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Virtual Planetary Space Weather Services offered by the Europlanet H2020 Research Infrastructure

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ABSTRACT

Under Horizon 2020, the Europlanet 2020 Research Infrastructure (EPN2020-RI) will include an entirely new Virtual Access Service, "Planetary Space Weather Services" (PSWS) that will extend the concepts of space weather and space situational awareness to other planets in our Solar System and in particular to spacecraft that voyage through it. PSWS will make twelve new services accessible to the research community, space agencies, and industrial partners planning for space missions. These services will in particular be dedicated to the following key planetary environments: Mars (in support of the NASA MAVEN and European Space Agency (ESA) Mars Express and ExoMars missions), comets (building on the outstanding success of the ESA Rosetta mission), and outer planets (in preparation for the ESA JUpiter ICy moon Explorer mission), and one of these services will aim at predicting and detecting planetary events like meteor showers and impacts in the Solar System. This will give the European planetary science community new methods, interfaces, functionalities and/or plugins dedicated to planetary space weather as well as to space situational awareness in the tools and models available within the partner institutes. A variety of tools (in the form of web applications, standalone software, or numerical models in various degrees of implementation) are available for tracing propagation of planetary and/or solar events through the Solar System and modelling the response of the planetary environment (surfaces, atmospheres, ionospheres, and magnetospheres) to those events. But these tools were not originally designed for planetary event prediction and space weather applications. PSWS will provide the additional research and tailoring required to apply them for these purposes. PSWS will be to review, test, improve and adapt methods and tools available within the partner institutes in order to make prototype planetary event and space weather services operational in Europe at the end of 2017. To achieve its objectives PSWS will use a few tools and standards developed for the Astronomy Virtual Observatory (VO). This paper gives an overview of the project together with a few illustrations of prototype services based on VO standards and protocols.

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1. Introduction

Planetary Space Weather Services (PSWS) aims at extending the concept of space weather to other planets in our Solar System and in particular to spacecraft that voyage through it. PSWS will give the European planetary scientists for the first time new methods, interfaces, functionalities and/or plug-ins dedicated to planetary space weather in the form of tools and models available in the partner institutes.

Space Weather – the monitoring and prediction of disturbances in our near-space environment and how they are controlled by the Sun - is now recognised as an important aspect of understanding our Earth and protecting vital assets such as orbiting satellites and power grids. The Europlanet 2020 Research Infrastructure (http://www.europlanet-2020-ri.eu/) aims to transform the science of space weather, by extending its scope throughout the Solar System. An entirely new Virtual Access Service, "Planetary Space Weather Services" (PSWS, http://planetaryspaceweather-europlanet.irap.omp.eu/) has therefore been included in the Europlanet H2020 Research Infrastructure funded by the European Union Framework Programme for Research and Innovation.

Planetary Space Weather can be seen as the physical and phenomenological state of natural space environments; the associated discipline aims, through observation, monitoring, analysis and modelling, at understanding and predicting the state of the Sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them; and also at forecasting and now-casting the possible impacts on biological and technological systems' (Lilensten and Belehaki, 2011). Planetary Space Weather therefore refers to the study of the variability of planetary (or satellite) environments (e.g. atmospheres, exospheres, intrinsic magnetospheres) determined by the variability of the solar activity or/and the interplanetary space dynamics (Plainaki et al., 2016). A detailed discussion on why we need to take account for planetary space weather as well as a few illustrations on some planetary space weather impacts on space environments, spacecraft and technology can be found in Lilensten et al. (2014).

A variety of tools (in the form of web applications, standalone software, or numerical models in various degrees of implementation) are available for tracing propagation of 1) planetary or 2) Solar events through the Solar System and modelling the response of the planetary environment (surfaces, atmospheres, ionospheres, and magnetospheres) to those events. As these tools were usually not designed for 1) planetary event prediction and 2) space weather applications, additional research and tailoring is required to apply them for these purposes. The overall objectives of PSWS will be to review, test, improve and adapt methods and tools available within the partner institutes in order to make prototype 1) planetary event and 2) space weather services operational in Europe at the end of the programme. In particular the aims are:

- To define a service for 1) planetary event and 2) planetary space weather predictions. Such a service is motivated by various needs including (a) the need to protect planetary probes from dust events (e.g., when a C/2013 A1 (Siding Spring) passed nearby Mars in 2014, see Tricarco, 2015) or solar/solar wind disturbances during cruise or at destination; (b) the need to gain new insights on other planetary environments in relation to the evolution of the Solar System in general (e.g., The Mars Atmosphere and Volatile Evolution (MAVEN) Mission that is dedicated to the study of the importance of loss to space in changing the Mars climate and atmosphere through time, see Jakovsky et al., 2015); (c) the need for providing multi-scale context to the analysis of data or to the preparation of special observational campaigns for a given planetary mission (e.g., scheduling Hubble Space Telescope observations of Uranus' aurorae through solar wind tracking, see Lamy et al., 2012);
- To develop new methods, interfaces, functionalities and/or plug-ins dedicated to planetary space weather in the tools and models already available within the partner institutes;
- To define planetary proxies and reliability factors for planetary space weather applications;
- To validate, compare and enhance the capability of the existing models and tools in order to predict the impact of solar events in the vicinity of Solar System objects;
- To identify user requirements, develop the way to implement event alerts, and chain those to the 1) planetary event and 2) planetary space weather predictions;
- To facilitate discovery or prediction announcements within the PSWS user community in order to watch or warn against specific 1) planetary and 2) planetary space weather events;
- To set up dedicated amateur and/or professional observation campaigns, diffuse contextual information for science data analysis, and enable safety operations of planet-orbiting spacecraft against the risks of impacts from 1) meteors and 2) solar wind disturbances.

The Planetary Space Weather Services will provide 12 services distributed over 4 different service domains – Prediction, Detection, Modelling, Alerts - having each its specific groups of end users. The PSWS portal (http://planetaryspaceweather-europlanet.irap.omp.eu/) gives access to an initial presentation of PSWS activities. Section 2 gives an overview of the foreseen services. Each service will be implemented through a combination of data products, software tools, technical reports, and tutorials. Section 3 describes how the services will comply with Virtual Observatory (VO) methods and standards. Section 4 illustrates some of the VO-compliant functionalities already implemented in some services that are already operational. Section 5 summarizes the status of the project and lists a few perspectives for PSWS services in the VO context and beyond.

2. Overview of Planetary Space Weather Services

The Planetary Space Weather Services will provide 12 services distributed over 4 different service domains – Prediction, Detection, Modelling, Alerts. These services are summarized in the Table below and detailed in this section.(Table 1).

2.1. Prediction

2.1.1. 1D MHD solar wind Prediction Tool

The *Centre de Données de Physique des Plasmas* (CDPP) within the *Institut de Recherche en Astrophysique et Planétologie* (IRAP/CNRS) will provide real time and archive access to solar activity proxies (e.g. the solar decimetric radio flux, F10.7), galactic cosmic ray fluxes, propagated solar wind parameters (density, velocity, temperature, dynamic pressure, angle of the Parker spiral, tangential magnetic field component) at various planetary bodies (Mercury, Venus, Mars, Jupiter, Saturn,…) and spacecraft (Rosetta, Juno, Maven,…) using a 1D magnetohydrodynamic (MHD) code available through the CDPP/AMDA tool (http://amda.cdpp.eu) initially developed by Chihiro Tao (Tao et al., 2005).

2.1.2. Extensions of the CDPP Propagation Tool

The *GFI Informatique* (GFI) will extend the Propagation Tool (Rouillard et al., this issue) available at CDPP (http://propagationtool.cdpp.eu) to the case of comets, giant planet auroral emissions, and catalogues of solar wind disturbances. The Propagation Tool includes as targets all eight planets of the Solar System as well as various spacecraft (Rosetta, Cassini, Mars Express, Venus Express, STEREO A and B, WIND, ACE, MESSENGER, SOHO, Juno, plus Voyager 1 and 2, and New Horizons to be added in the near future). The service will provide new plug-ins including selection of comets as targets, visualization of their trajectories, projection onto solar maps, projection onto J-maps (maps of solar wind outflows obtained from the Helio-