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Towards a Unified Systems Architecture: Combining Hierarchical and Behavioral Models for the Einstein Telescope Development

For the detection of gravitational waves with the Einstein Telescope very high requirements regarding sensitivity must be met. The telescope is designed to be able to detect changes in length twenty-six orders of magnitude below its own size. Due to the required sensitivity the number of disturbance factors, such as seismic noise, that must be overcome, is extensive. This leads to the necessity of highly sophisticated technical equipment, that is currently under development in research facilities all over Europe employing more than 1700 researchers. These research facilities build expert models describing individual aspects of the physical behavior of the telescope's subsystems in a bottom-up approach. To ensure parameter consistency, evaluate the impact of design choices across the entire ET development in the past efforts were made to create a top-down systems hierarchy, referred to as the Product Breakdown Structure (PBS) following a Systems Engineering (SE) approach. In this joint presentation with the Project Office it is demonstrated how the potential of this can be improved by advancing the SE approach to a Model-Based Systems Engineering (MBSE) approach, as it enables the use of the PBS to create data traceability across the development. To achieve that, MBSE uses a central systems architecture model utilizing two key concepts: Hierarchy, as in the PBS, and interaction via functional and physical interfaces between different subsystems on the same hierarchical level. The requirements that are posed on the overall system can be broken down and assigned to individual architecture elements that represent subsystems. The interactions enable the use of traceability mechanisms to analyze the influence of parameters across the entire systems. By enriching the individual subsystems with physical behavior models the parameter influence can be quantified which enables virtual requirement verification based on specific design parameters. The application of this approach is key to combine the Top-Down SE and Bottom-Up Development approach in ET and thereby create a requirement traceability from science case to design parameter, a means to analyze the impact of specific design choices on the entire system and a seamless parameter space that realizes a Single Point of Truth (SPOT). However, the application of this approach necessitates a process that allows the implementation of the MBSE approach accessible for the distributed researchers and the possibility to integrate all development results in one common data space. To tackle this, an expert toolchain is designed that relies on a cloud-based engineering platform functioning as a central hub. Different expert tools, for requirements management, system architecture development as well as CAD and behavior modeling can be connected to the hub from local machines. To demonstrate the effectiveness of the approach the Vacuum Beam Pipe was chosen as demonstrator subsystem and implemented in an expert toolchain, creating a first example of the MBSE application in ET development. Within that application, exemplarily we use the analysis of the impact of different pump layouts on the telescope sensitivity as well as the overall cost as a demonstration in the presentation. The approach allows an extension to other subsystems on different hierarchy levels and will in future be extended to the interferometer layout as well as an integrated tower, to demonstrate the effects of design choices on other subsystems.

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