding of comparative auroral and magnetospheric physics of giant planets and will enhance the scientific return of previous, current and future (e.g., NASA/Juno and ESA/JUICE) planetary missions to these environments. This extended service will ultimately serve and benefit the European planetology community (and beyond) as well as promote and enlarge the application domain of astronomical VO tools. Also, this consists of one of the first experiment to combine tools at the interface of the plasma (SPASE) and astronomy (IVOA) communities.

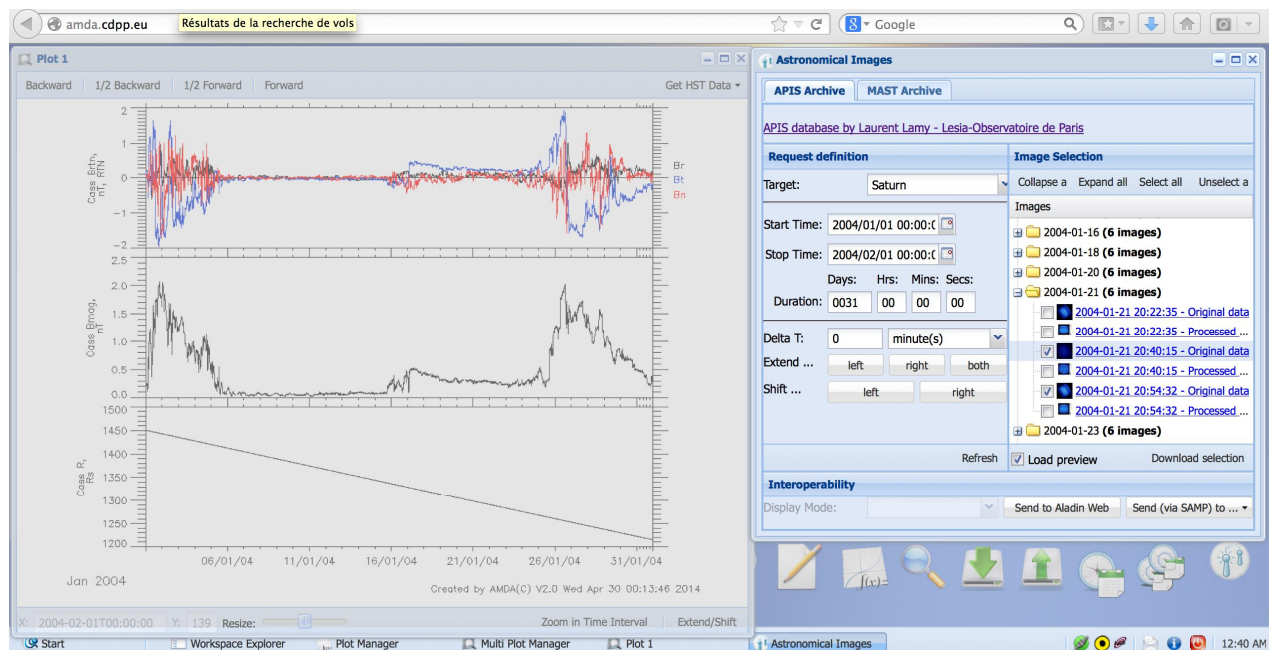


Figure 10: on the AMDA desktop the user has displayed the 1 minute Cassini magnetic field data in RTN coordinates with radial distance to Saturn in planetary radii (left window), clicked on the Get HST Data button to open the second window on the right, select the APIS database to be queried and define the target and time period to request. The results of the request are shown on the right part of the second window. The two  $\delta$ Send  $\acute{\imath}$   $\grave{o}$  buttons enable connexion to other tools.

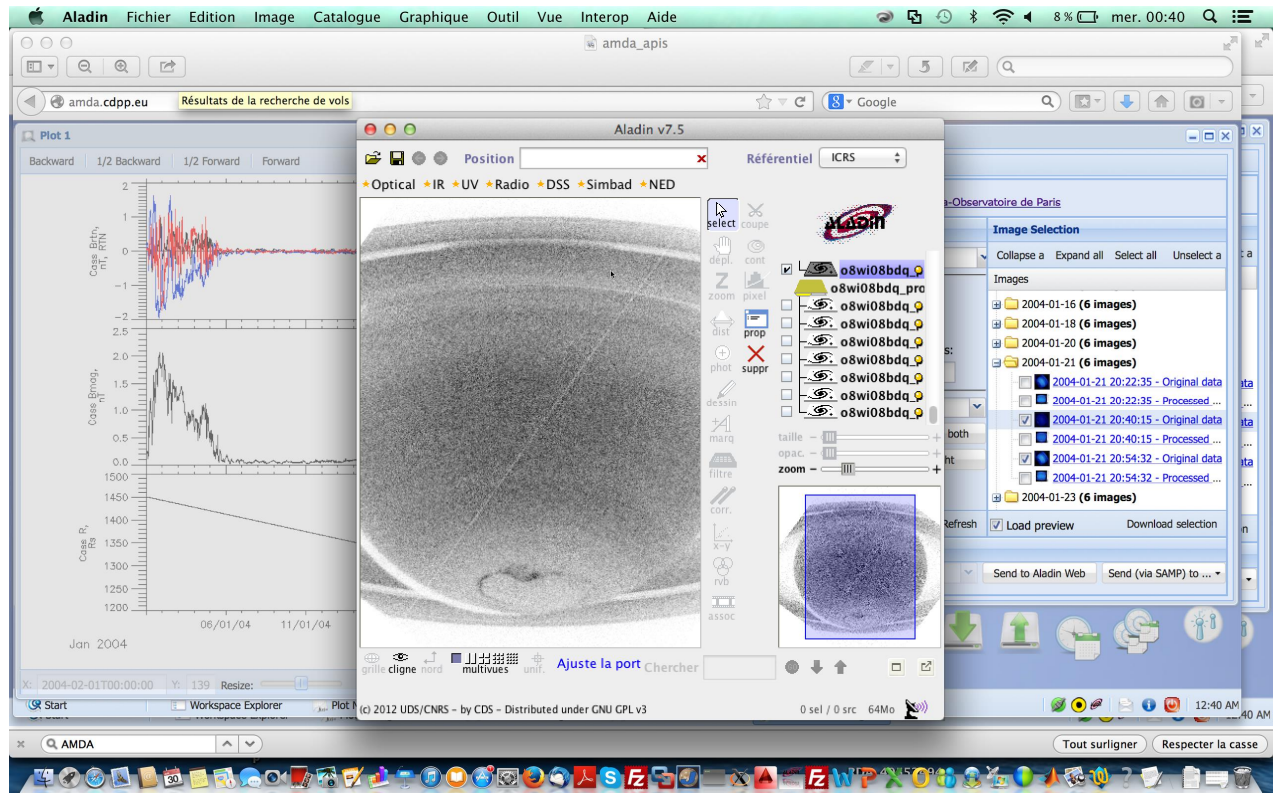


Figure 11: on the AMDA desktop the user has displayed a selected HST observations from the APIS database using a local instance of Aladin connected to AMDA via the SAMP protocol.

## CONCLUSION

This paper aimed at presenting current space physics applications which take benefit of the Simple Application Messaging Protocol initially developed by IVOA in the context of astronomy and astrophysics. By  $\delta$ joining the  $\odot$  hub  $\acute{o}$  these applications gain mutual advantages of their respective specialized functionalities: each development team can stay focused on its own domain of expertise knowing that it can relate on some other specialized tools (for particular plots, rendering, mathematical or physical operation pipelines,  $\acute{\imath}$  ). The French Plasma Physics Data Centre (CDPP) has been among the pioneering teams in this domain and a particular emphasis is placed on its tool suite. Other CDPP tools will soon integrate interoperability functionalities: the Propagation and the SpaceWeather Tools, devoted to the analysis of solar perturbations propagation in the interplanetary medium (imagery and analytical models are used in conjunction to in-situ measurements). They will naturally be connected to AMDA, the Helio and Helcats infrastructures (both European FP7 project) and the solar MEDOC database. In this paper a number of science cases exposing different facets of CDPP and companions tools have been presented which all illustrate the attractiveness of SAMP. Together with its facility of use in stand-alone or web-based applications, it constitutes a central building brick of the current Virtual Observatories.

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