EXECUTIVE SUMMARY REPORT

Technical Note

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Table of contents:

1 INTRODUCTION

1.1 Purpose

In this document we provide the executive summary of the activity performed during the CosmoWeather project.

1.2 Document Overview

Section 1- Introduction (this section) provides the purpose, and this document's overview.
Section 2- **Error! Reference source not found.** provides a list of acronyms and terms used throughout this document.
Section 3 - Executive Summary is the actual Executive Summary.

2 TERMS, DEFINITIONS AND ABBREVIATED TERMS

2.1 Acronyms

Acronyms	Description
AR	Augmented Reality
CME	Coronal Mass Ejection
ESA	European Space Agency
EUHFORIA	European Heliospheric Forecasting Information Asset
GONG	Global Oscillation Network Group
HEEQ	Heliocentric Earth Equatorial
MHD	Magneto Hydro Dynamics
PFFS	Potential Field Source Surface
VR	Virtual Reality
VTK	Visualization ToolKit

3 EXECUTIVE SUMMARY

Despite the advances of methods based on Machine Learning techniques, human interpretation of the simulation results and data products still provides the best forecasts, and thus, data visualization is crucial for understanding the outputs of space weather models and to effectively mitigate the associated risks. This does not only include an effective and clear visualization of the simulation results, that needs to guarantee decent frame-rates independently from the size of the data to be visualized, but provides also novel strategies for interacting with the data, i.e., by manipulating it, through thresholding, highlighting region-of-interest or critical areas of a simulation (as identified in the modeling/analysis pipeline). Also, explorative strategies in visualization are expected since there is still the need to define platforms/ways for the live communication and share of findings between researchers.

Though recent advances in the performance of both VR and AR hardware, that can now produce very realistic experiences, prove that these technologies become finally powerful enough and (realistically) cheap to be made available to a larger public. Powerful and sophisticated AR and VR goggles are available on both high-end hardware as well as on low fidelity devices, like a smartphone. These state-of-the-art AR and VR headsets are already used productively in several professional areas like in surgery, design and training where they can provide a new level of immersion and understanding of complex 3-dimensional datasets/models and environments.

Therefore, in the CosmoWeather project we have tackled several challenges:

- Provide a prototype of a visualization tool for the immersive visualization of such phenomena to domain experts, supporting high-end HMDs for immersive interaction with the data (referred in the following as EXP Prototype).
- Create awareness in the general public by providing a prototype for an immersive guided visualization on space weather phenomena as an educational experience (referred in the following as EDU Prototype).

This results in the creation of two distinct immersive visualization prototypes.

Also, since in the project we plan to visualize the Coronal Mass Ejection (CME) evolution from solar corona through the heliosphere, there is the need to deal also with large scale data provided by the major space agencies through two main models, EUHFORIA and ENLIL, supported by ESA and NOAA/NASA, respectively. Both models are based on the ideal magnetohydrodynamic (MHD) plasma description and uses an explicit TVD (Total Variation Diminishing) Lax-Friedrichs scheme for the numerical solution of the MHD equations. The output then are the values of magnetic field components and quantities characterizing the plasma as one fluid with no distinction between electron quantities. These quantities are mass density, fluid speed, temperature, and pressure. The values for the plasma quantities are defined on a numerical grid that discretizes the space at different time steps. The ENLIL and EUFHORIA models are defined in spherical coordinates with the Sun in the origin. In practical terms, ENLIL and EUFHORIA use very similar numerical approaches, discretization, and initialization. They target the same simulation problem: heliospheric plasma transport and CME modelling. ENLIL had a longer development and it is a mature tool widely used by the space weather community. EUFHORIA is a more recent and very promising tool that aims at having the same ENLIL functionalities.

As the data generated by the two models is fairly different (even if the quantities/properties encoded are pretty similar), we plan to effectively pre-process the data generated by the two models such that it is cross-compatible between the two prototypes. This preliminary step is fundamental, and it will also enable the compatibility to other models in the future (if needed or if new forecasting strategies become available).

This pre-processing performs the following steps: (i) coordinates transformation, (ii) feature selection, and (iii) resolution selection. The coordinates transformation is a spherical to cartesian coordinates transformation that is performed since some frameworks are not compatible with the spherical one. This is indeed a time-consuming step, since a trigonometric function needed to be computed for all spherical components. The second step of the pre-processing pipeline is the selection of a feature. Each Space Weather model outputs different quantities in the output files (e.g. the density, the fluid velocity, pressure, magnetic field, ...), and in general all time-steps are encoded in a single file. For example, in case of the EUHFORIA model, which encodes the full volume, this results in a very large file that is then hard to load and handle at run-time in the visualization prototype. The overall rationale for doing this is to have multiple files encoding only the quantities of interest and a single time-step to be loaded by the selected prototype, to overall reduce the I/O times. The last step is needed since different prototypes have different requirements and, in some case, cannot render the high-resolution data coming from EUHFORIA and ENLIL directly.

The EXP prototype had to support domain experts at analysing time-varying data in an intuitive way, and had to support diverse hardware, ranging from a classical desktop workstation to innovative immersive visualization through a Head Mounted Display (HMD). For this latter, the implementation plan has been defined in order to improve the interaction with such data, to ease the navigation through time and to provide an immersive navigation inside the volume. As base tool for this development CosmoScout VR has been used, a visualization tool developed by the German Aerospace Center. As depicted in Figure 3-1, CosmoScout VR has a plugin-based structure that eases the addition of new features. In this activity we focused on extending the current prototype of csp-volume-rendering, which is meant to render 3D volumetric data. The main goal of this plugin is the handling of an asynchronous volume visualization.

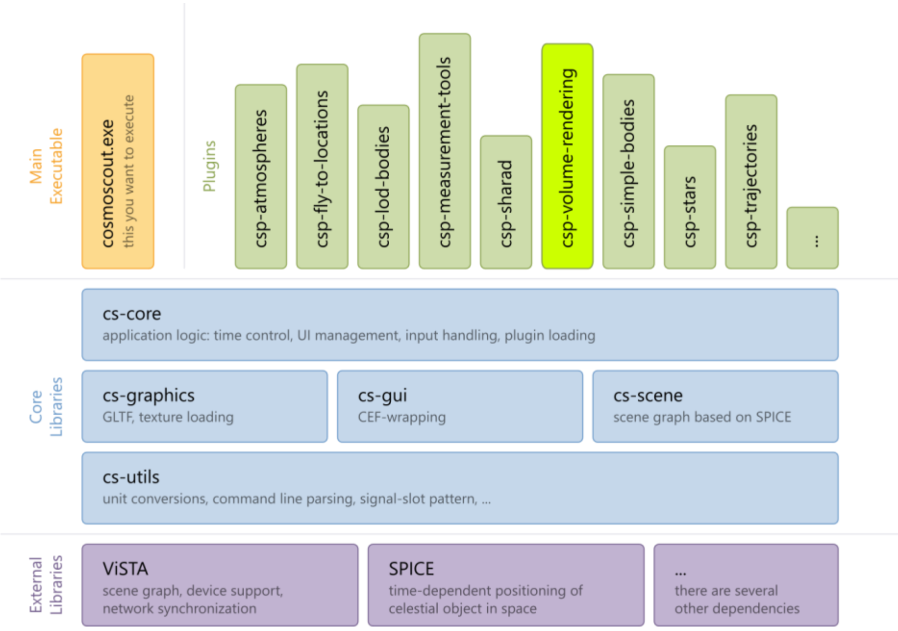

Figure 3-1 CosmoScout VR current core libraries and dependencies

During CosmoWeather project, the DLR team focused first on supporting Space Weather phenomena and then on enhancing the interaction a user can perform to analyse and extract features from such data. The volume-rendering plugin provides a full-fledged javascript-based GUI, currently providing a transfer-function editor, animation button for sequentially loading all time-steps of the simulation and several rendering and lighting options. Since the density of the data to be rendered is allegedly large, we enhanced the transfer function editor for adding a log-scaling option on the x-axis (see Figure 3-2). This enhances the understanding of scalar value ranges that are extremely dense.

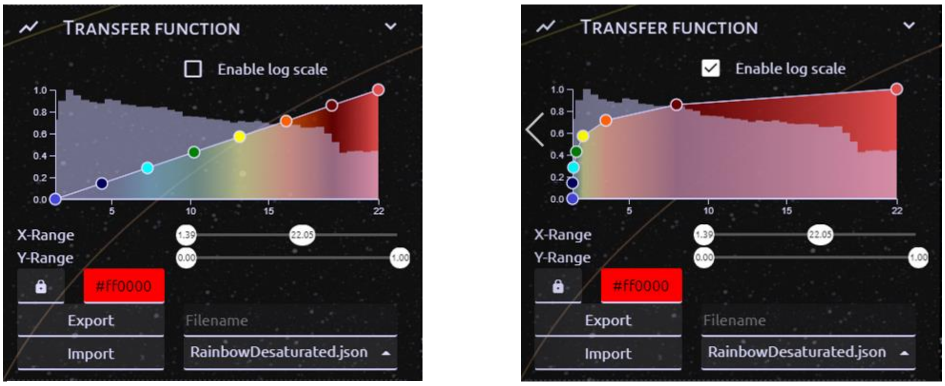

Figure 3-2 Transfer function editor with log-option disabled (left) and enabled (right)

One last feature to enhance the way the user interacts with the Space Weather data is by synchronizing the already implemented time bar in the main interface of CosmoScout VR (depicted in Figure 3-3) with the loading of subsequent time steps.

Figure 3-3: CosmoScout VR's user interface for time navigation

Since the timing information is already encoded in the file name, we developed a wrapper that by interpreting the date and time encoded as UNIX time-stamp, loads a corresponding file, when a certain instant in time is passed in CosmoScout VR. This means that a user can now go back and forth in time and immediately realize when a certain phenomenon in a simulation started/ended or reached its maximum peak. A shown in Figure 3-3 the time bar provides easy to use play, fast-forward and rewind buttons, that let the user easily manipulate the time also with the controllers provided with HMDs.

Lastly, in the EXP prototype we enhanced how the volume is rendered to completely support an immersive navigation in it. Previously, the csp-volume-rendering plugin supports the rendering of time-varying volumetric data as soon as the view-point is outside the volume. This means that when the zoom is too close to the volume, the volume was simply not rendered. We have enhanced the rendering of the interior of the volume, by supporting selective-view-dependent rendering (see Figure 3-4). Now an expert can explore the data from inside and also explore the structures selected with either the transfer function or the parallel coordinates (see Figure 3-5).

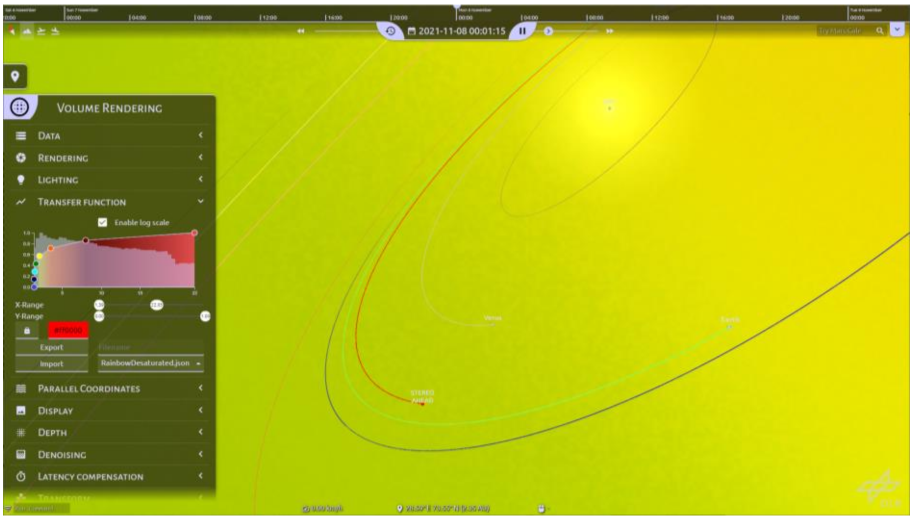

Figure 3-4 A user can dive in the Space Weather phenomenon to gain further knowledge

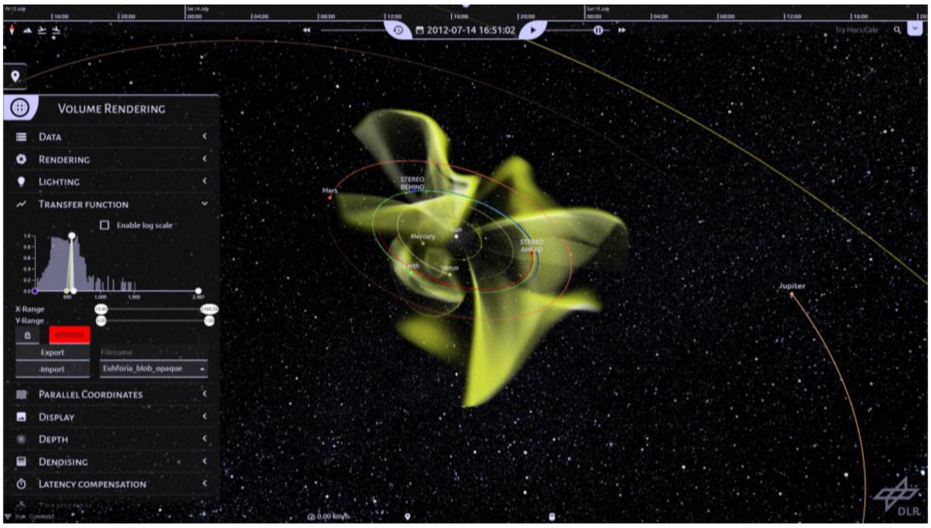

Figure 3-5 Example of Volumetric visualization of EUHFORIA Dataset highlighting Ballerina Effects

Conversely, the EDU prototype has the objective to create awareness in the general public and laymen, and it is meant to be used by ESA (or authorized partners) in fairs, workshops, etc. As a result of this activity we provide a prototype for a 7-10min experience, which can be developed further by including additional visual effects, as well as a 3-4min executive summary, focusing on the main message and visualizing a subset of possible effects. The experience provides information on space weather phenomena through visual effects as well as a narration (that is going to be defined with the approval of domain experts) and at the same time provide additional information as interactive displays, for the interested audience. This prototype is implemented using the widespread game engine Unity to develop a flexible framework and a customizable pipeline in which effects and narration for further phenomena can be added as needed. The general concept of the application consists of five scenes with their respective game objects, which are played in sequence, as illustrated in Figure 3-6. Each of these scenes depicts and narrates what is currently happening in a CME and which are the risks for the human technology in Space and on Earth.

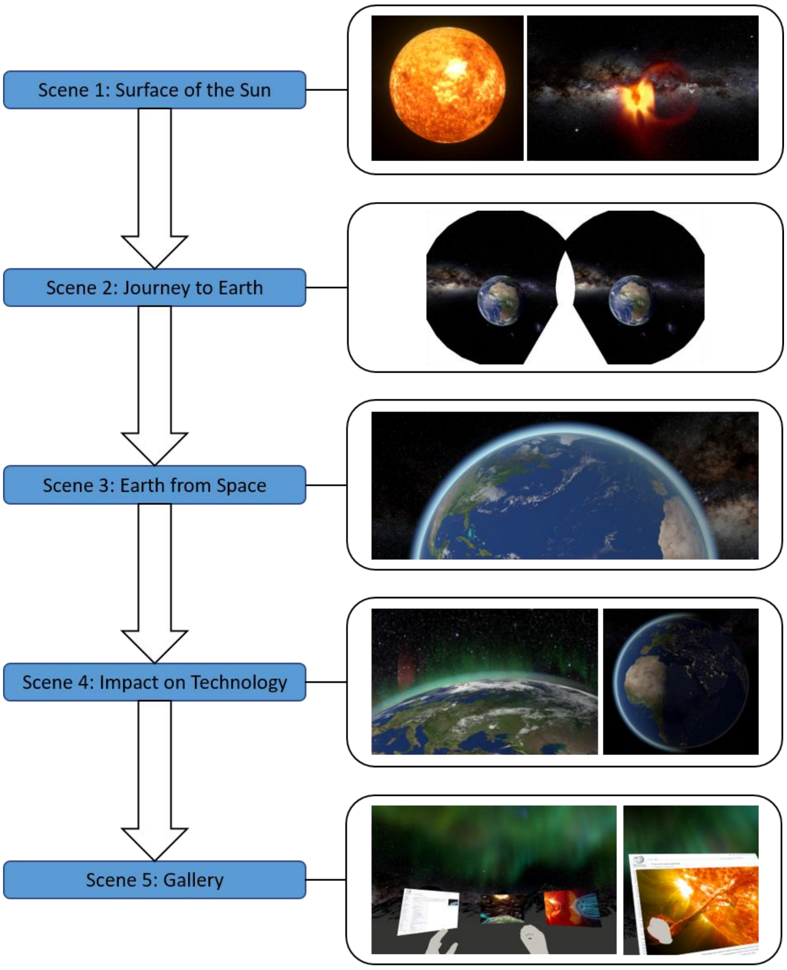

Figure 3-6 Core Scenes of the EDU Prototype