

# The Galileo 3D Real-Time Constellation Display

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**Decreased costs for launching and manufacturing of Spacecraft over the last decade have given the possibility to deploy constellations of spacecraft for various applications, especially for Navigation of Earth Observation purposes. Both in simulation and operational facilities the need to visualize the current state of the constellation allows several actors to have a quick and effective grasp on the situation, increasing operators responsiveness. 3D real-time display of a spacecraft constellation is a challenging task, but thanks to the availability of suitable displays in the open source software space, it is possible to make such a display within a reasonable budget and timescale. This presentation goes through the customisation and integration activity required to make a 3D real-time constellation display with Celestia. The display has been integrated with the Galileo Constellation Simulator (CSIM), and a suitable protocol has been developed to transfer the data over TCP/IP to CELESTIA. In CELESTIA a set of Lua scripts are used to connect to, monitor and decode the data stream and the visualize it. The display is capable to showing the constellation in its context, with the Earth, the Moon and the Sun, allowing to zoom-in on any spacecraft, inspect its main current properties and also graphically represent its attitude and other characteristics (Solar Array Panel position, Thruster firings, etc.)**

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## 1. What is CSIM3DV ?

CSIM3DV is the name for the 3D visualisation of the Galileo constellation. In particular it includes:

- CELESTIA-based Visualisation of up to 40 Galileo spacecraft in orbit
- Detailed IOV and FOC 3D models (distinguishable)
- Deployable, rotatable Solar Array Wings
- 2D Status Display Overlay (movable, transparent) for selected spacecraft
- Colour coded On-board Software Mode and Thruster firing indicator frames with Status Overview label
- Split-screen and Zoom functionality (inherited CELESTIA functionality)
- Standalone or CSIM data driven
- Client/Server architecture
- CELESTIA client runs on Windows and Linux

## 2. Purpose

This display is not meant for operational usage, operators have all the information they need on their mission control system. Moreover it will initially be made available only with bindings to the Constellation Simulator. In this context it can be used to have a rough idea of the constellation status, especially by persons not into the operations details.

## 3. Galileo Constellation Visualisation

CSIM3DV is connected to the Galileo constellation simulator CSIM via TCP/IP. The number of satellites displayed corresponds to the number of satellites simulated in the CSIM simulator, so from 1 to the full blown constellation, depending on the simulation scenario loaded.

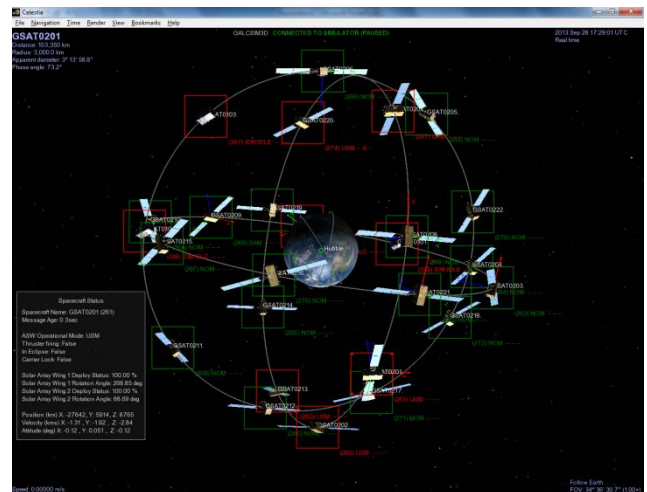


Figure 1 CSIM3DV Display

The display does not use a real scale representation. This would make the display unusable. For visibility reasons the spacecraft are rendered bigger than they are in proportion to the Earth. Along with the spacecraft, the orbit and some data fields are also displayed.

Each spacecraft has a data field, filled in with information from the TM data streams for the relevant spacecraft, with state, attitude information, position information, and so on.

It is quite difficult on the constellation display to read this information, but it become readable when zooming in on a single spacecraft, or when using a split screen, like shown in figure below

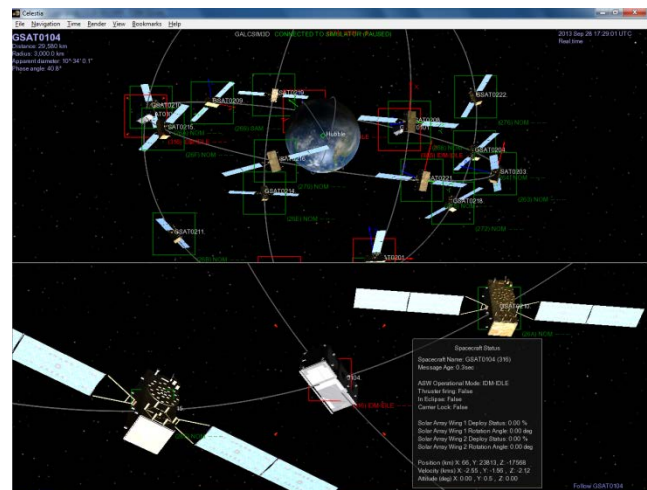


Figure 2 CSIM3DV Split Screen

Data fields can be switched off when additional information is not required or a more streamlined representation of the constellation is desired.

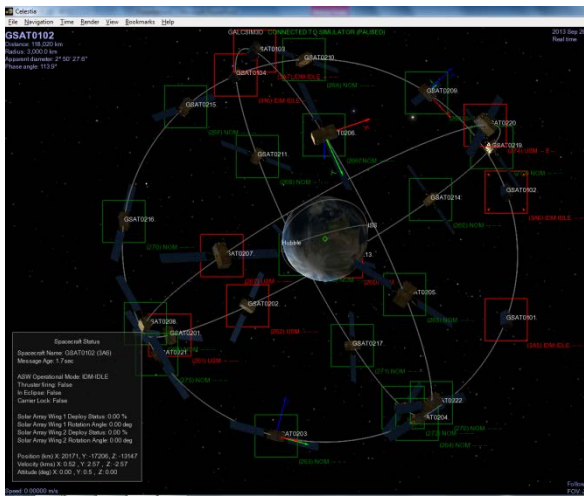


Figure 3 CSIM3DV Information Displays

#### 4. Architectural Overview

The architecture of CSIM3DV is kept as simple as possible. The CSIM3DV data server polls the S/C and scheduler status data periodically reading the TM status via the master scheduler. The master scheduler itself is not aware of the presence of the data server. In this way the solution does not require a modification of CSIM and only 2 scripts need to be installed.

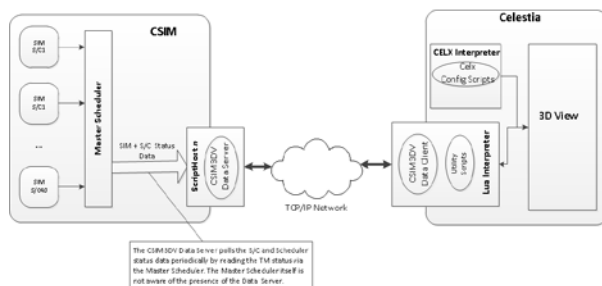


Figure 1 CSIM3DV High Level Architecture

The data is then transferred via TCP/IP to the CSIM3DV data client, which provides the data to the CELESTIA application.

#### 5. CELESTIA

CELESTIA is an open source software which provides the following features:

- Open source 3D Space Simulation and Astronomy software (current version 1.6.1)
- GPL License
- Available for Windows, Linux, Mac OS X, multi-language support
- Uses OpenGL for 3D rendering, multi-level-of-detail texture support
- Limitation: No perturbations, Earth modelled as a perfect sphere
- Many add-ons available, easy add-on installation (3D models, scripts) CSIM3DV is among the most complex add-ons
- Supports Cel/Celx and Lua scripts (built in interpreters) for extensibility
  - Cel : Only simple instructions (configuration commands), no complex programming concepts (no loops or control structures)
  - Celx: Lua programming language + CELESTIA-specific API Control structures, functions, loops, interactivity Since CELESTIA v1.3.1
  - Includes Luagl API for access to 3D rendering from Lua scripts
- Already used as standard visualisation tool by ESA and NASA

#### 6. CELESTIA Customisation

For our purposes we could identify two possibilities for CELESTIA customisation:

- Modify CELESTIA Source Code (Open Source, GPL license)
  - Source code available for Windows and Linux and Mac OS X
- Celx/Lua script add-ons via CELESTIA Lua-hooks
  - Hooks are executed by CELESTIA once per rendering frame (thus frame rate important)
  - User writes Lua scripts and registers entry point functions as Lua-Hook in CELESTIA.cfg file
  - ScriptedOrbit and ScriptedRotation hooks are pre-defined by CELESTIA and dictates call structure
  - Advantage: Lua script is platform independent => portable

- Third-party Lua libraries can be imported in Lua scripts (i.e. Lua-Socket)

## 7. Frontend

CSIM3DV can be divided into two elements, the frontend and the backend. The frontend element is the part which is running on the user side. It is composed of:

- CELESTIA (v. 1.6.1)
- Celx scripts for CELESTIA start-up configuration
- SSC (Solar System Catalogue) files for spacecraft model and orbit definition
- Lua scripts (Lua v.5.1)
  - Add-on configuration settings
  - TCP/IP network communication with Data Server
  - Simulator data processing (decoding, transformation)
  - Spacecraft position, attitude, SA Wing deployment, SA Wing rotation calculation, orbit calculation
  - 2D Overlay Spacecraft Status Display,
  - Spacecraft Status Indicator Frames with Status Overview Labels

## 8. Backend

The backend of CSIM3DV is the CSIM simulator running either distributed on several servers or on a multi-core server.

- SIMSAT running 26 Spacecraft Simulation (CSIM)
  - 32 core SLES9 server
  - 1 Master Scheduler
  - 26 Site daemons
- Data Server (JavaScript)
  - Running on separate SIMSAT ScriptHost in CSIM Master Scheduler
  - Interfaces via CORBA with Simulation Models published in SimTree
  - Polls periodically status information from models and sends encoded spacecraft status data messages to frontend via TCP/IP network connection
  - Automatically detects available spacecraft in simulation and only queries those.

- Does not interfere with actual constellation simulation.

## 9. Challenges

- Poor CELESTIA documentation, especially beyond basic scripting, very few websites with useful information and tips, important forums not reachable
- LuaJ script support (for 2D Overlay displays) not documented, needed to analyse very complex Add-on (Lua-Edu-Tools) to find out
- Bugs in CELESTIA (rotation quaternions swapped, function parameters swapped, 3D models rotated 90 deg. around X-axis during import)
- No error messages in case of coding errors. Debugging by observing “abnormal behaviour” and inserting print statements, very slow process (trial and error)
- Use of debugger blocks scripts and causes CELESTIA to terminate scripts (scripts must return or call wait() within 5sec, hooks must terminate within 1 sec)
- Differences/Incompatibility between Lua script/ CELESTIA versions (Lua script versions affect use of Environments and Global Tables)
- Coordinate Systems / Reference Frames used by CELESTIA not clear (trial and error)
- Relation of CSIM attitude data and reference systems vs. the ones used by CELESTIA not clear (trial and error)
- No dynamic orbit lines drawing capability (trial and error)
- Complex spacecraft definition structure in SSC files due to complex moving parts and the fact that only one label and marker (frame) per component can be displayed => Artificial models for ASW Mode Indicator Frame, Thruster Activity Indication Frame and Status Overview Label required (trial and error). Their positioning is fixed relative to each other and not controllable.
- Communication between Data Client, Attitude/Rotation scripts and 2D Status Display possible only via Global Tables (components exist in separate environments). Requires system access rights which is not enabled in CELESTIA by default and is not documented (trial and error)

## 10. Summary

CSIM3DV is the 3D visualisation of the Galileo constellation. It is based on the open source tool CELESTIA.

With CELESTIA as a COTS and the CSIM available, the production of the CSIM3DV could be limited to the development of 3D models for the satellites, the interfaces to the simulator and some LUA scripts. It sounds like a straight forward activity, but as many things in life there are details and roadblocks that made it harder that it should have been. For starters CELESTIA has a number of important bugs, functional limitations, with primitive debugging capabilities and poor overall documentation.

However, once all issues were discovered, solved or workarounds implemented, CELESTIA started working as required.

The biggest challenge in the context of this work was not the set up and configuration of CELESTIA. The biggest challenge was to build simulation scenarios for validating the display, with up to 40 spacecraft in the simulator, with right orbits and positions, and then verifying that the right data stream was feeding the right spacecraft, and so on.

The performance is also an issue. CSIM3DV displays up to 40 spacecraft, including rotating solar arrays (80), animated thrusters (320) and the data displays.

The use of CELESTIA, that comes with no licence fee, allowed us to provide the Galileo Project with a cost effective tool to display the constellation state during simulations. A 3D constellation display on a shoestring, that does not pale in comparison of more expensive implementations.