NASA's GMAT: a software tool-kit for general space-mission design and space-craft trajectory analysis

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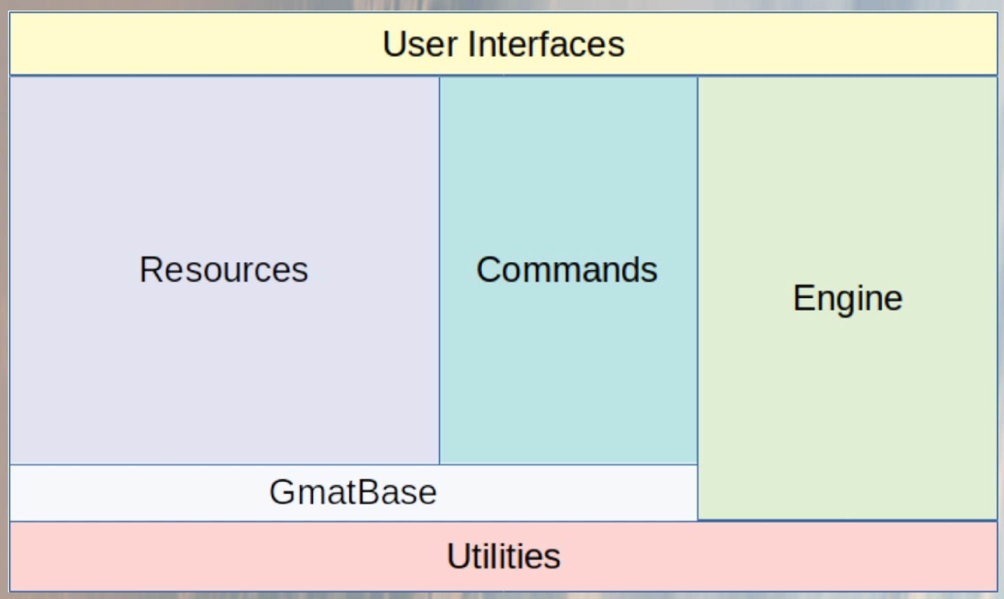
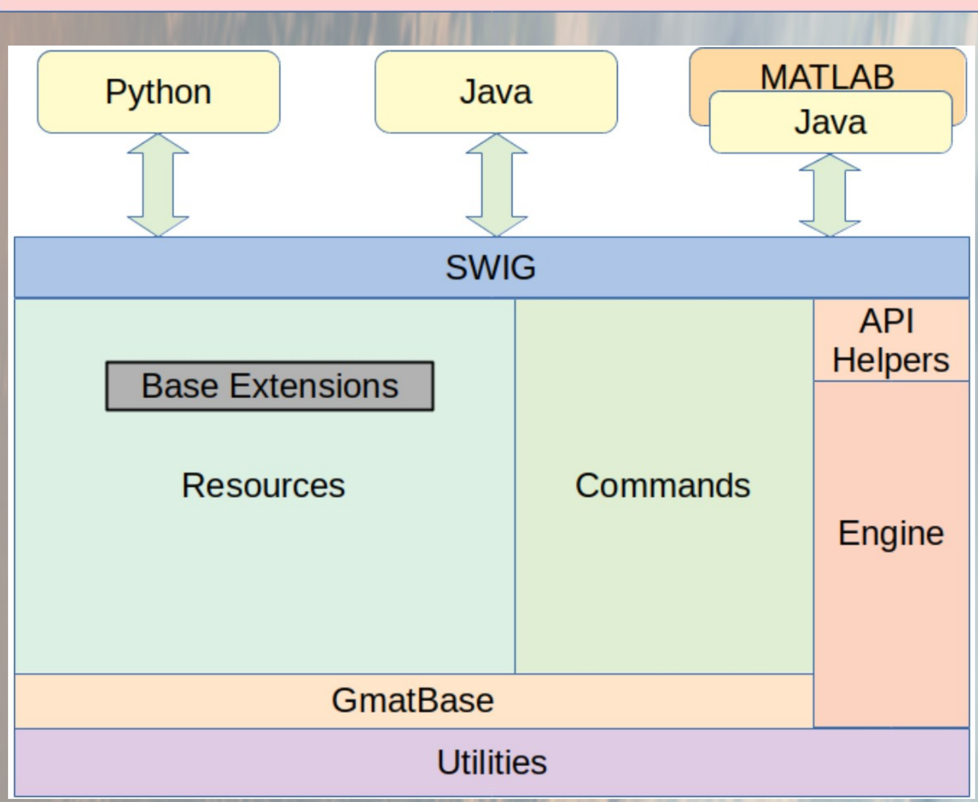
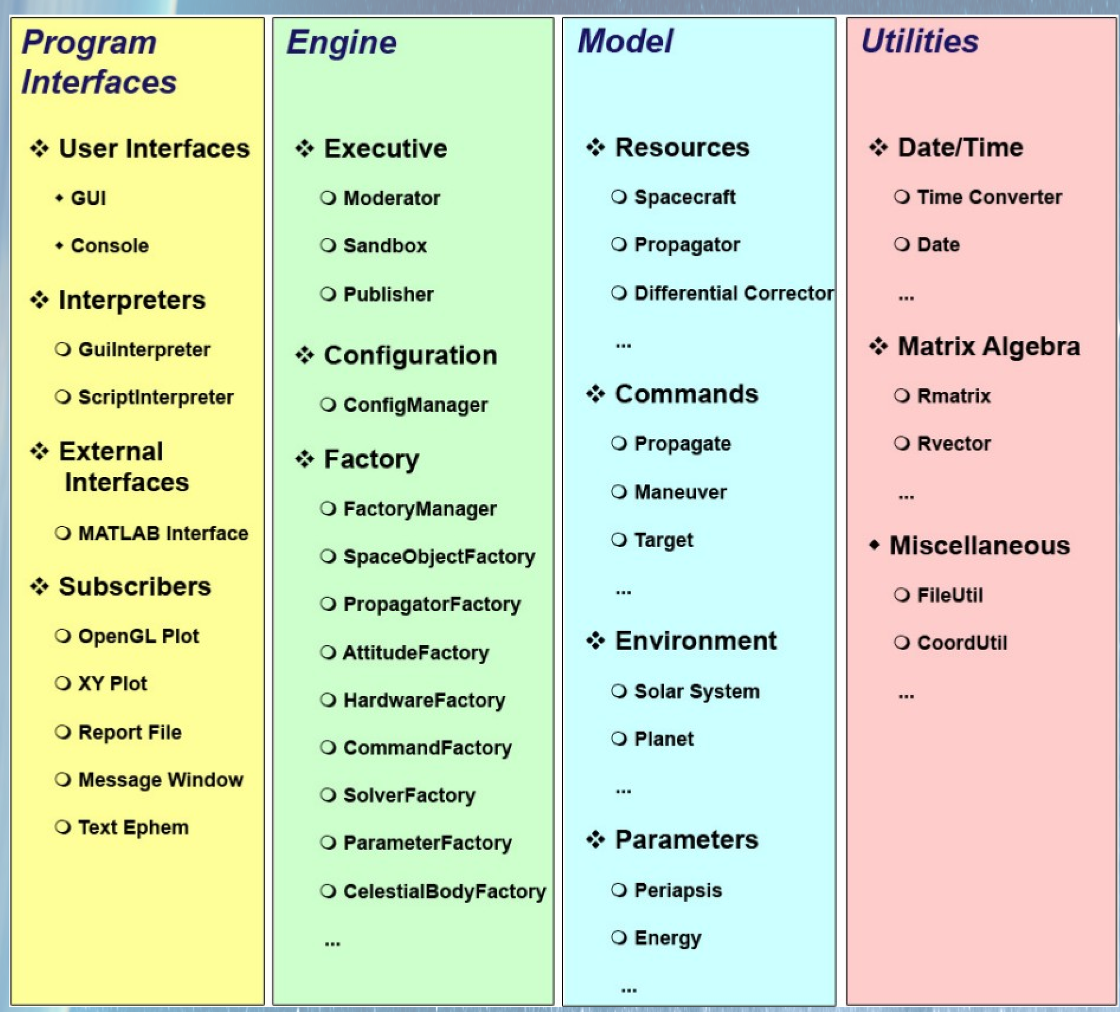
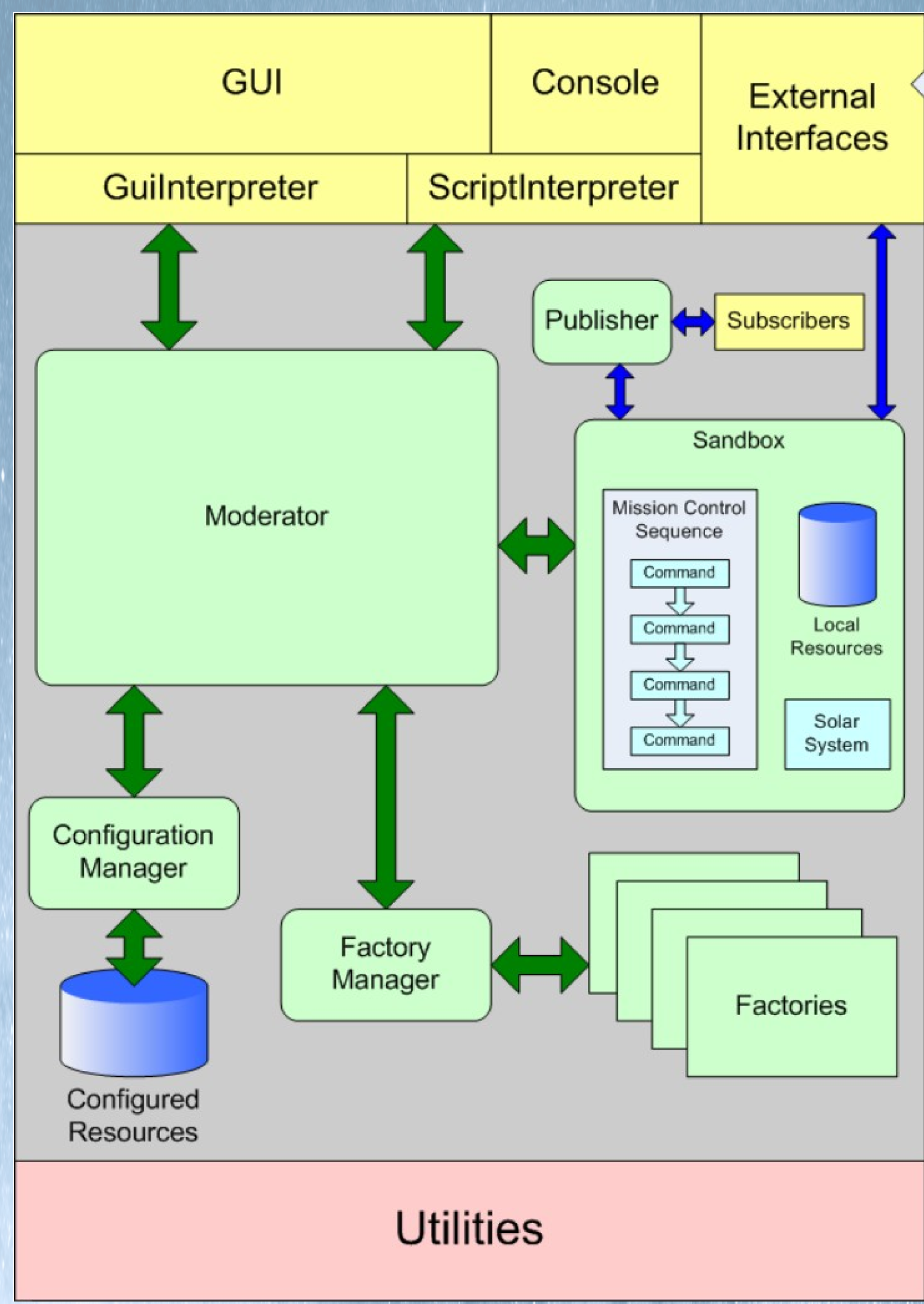
Abstract: We introduce and raise awareness of NASA's GMAT (General Mission-design and Analysis Tool) software system tool for spacecraft trajectory optimization and mission design, navigation and orbit analysis. GMAT is developed by NASA Goddard Space Flight Center (GSFC) in collaboration with private industry, public developers and various national space agencies. The tool has applications in all orbital regimes (mission to libration points, LEOs, landing scenarios, gravity-assist fly-by's). GMAT is fully tested and certified for operational use and was chosen as the primary operational tool for NASA's ACE (Advanced Composition Explorer) mission for maneuver planning, orbit determination. Various spacecraft models (various thruster models, impulse burn, etc), numerical propagators (Prince-Dormand, Adams-Bashford) and force models (atmospheric drag, solar pressure, etc.) are implemented. GMAT was selected as the primary mission design tool for NASA's TESS space telescope mission and was used for mission design for the James Webb Space Telescope. At SDU/SDU-Galaxy we have embarked on weekly workshop-like meetings to gradually gain experience with this tool aiming to apply gained knowledge to the Århus University-led "STEP-A" space telescope mission (2025/2026) and optimal geolocation-planning of ground stations (based on predicted TLE's) for effective Earth-spacecraft communication and data telemetry. This tool can also be used for science communication, STEM outreach activities raising awareness of space science, spacecraft control and astrodynamics.

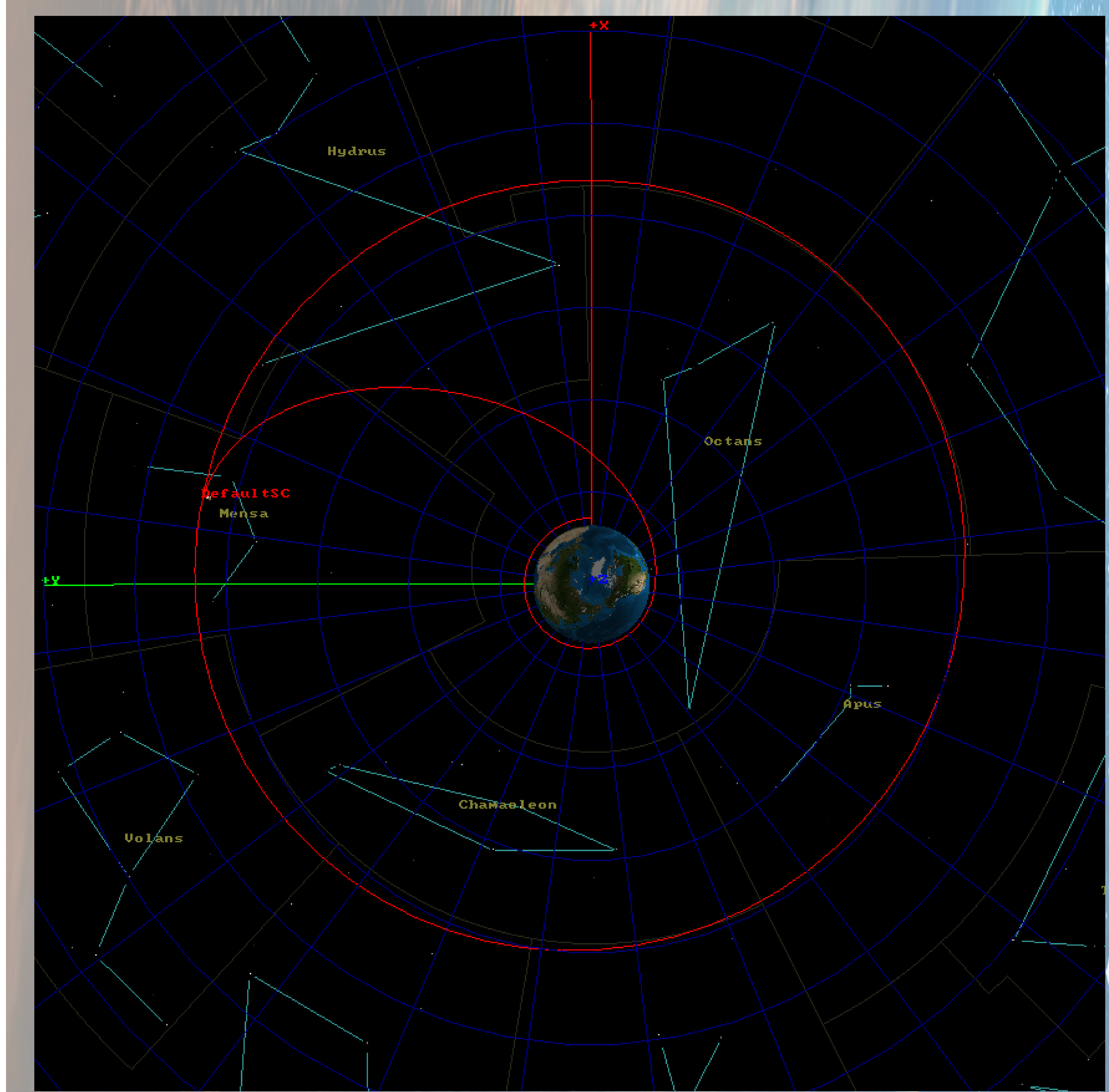


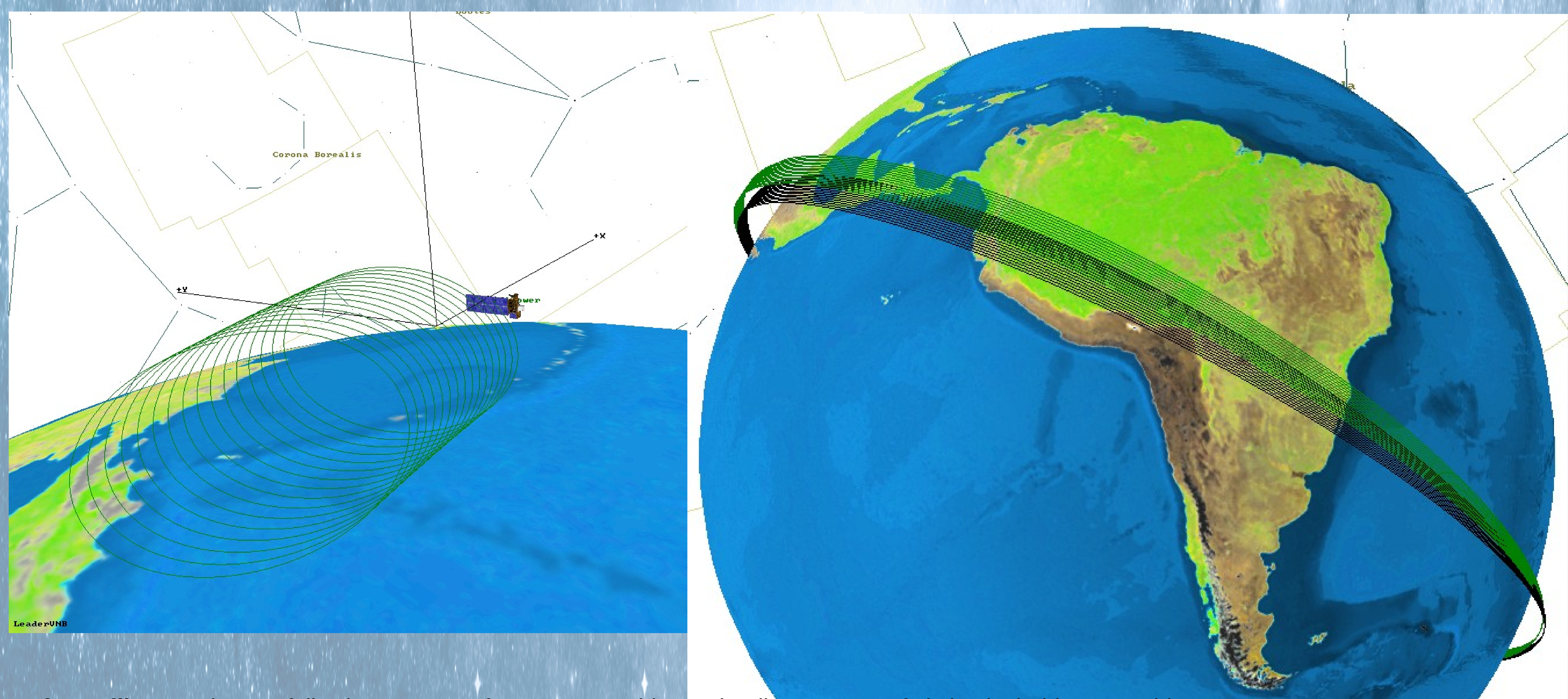






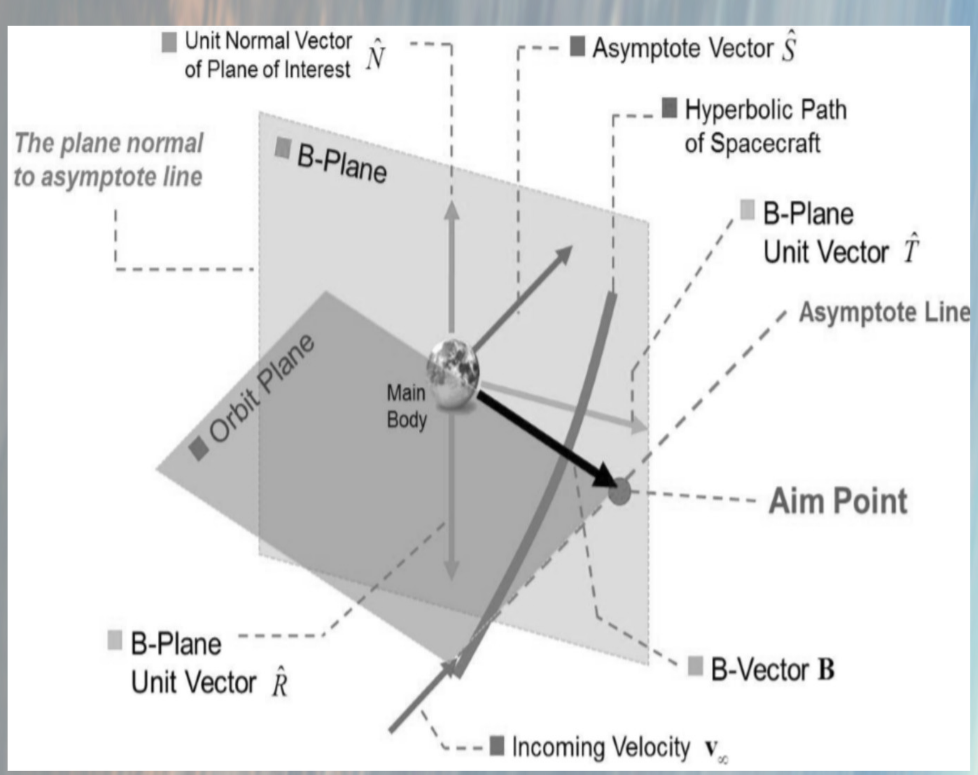
High-level key architecture components of GMAT and their interaction to solve a satellite / space-craft mission design problem. GMAT is highly complex. Each set of components are grouped into functional packages that interact with each other in the process of message passing, information exchange and data flow. The Program Interface component is the top-level interface between user input and the GMAT engine. The interaction with GMAT can either be via a GUI or at scripting level. At engine level we have the core simulation engine controlling the model of the flight dynamics problem in GMAT. Model elements are used to simulate a particular spacecraft mission. For example a model component could be an atmosphere model for Earth or Mars. We have worked out a number of worked tutorials which will be described below for their functionality and purpose.





Safety Ellipse: When a following spacecraft are approaching a leading spacecraft it is desirable to avoid collision. This is possible with a relative motion between the spacecrafts called "safety ellipse". This kind of orbits are providing a safe, passive collision avoidance. In a coordinate system with origo in the center of the earth, the orbits look like two bands. If one looks closely it can be seen that the one band is under the other in one side of the earth and vice versa on the other side of the earth. The relative movement of the trailing spacecraft with respect to the leading are shown with the coordinate frame centered at the leading spacecraft. In one orbit the trailing spacecraft is also moving in an ellipse around the leading spacecraft. The trailing spacecraft can then be moved closer to the leading spacecraft without risk of them to collide. It is even possible to come in the situation where the trailing spacecraft is moving around the leading spacecraft witch is fortunate in the case of inspection on a spacecraft. This last situation has been successfully conducted on the Hubble Space Telescope.

Hohmann Transfer: Going from one circular orbit to another in the same orbital plane is a common maneuver in space missions. This is used in many situations: raising LEO satellites that has degraded because of atmospheric drag, moving a satellite from LEO to GEO or even going to Mars. The Hohmann transfer is a sequence of maneuvers that can do exactly that. The transfer consists of two maneuvers: going to an elliptic orbit with apoapsis in the altitude of the desired orbit then circularize the orbit at the right altitude.



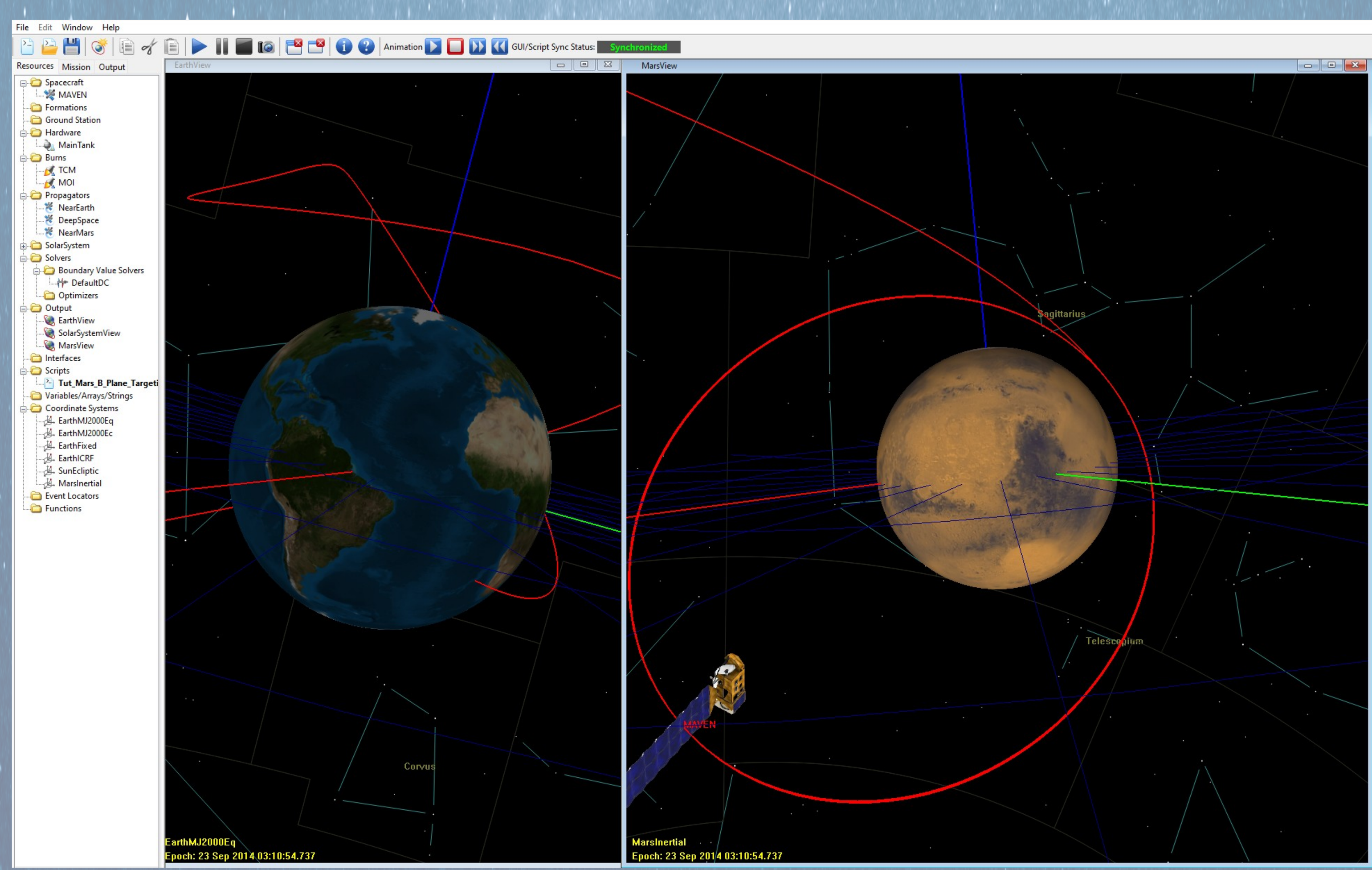
Mission to Mars & Mars B-plane: This tutorial focuses on designing a mission to Mars, demonstrating GMAT functions. It starts with an outgoing hyperbolic trajectory from Earth, then performs a Trajectory Correction Maneuver (TCM) to target Mars' B-Plane. Upon approaching Mars, the tutorial adjusts the maneuver to achieve Mars Orbit Insertion (MOI) and places the spacecraft in an elliptical orbit with a 90-degree inclination.

Two targeting sequences are created:

First Target Sequence: This uses maneuvers in Earth-based Velocity (V), Normal (N), and Bi-normal (B) directions, comprising four propagation sequences. The maneuvers target the BdotT and BdotR components of the **B**-vector, ensuring a polar orbit and avoiding intersection with Mars. This sequence is encapsulated in a GMAT function, with relevant objects declared global for data continuity.

Second Target Sequence: This involves a single Mars-based anti-velocity (-V) maneuver at periapsis to achieve MOI by targeting a specific vector magnitude of 12,000 km at apoapsis. Unlike the first, this sequence is not encapsulated in a function.

The tutorial aims to demonstrate the creation, population, and execution of GMAT functions within practical mission design, emphasizing the continuous flow of data and proper configuration of targeting sequences.



References:

- https://gmatcentral.org
- GMAT tutorial 1: https://youtu.be/0anA2qy7Yu8?si=YLNVRyUc7PC2cFDg
  GMAT tutorail 2: https://youtu.be/ThrjcyHGD6o?si=AKB6BILQN6sUkEcr
- GMAT tutorail 3: https://youtu.be/c8I31-7Y9L8?si=sgXeyBfIGp_I9H-u0
- Graef. J., 2000, "*B-PLANE TARGETING WITH THE SPACECRAFT TRAJECTORY OPTIMIZATION SUITE*", PhD thesis, California Polytechnic State University, USA.

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