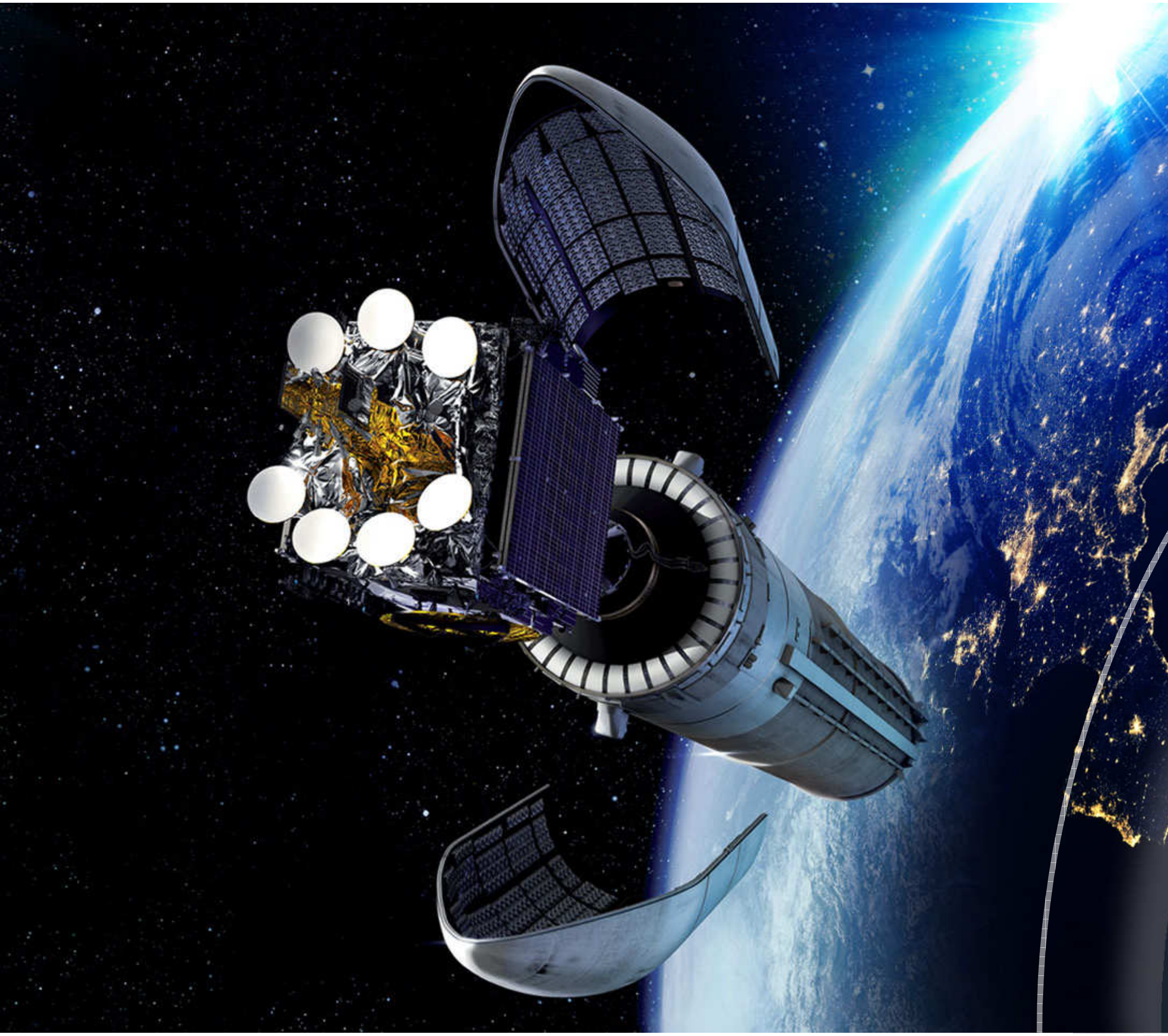

Orekit in NEOSAT FDS

Alexandre Janer & Pol Sola Romeu (TAS)

Maxime Journot (CS)

Orekit Day 2017

ThalesAlenia Space
a Thales / Leonardo company

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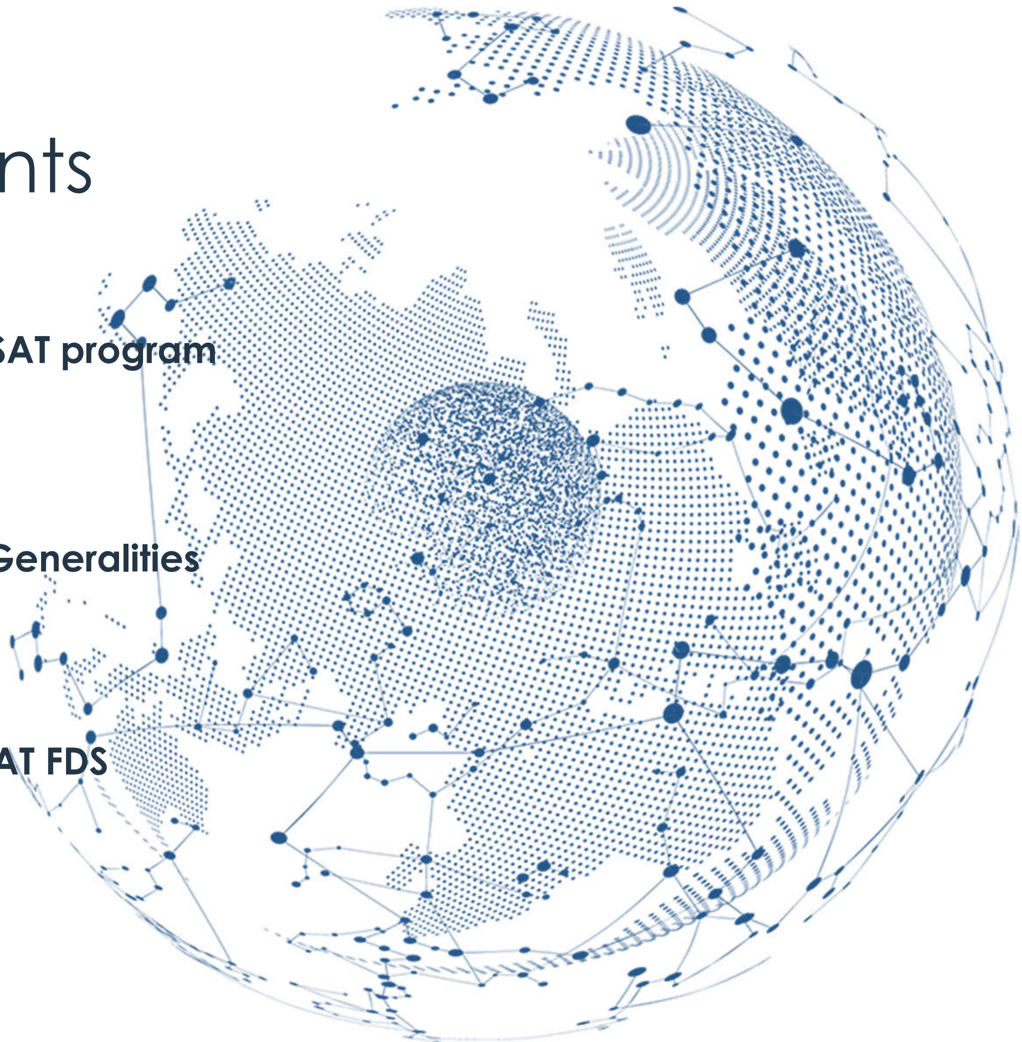


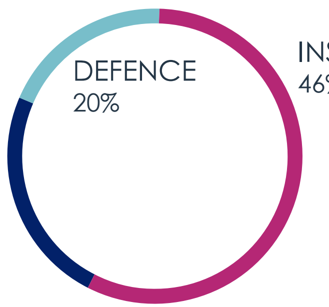
Thales Alenia Space

7,980
Employees

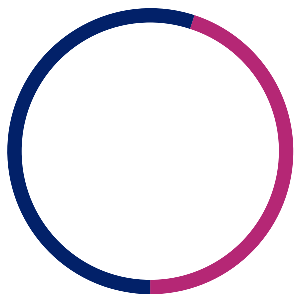
15
Sites in Europe

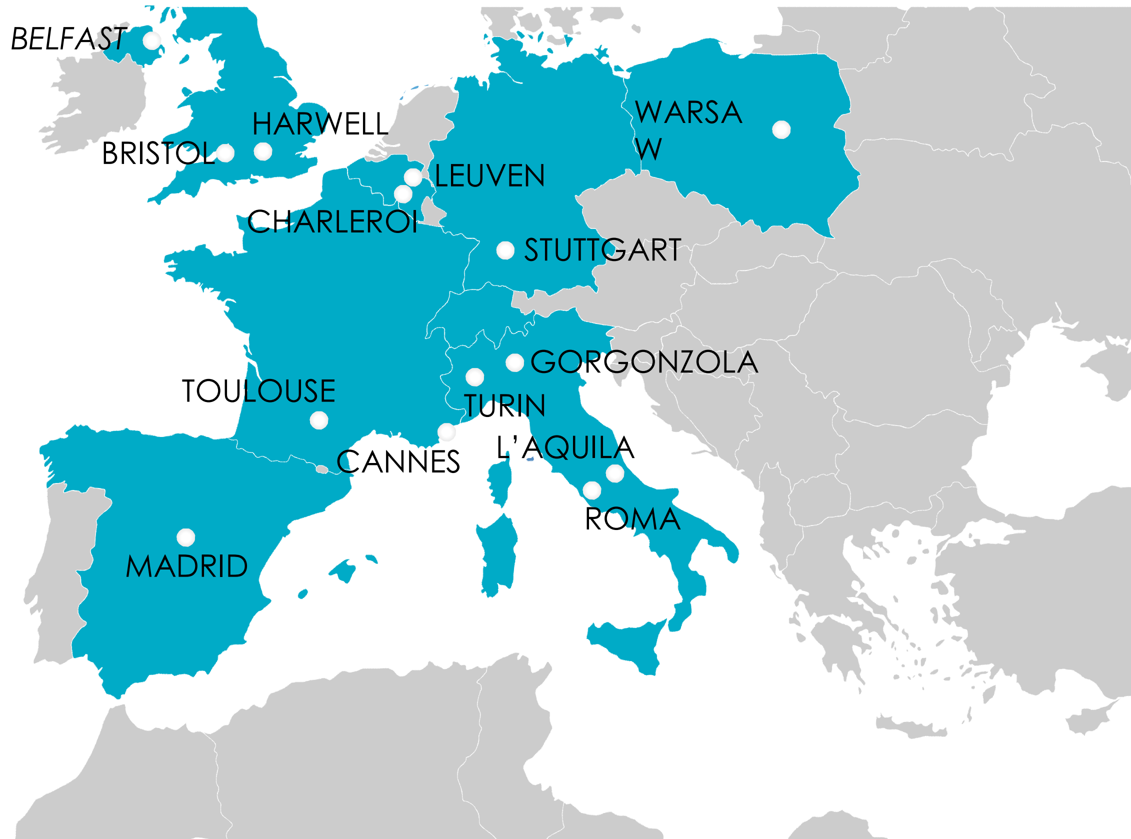
2,4 BN€
Sales

BREAKDOWN PER MARKET



BREAKDOWN PER ACTIVITY





A global offer from equipment to end-to-end space systems:

EQUIPMENT PAYLOADS SATELLITES SERVICES SYSTEMS

NEOSAT

SpaceBus Neo

NEOSAT is part of ESA's Advanced Research in Telecommunications Systems program

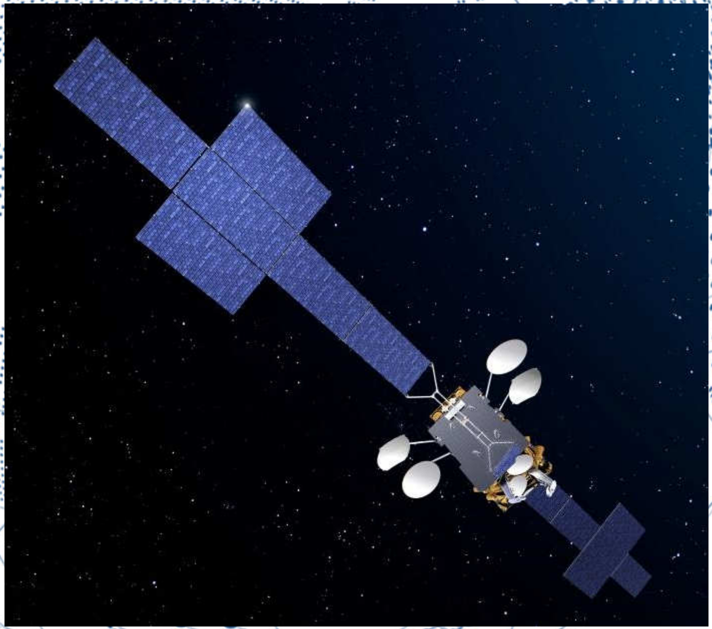
A contract with Thales Alenia Space was awarded on 15 September 2015 → **SpaceBus Neo** product line

Full electric telecommunications platform:

- Electric Orbit Raising
- Electric Station-Keeping

Payload capacity: up to 2000 kg, and in the range of 20kW

Mass at launch: from 3 to 6 tons



Orekit in TAS

In the frame of the NEOSAT program, TAS is developing a new FDS (Flight Dynamics Software) in collaboration with CS-SI and CS-Romania

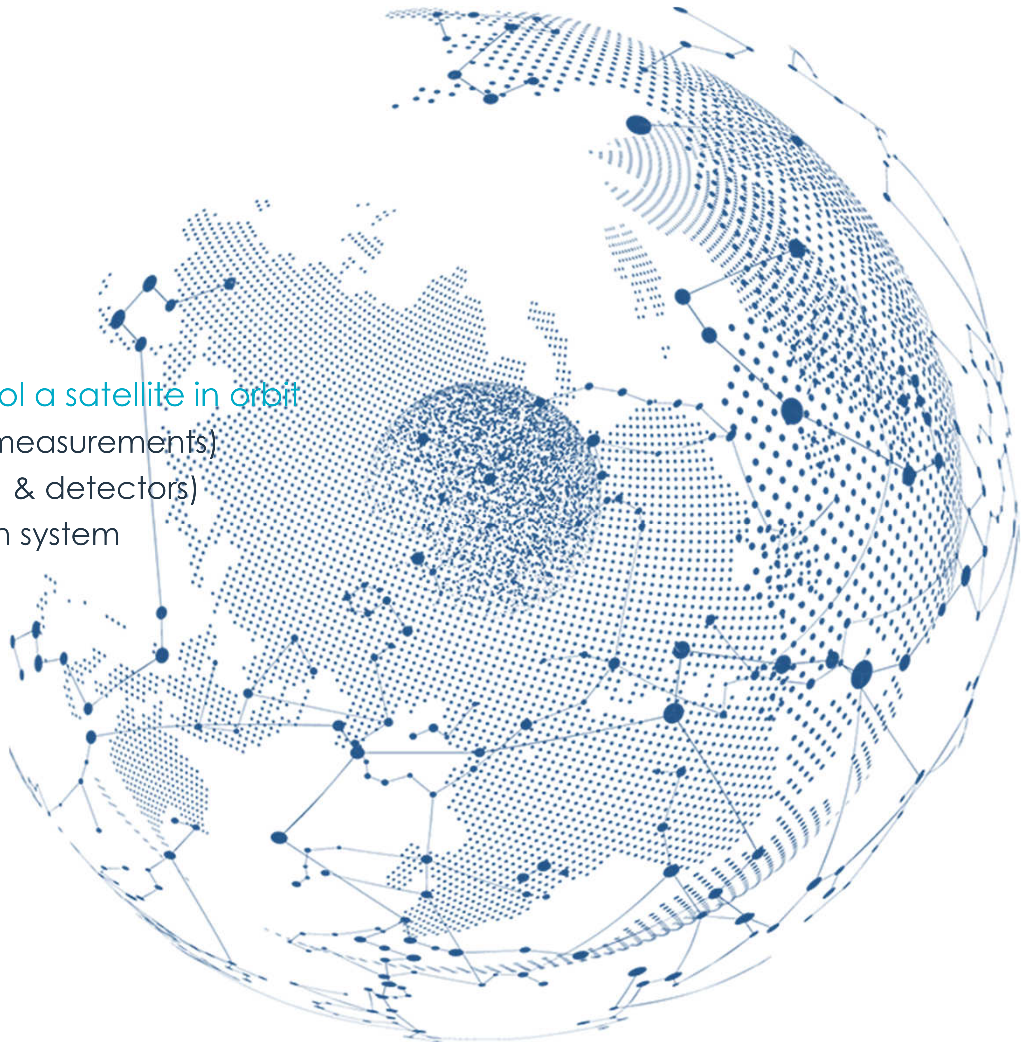
For this FDS, the library Orekit has been retained as the solution for the low-level orbital dynamics components:

- Open source space dynamics library in Java
- Simple and efficient implementation of all required orbital dynamics elements and functions
- Well validated in several operational applications

Thales Alenia Space is a member of the Orekit PMC (Project Management Commitee), contributing to the evolution of the library

27/11/2017
Ref. 0005-0009140310
Ref. Modèle = 83230347-DOC-TAS-FR-004

Flight Dynamics Software (FDS)



What is a Flight Dynamics Software ?

- A ground segment operational software used to control a satellite in orbit
  - Determine the orbit (GNSS and/or ground stations measurements)
  - Predict the orbit & orbital events (orbit propagation & detectors)
  - Plan the orbital maneuvers & monitor the propulsion system

When is it used ?

- During all the phases of a satellite lifetime
  - Launch & Early Orbit Phase (beginning of life)
  - Station Keeping (operational phase)
  - Disposal(end of life)

Who uses it ?

- Operators
  - Everyday survey and control of the satellite
  - Occasional help from experts in case of issue or emergency

NEOSAT FDS

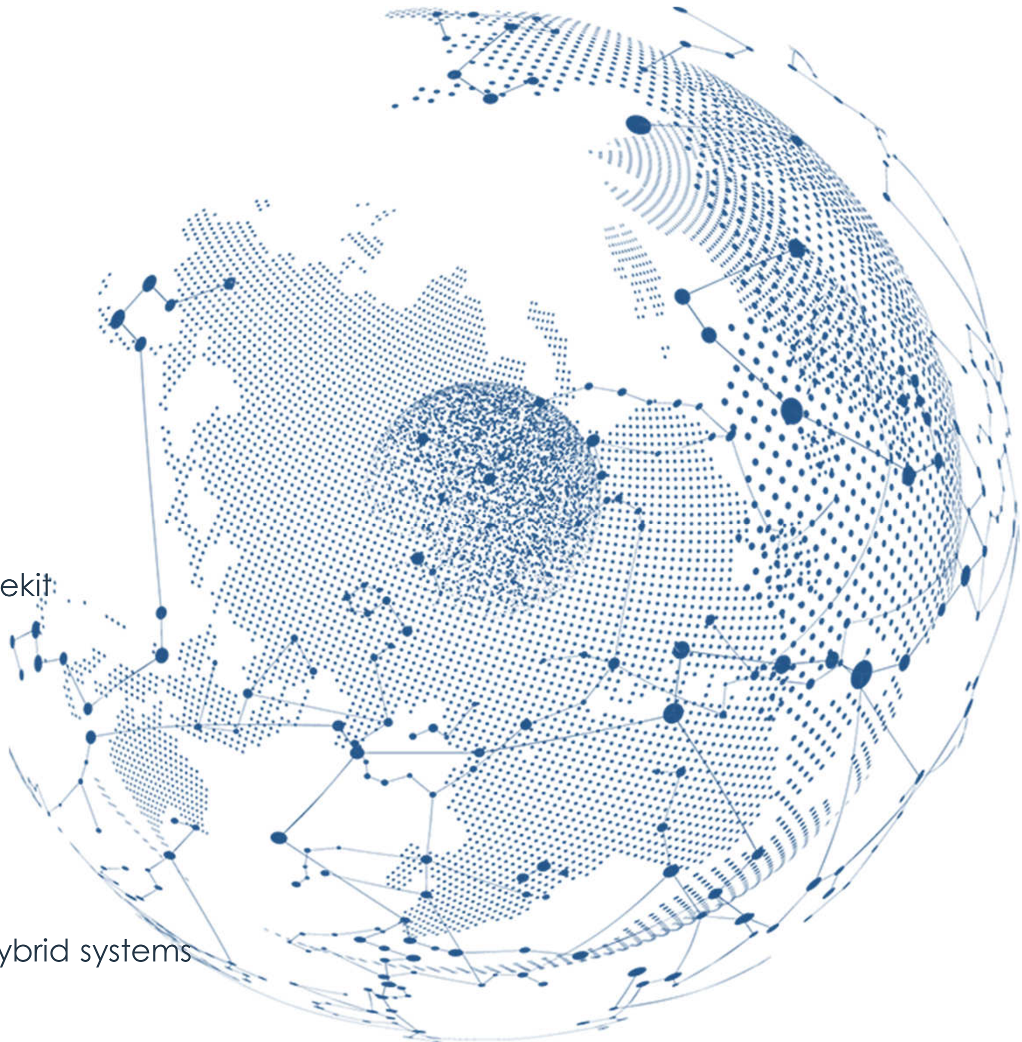
Flight Dynamics Software for SpaceBus Neo

A FDS tailored for SpaceBus Neo

- Geostationary orbits
- Station Keeping and disposal only (no LEOP)
- Electric propulsion management (Hall effect thrusters)
- Based on the latest version of Orekit
  - Most of the space dynamics functions based on Orekit
  - Uses almost all the functionalities of the library

But not only…

- CS-Ro and CS-SI will own the source code
- Plans are made to enhance the software for:
  - Other orbits: Low Earth Orbits
  - Other propulsion systems: Chemical propulsion or hybrid systems



NEOSAT FDS - Organisation

ESA

- Head of NEOSAT Program
- Final Customer

Thales Alenia Space (TAS)

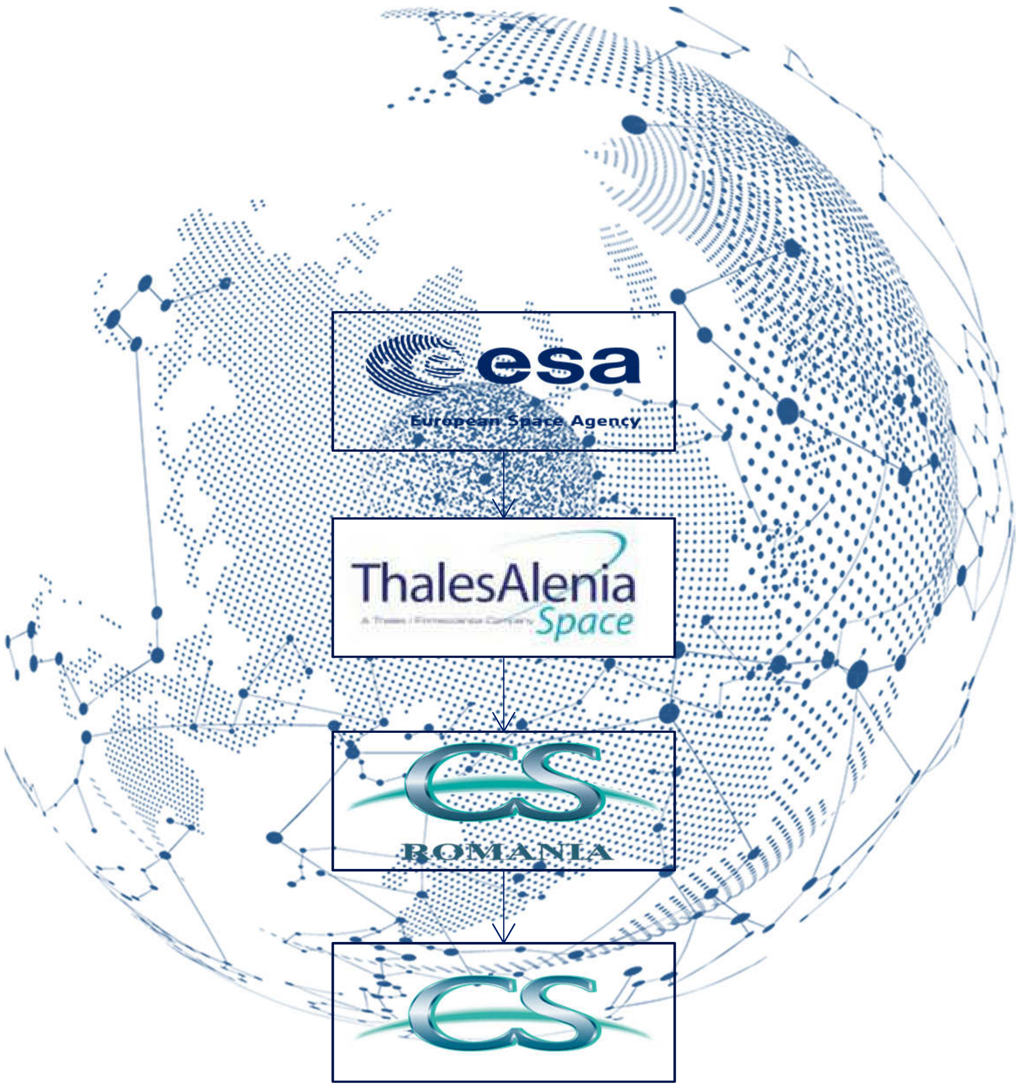
- Designer & Integrator of SpaceBus Neo
- Customer of NEOSAT FDS

CS-Romania (CS-Ro)

- Prime contractor of TAS
- FDS Management, Design, Development & Validation

CS-SI

- Contractor of CS-Ro
- Provides expertise in flight dynamics



NEOSAT FDS – Technology Stack

Client side: Web-like GUI

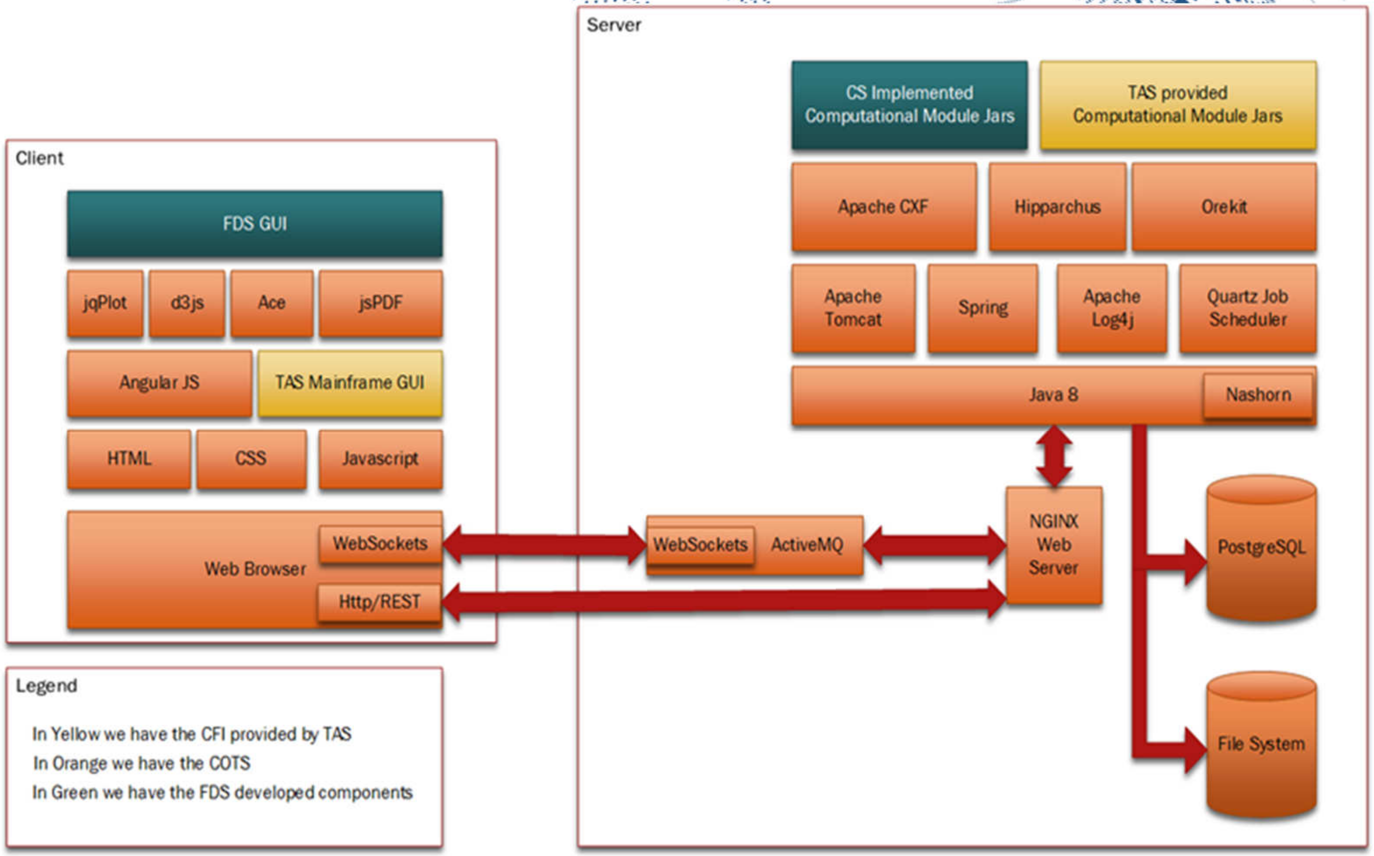
- Angular JS
- Organized in tabs
- TAS mainframe for menus

Client/server communication

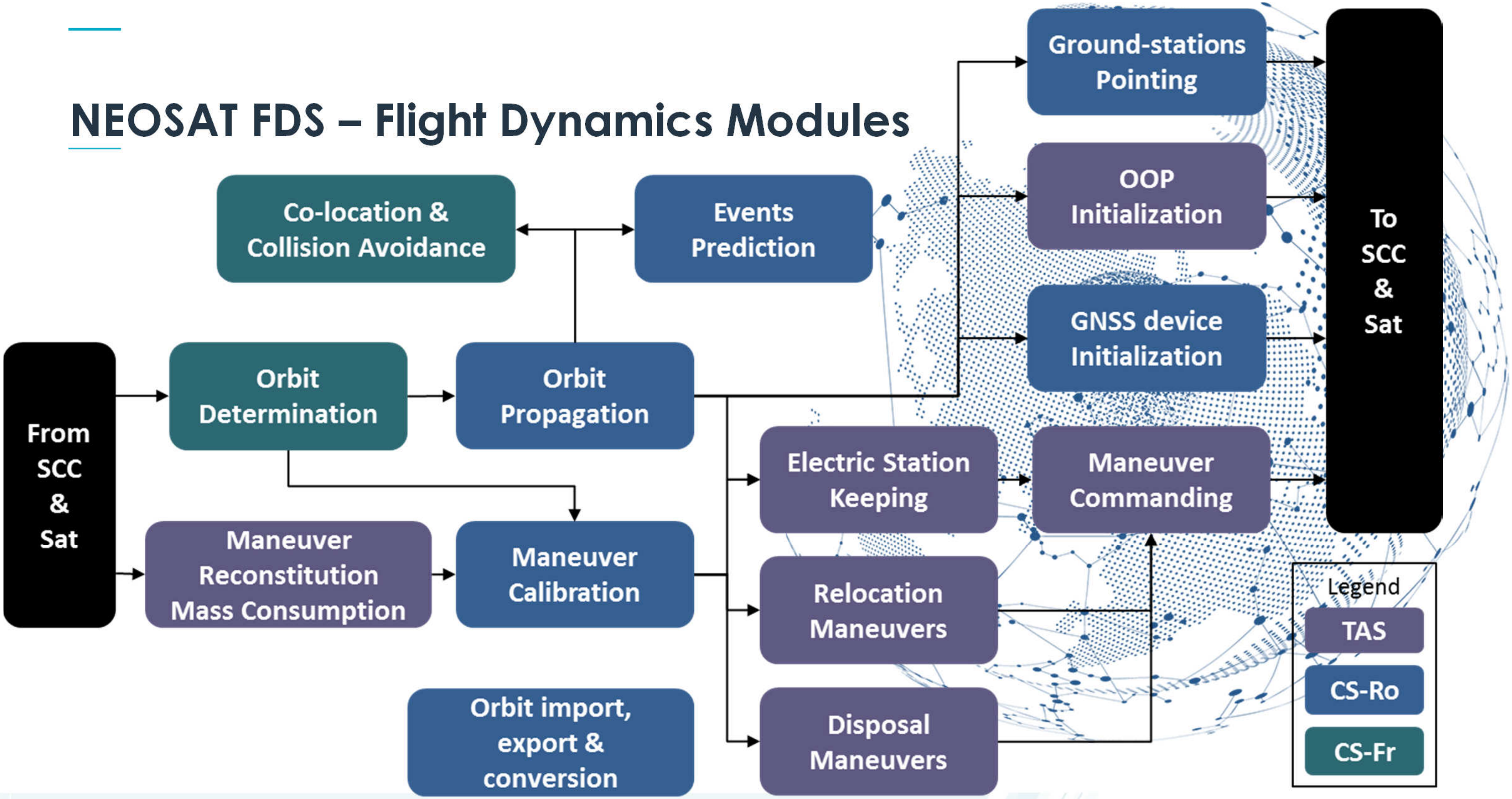
- No installation
- User login from navigator
- No direct access to file system
- Different type of users:
  - Operator, expert, admin

Server side: Java app

- Flight dynamics based on Orekit & Hipparchus
- Stored in obfuscated jar binaries

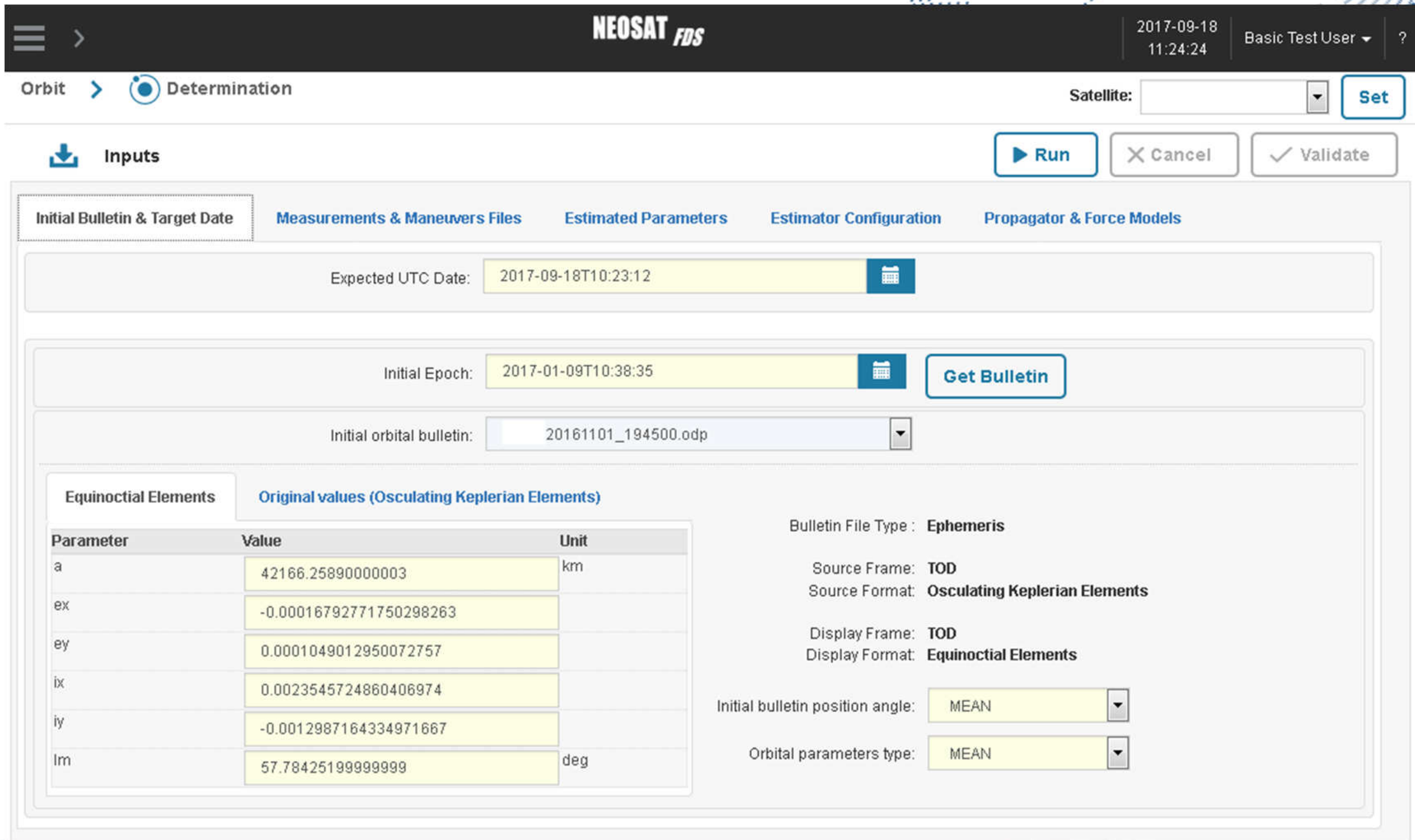


NEOSAT FDS – Flight Dynamics Modules

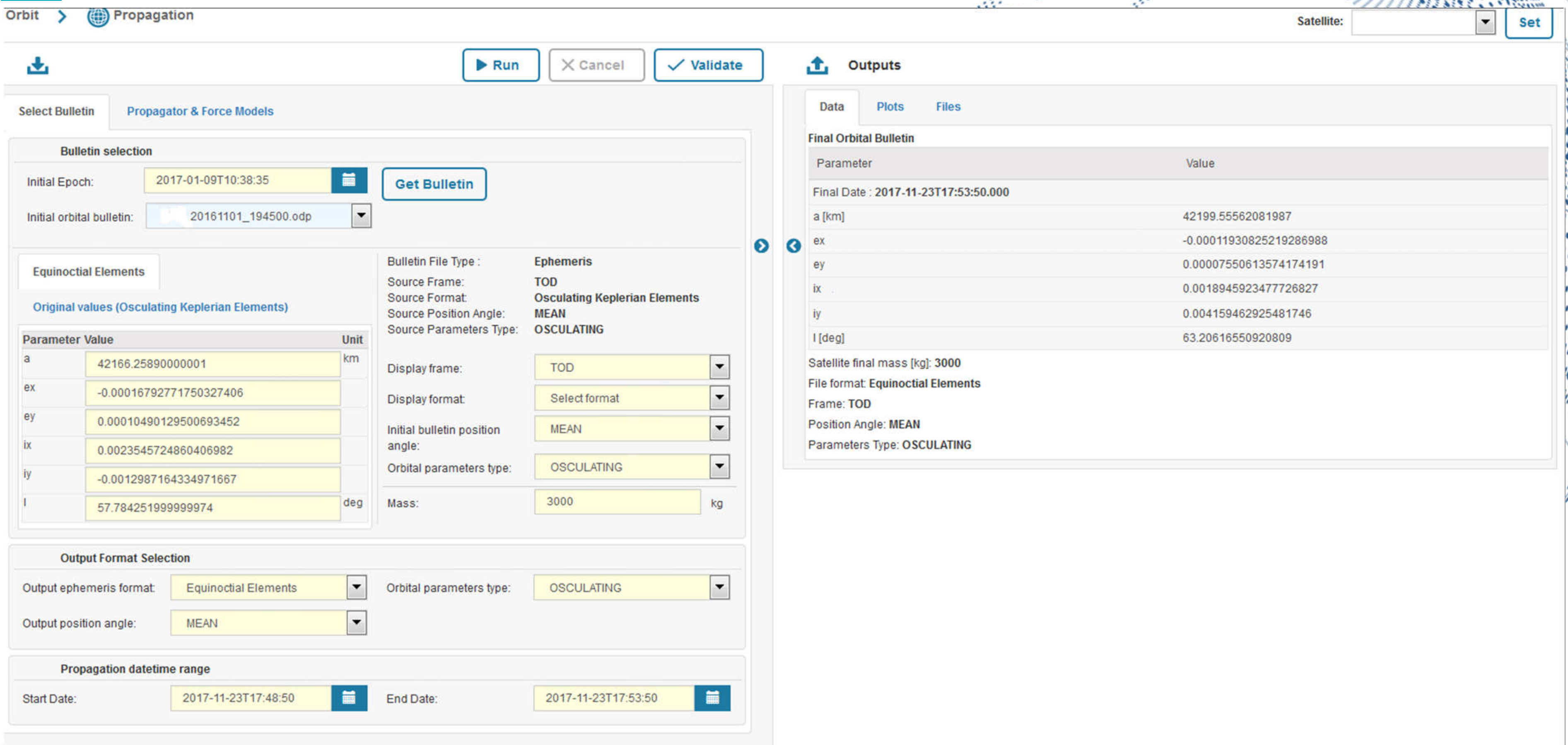


PROPRIETARY INFORMATION

NEOSAT FDS – Example

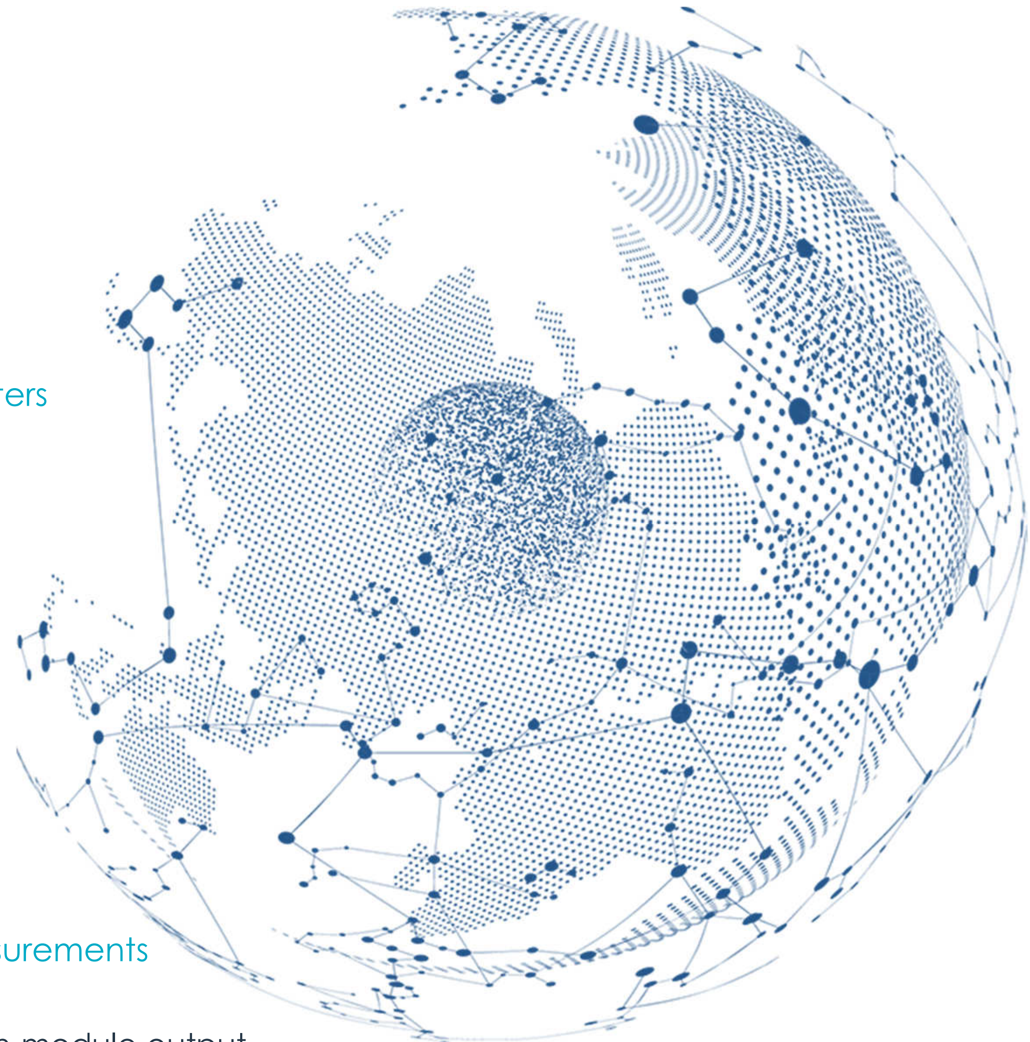


NEOSAT FDS – Example



Orekit in NEOSAT FDS

General Functionalities



Orbits

- Type: Equinoctial, Cartesian, Keplerian, Flight parameters
- Frames: IERS 2010 Conventions
  - Inertial: EME2000, TOD, Veis…
  - ECEF: ITRF2008, WGS84
  - Topocentric Frames for ground stations

Orbit Conversion

- Read/Write NORAD Two-Line Elements (TLE)
- Read Jspoc Conjunction Data Messages (CDM)

CCSDS Formats (XML)

- TDM - Tracking Data Message: Ground stations' measurements
- ODM - Orbit Data Message
  - OEM - Orbit Ephemeris Message: Orbit propagation module output
  - OPM – Orbit Parameters Message: Orbit determination output

Orekit in NEOSAT FDS

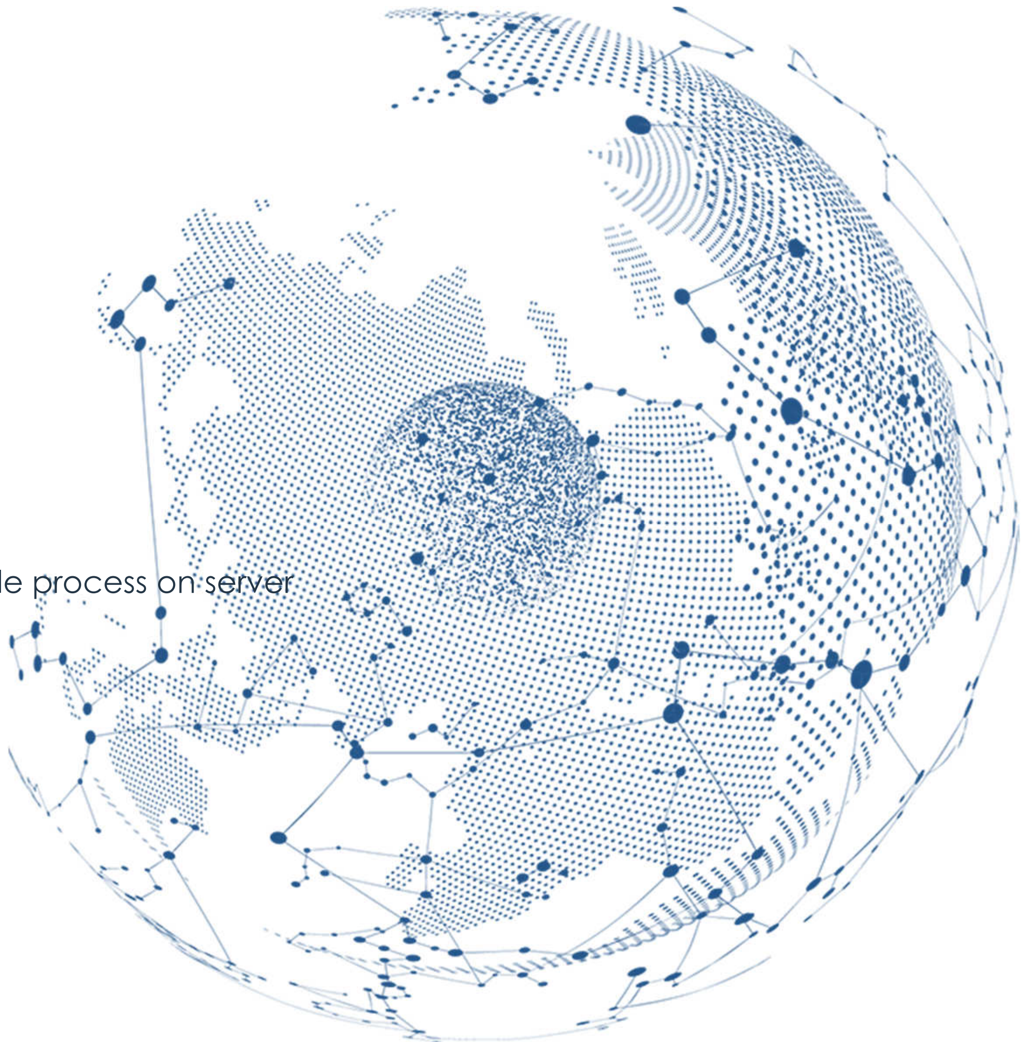
Orbit Determination

Two methods

- Batch least-square
  - Since Orekit 8.0
  - Hipparchus Levenberg-Marquardt optimizer
- « Real-time » orbit determination
  - Extended Kalman Filter – Runs permanently in an idle process on server

Ground stations measurements

- Distance
  - Range
  - Turn-around range
- Angular
  - Azimuth/Elevation
  - Right-ascension/Declination
- Robust linear regression for pre-processing



Orekit in NEOSAT FDS

Orbit Determination

GNSS measurements

- Raw data from the on-board GNSS device
- Pre-processed and added as PV measurements

Atmospheric corrections

- Ionospheric delay – Klobuchar model
- Tropospheric delay – Saastamoinen model

Estimations

- Orbital parameters & Covariances
- Force models
  - Solar Radiation Pressure
  - Maneuvers' thrusts
- Stations data
  - Measurements biases
  - Position biases

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Réf. Modèle = 83230347-DOC-TAS-FR-004

Orekit in NEOSAT FDS

Orbit Propagation

Mean elements propagation with DSST

- DSST – Draper Semi-Analytical Satellite Theory
- Since Orekit 7.0

Force Models

- Spherical harmonics Earth geopotential
- Luni-Solar gravity perturbations
- Solar radiation pressure
- Planned maneuvers

Orekit in NEOSAT FDS

Events Prediction & Ground Antenna Pointing

Orekit Satellite Events

- Apogee & perigee crossings
- Nodes crossings
- User defined Local Solar Time crossings
- Eclipses of the Sun & obscuration ratio
  - Earth
  - Moon
- Transits of Sun & Earth in satellites' sensors

Stations' Visibility

- Minimum elevation
- Azimuth/elevation masks
- Atmospheric refraction

Orekit in NEOSAT FDS

Co-location & Collision Avoidance

Multi-satellite Propagation

- Since Orekit 9.0
- With constant thrusts or impulse maneuvers

Close approach detection

- Minimum distance with Orekit events

Avoidance maneuvers

- Using Orekit small maneuver analytical model

Co-location strategies

- Longitude separation
- Eccentricity & inclination separation

NEOSAT FDS for Orekit

Adds-on for Orekit

Orekit new features based on NEOSAT FDS needs

- Developed in Orekit then added to NEOSAT FDS software

Extended Kalman filter for orbit determination

- On-going work by the Orekit team
- To be released in 2018

Ground stations measurements

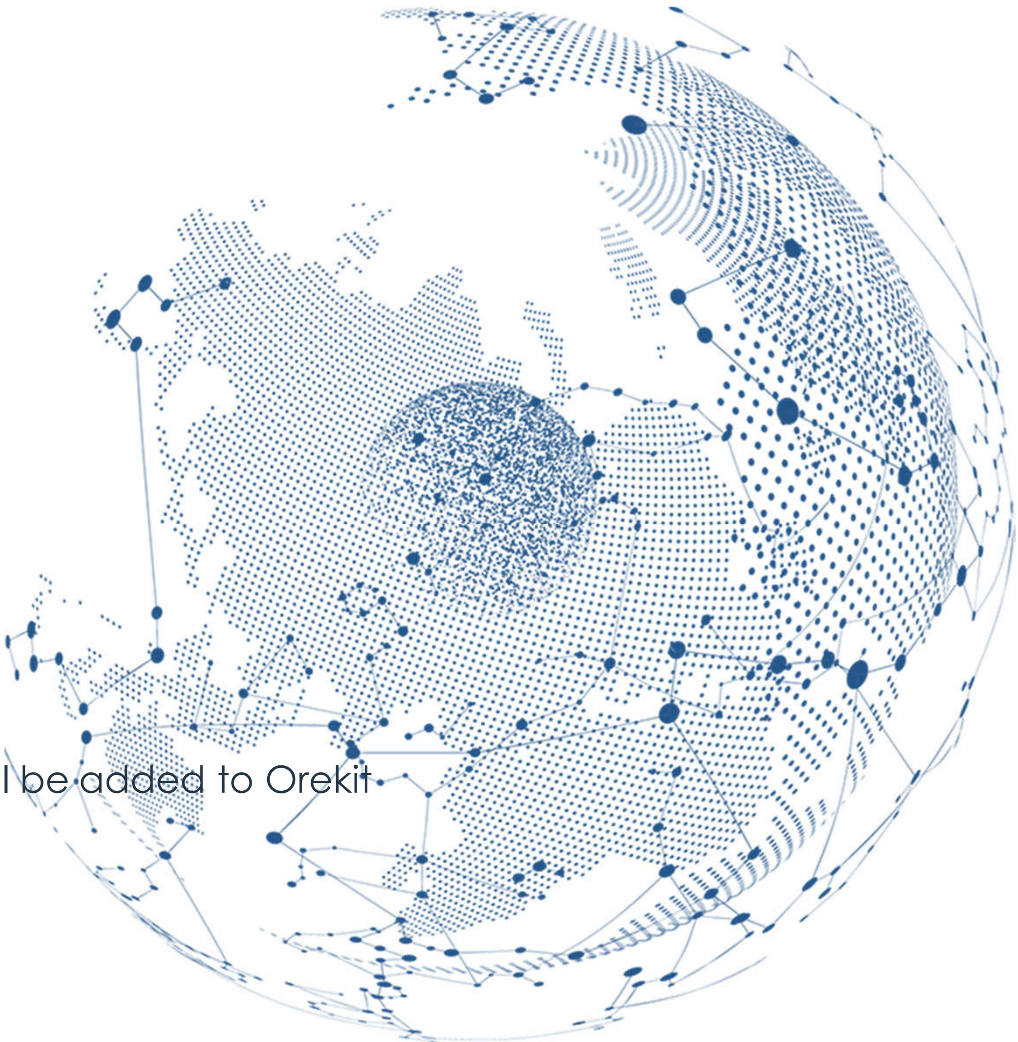
- Turn-around range measurements
- Loader & Reader for ionospheric data - Klobuchar-Style Ionospheric Coefficients from the University of Bern Astronomical Institute
  - Data fit with their own ionospheric models (IONEX)
  - Better performance than the data originally broadcasted by GPS
  - RINEX navigation data files format
  - Final, rapid (last 5 days) and predicted data for real-time orbit determination

Conclusion

Orekit used in an operational software
- Station keeping for geostationary satellites
- Electric propulsion

NEOSAT FDS use of Orekit
- Latest version
- Almost the full range of Orekit capabilities

Some of the features needed for NEOSAT FDS are or will be added to Orekit



Thank you for your attention!