



Orekit in NEOSAT FDS

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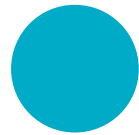
Maxime Journot (CS)

Orekit Day 2017

ThalesAlenia
a Thales / Leonardo company **Space**



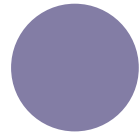
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TAS & the NEOSAT program



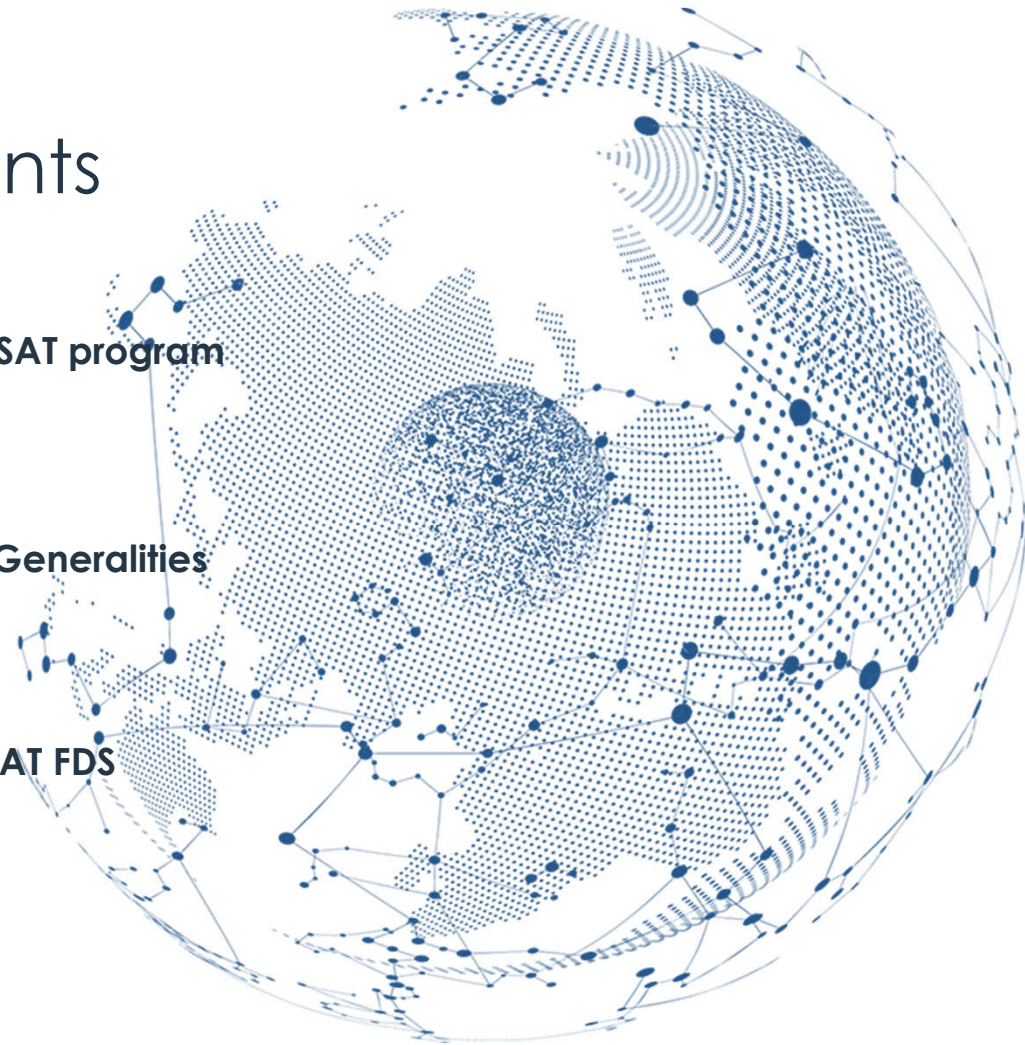
NEOSAT FDS - Generalities



Orekit in NEOSAT FDS

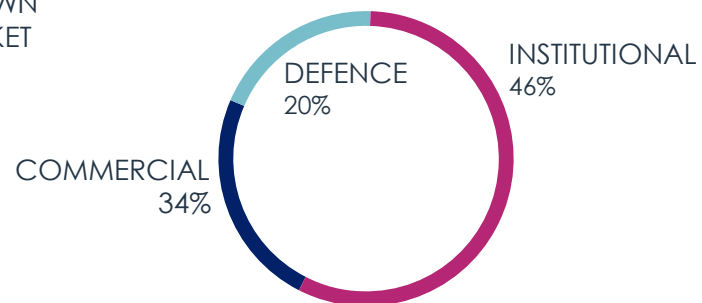


Conclusion



Thales Alenia Space

BREAKDOWN
PER MARKET



BREAKDOWN
PER ACTIVITY



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

EQUIPMENT PAYLOADS SATELLITES SERVICES SYSTEMS

7,980

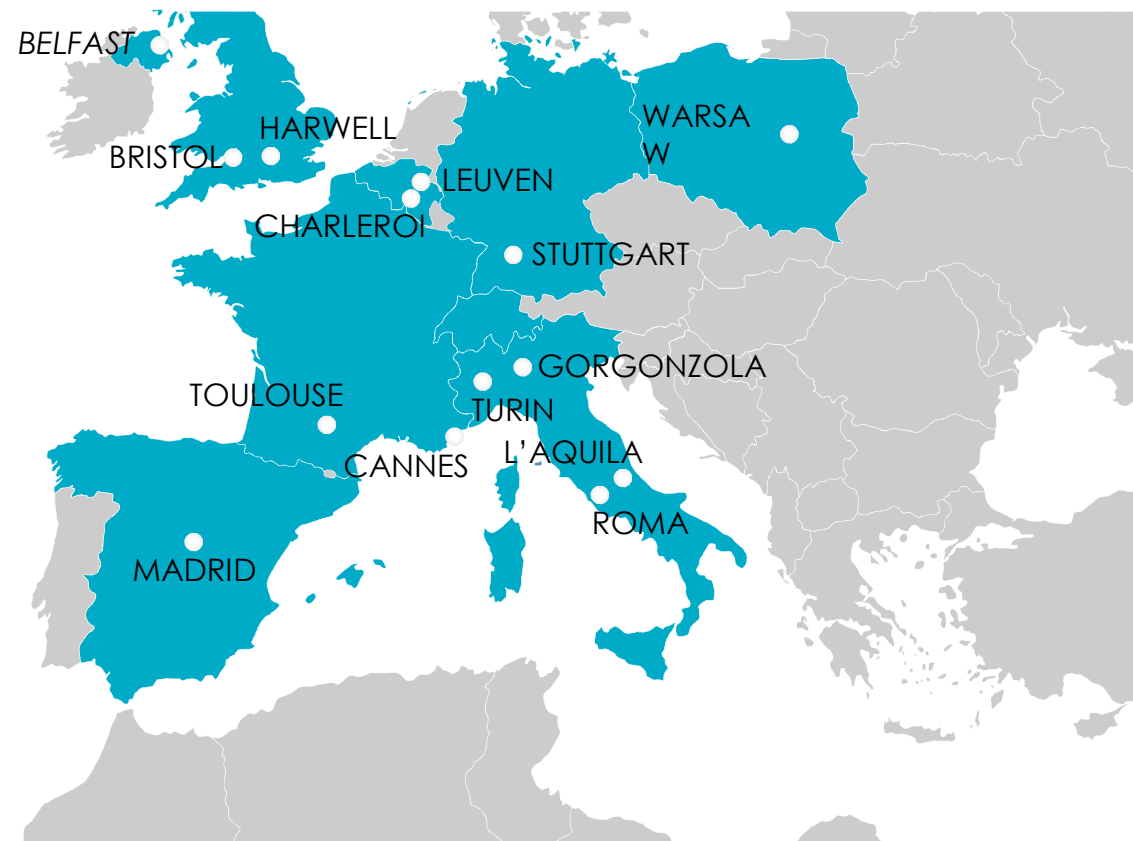
Employees

15

Sites in Europe

2,4 BN€

Sales



NEOSAT

SpaceBus Neo

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

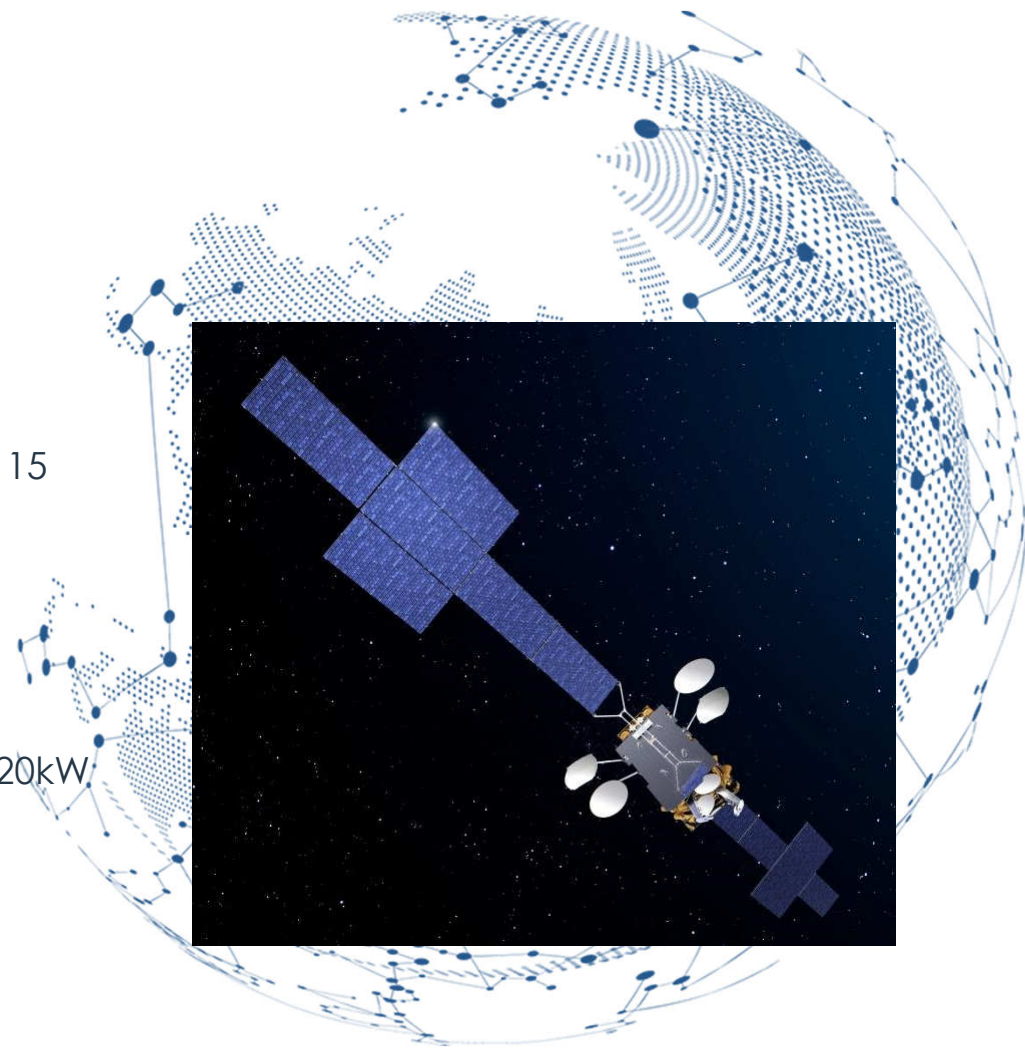
A contract with Thales Alenia Space was awarded on 15 September 2015 → **SpaceBus Neo** product line

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 Committee), contributing to the evolution of the library



Flight Dynamics Software (FDS)

What is a Flight Dynamics Software ?

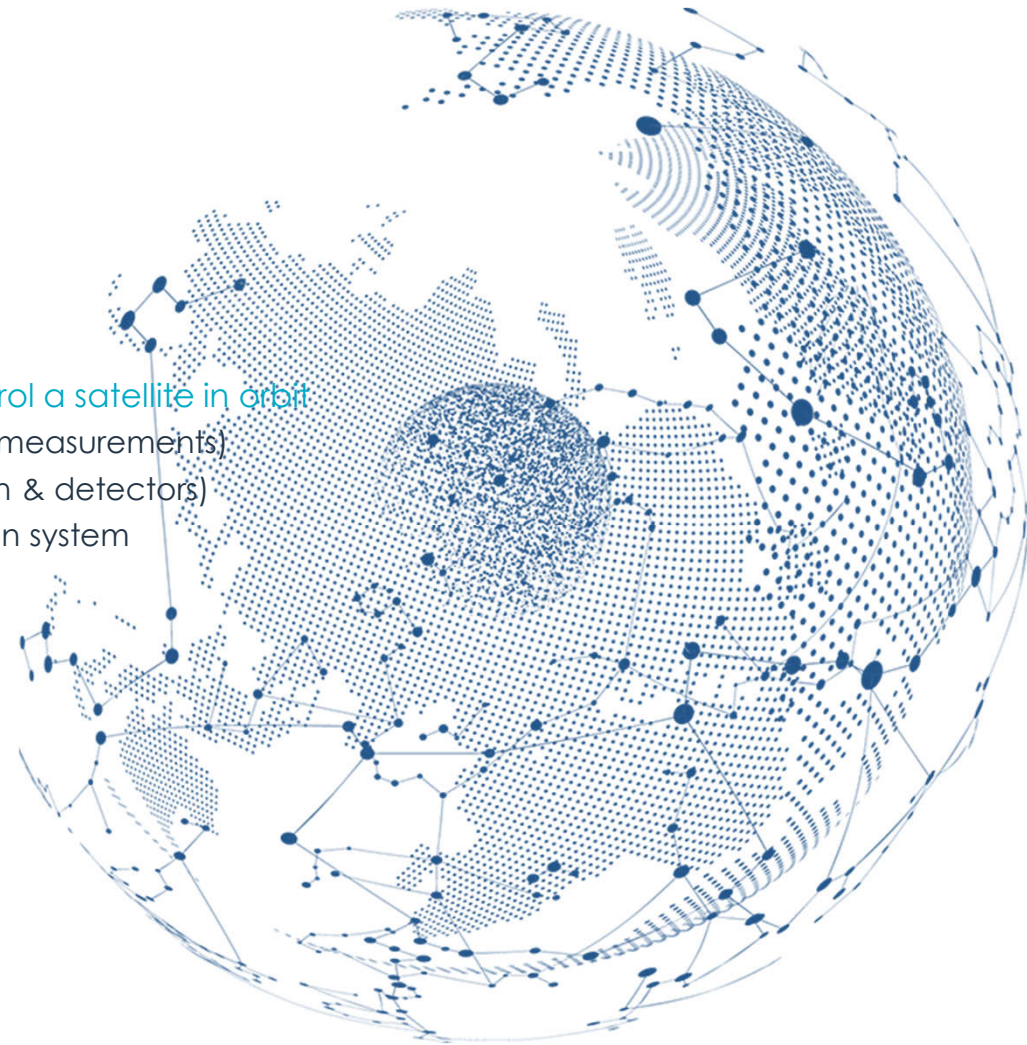
- ✈️ A ground segment operational software used to control a satellite in orbit
 - 📡 Determine the orbit (GNSS and/or ground stations measurements)
 - 📡 Predict the orbit & orbital events (orbit propagation & detectors)
 - 📡 Plan the orbital maneuvers & monitor the propulsion system

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

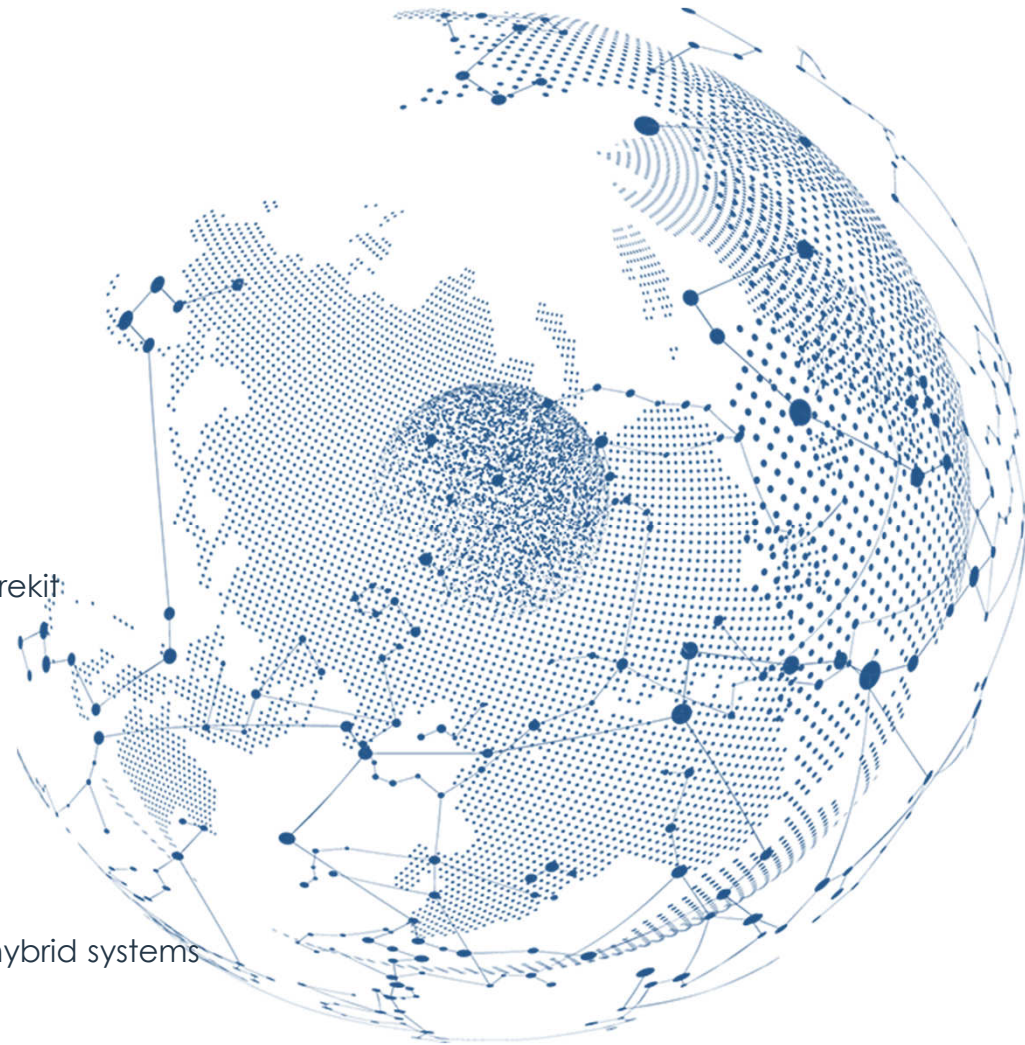
Flight Dynamics Software for SpaceBus Neo

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

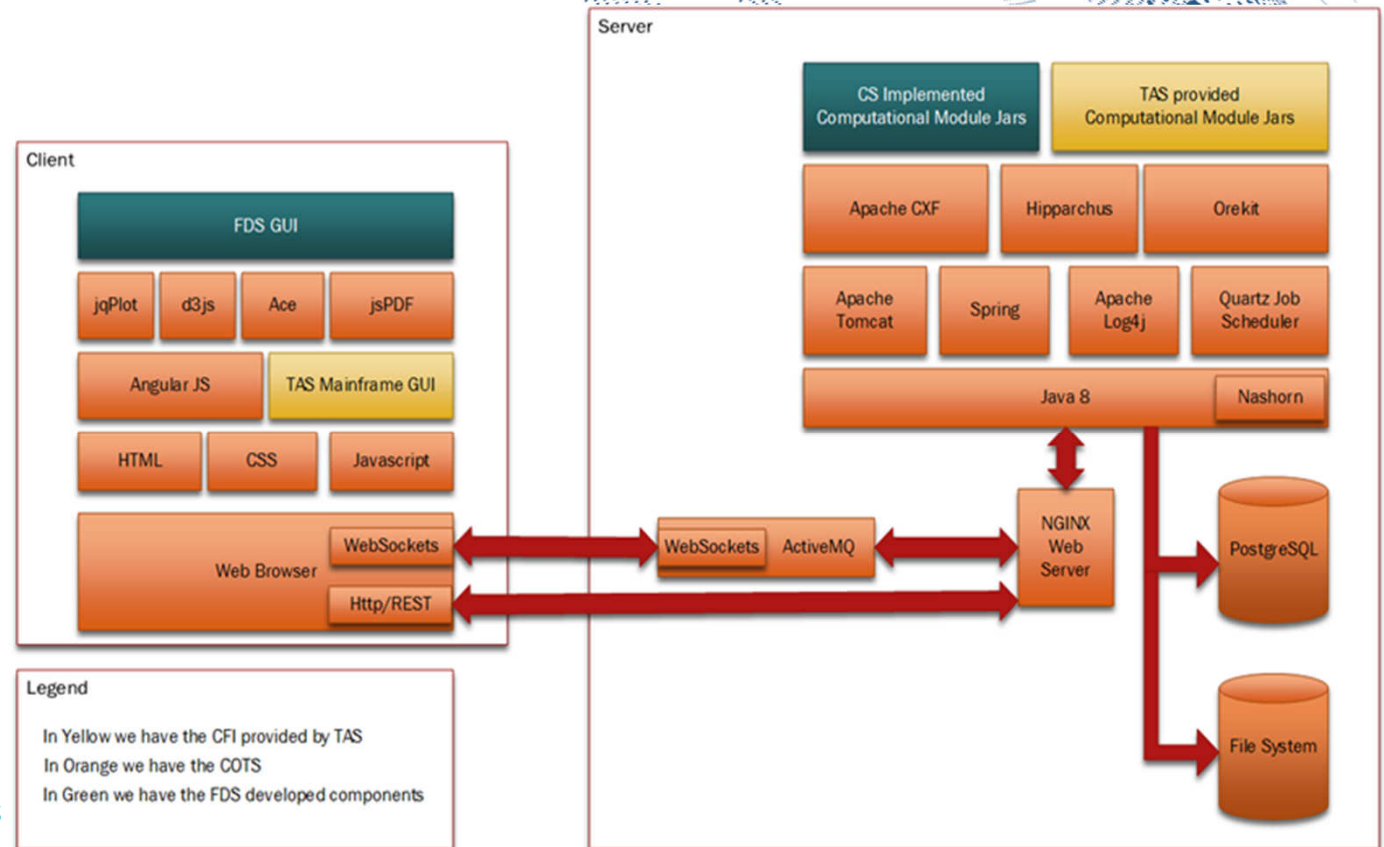
- Angular JS
- Organized in tabs
- TAS mainframe for menus

Client/server communication

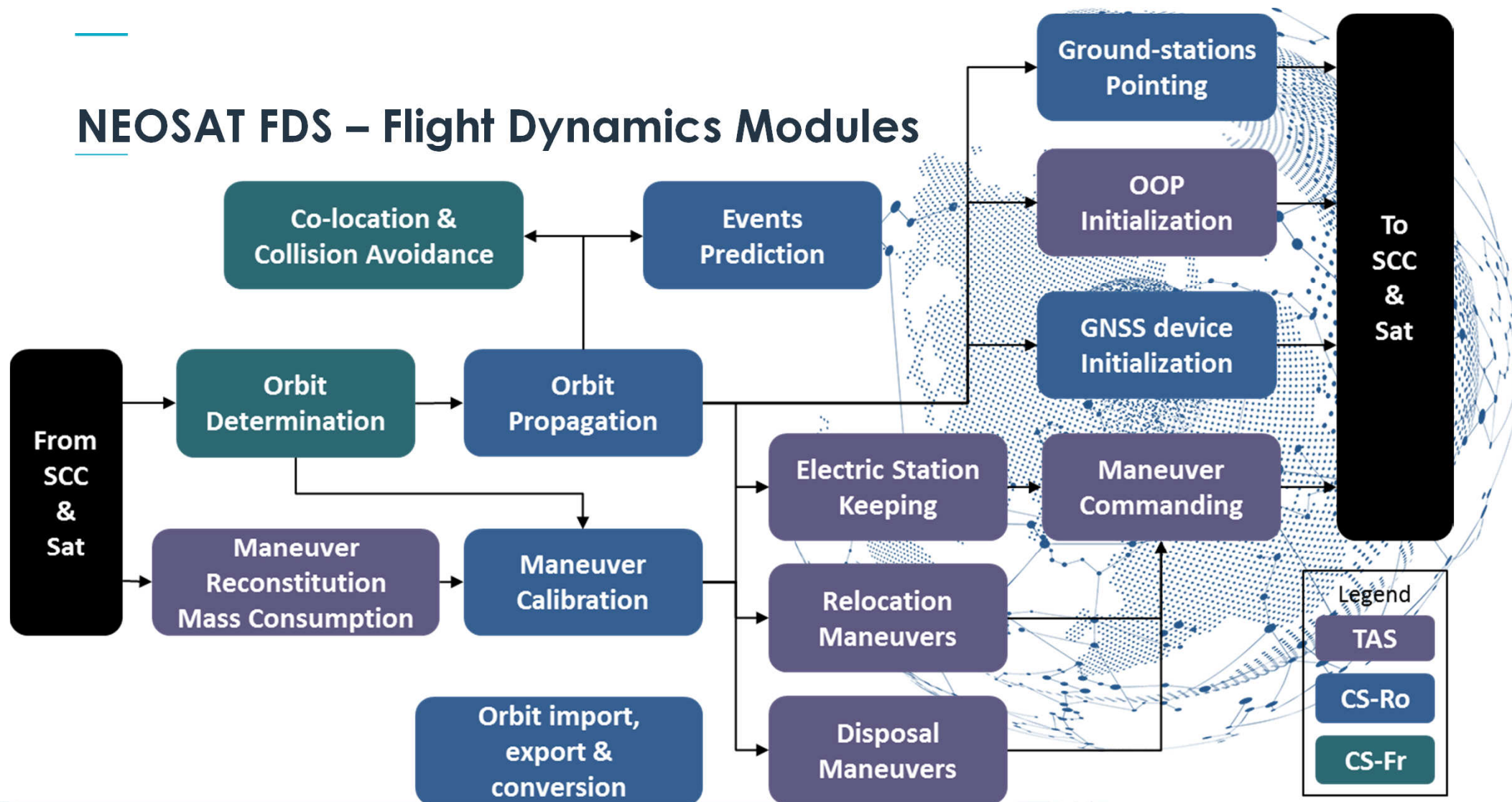
- No installation
- User login from navigator
- No direct access to file system
- Different type of users:
 - Operator, expert, admin

Server side: Java app

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



NEOSAT FDS – Flight Dynamics Modules



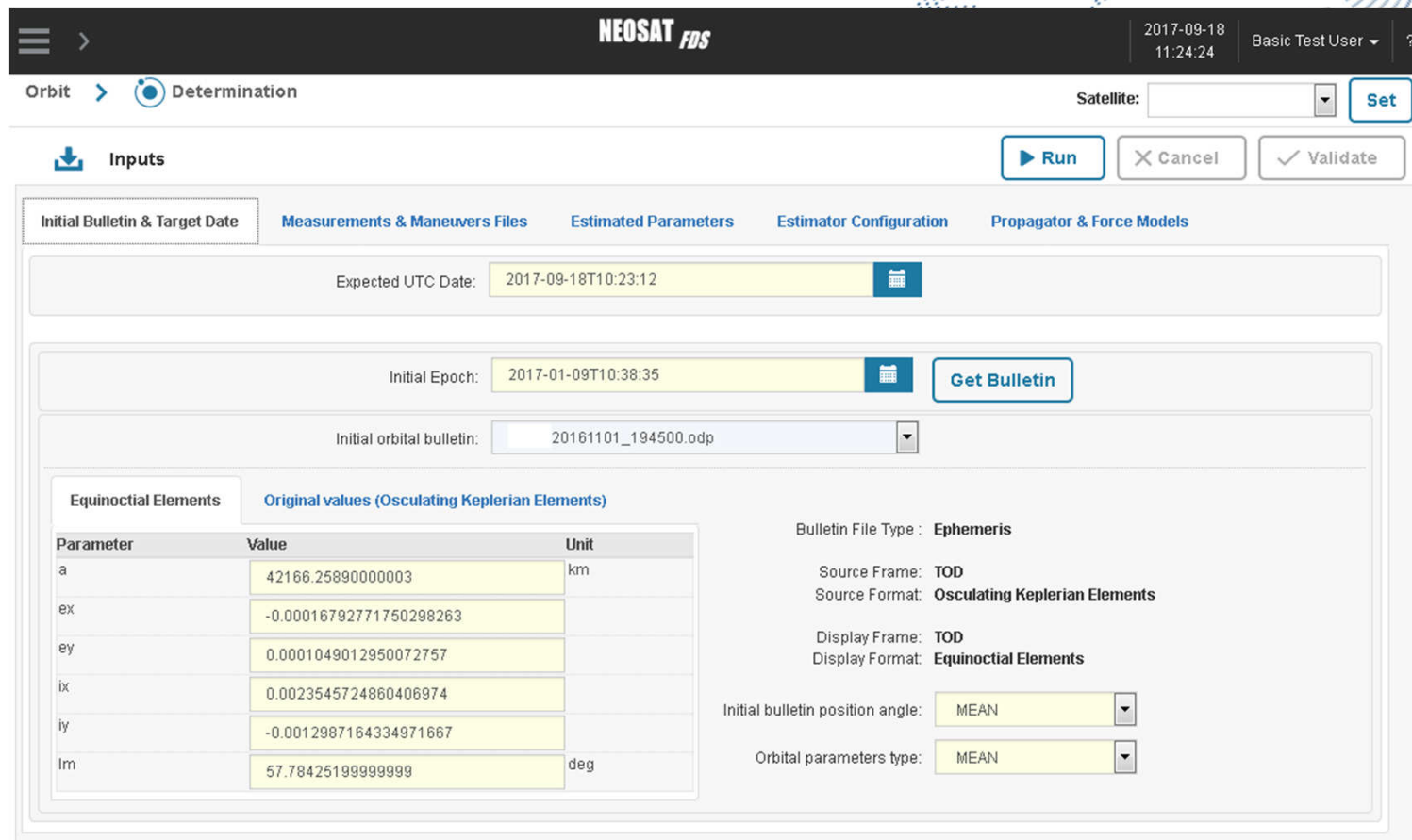
Legend

TAS

CS-Ro

CS-Fr

NEOSAT FDS – Example



NEOSAT FDS

2017-09-18 11:24:24 Basic Test User ?

Orbit > **Determination** Satellite: **Set**

Inputs **Run** **Cancel** **Validate**

Initial Bulletin & Target Date **Measurements & Maneuvers Files** **Estimated Parameters** **Estimator Configuration** **Propagator & Force Models**

Expected UTC Date: 2017-09-18T10:23:12 **Calendar**

Initial Epoch: 2017-01-09T10:38:35 **Calendar** **Get Bulletin**

Initial orbital bulletin: 20161101_194500.odp **Dropdown**

Equinoctial Elements **Original values (Osculating Keplerian Elements)**

Parameter	Value	Unit
a	42166.25890000003	km
ex	-0.00016792771750298263	
ey	0.0001049012950072757	
ix	0.0023545724860406974	
iy	-0.0012987164334971667	
Im	57.78425199999999	deg

Bulletin File Type: **Ephemeris**

Source Frame: **TOD**
Source Format: **Osculating Keplerian Elements**

Display Frame: **TOD**
Display Format: **Equinoctial Elements**

Initial bulletin position angle: **MEAN** **Dropdown**

Orbital parameters type: **MEAN** **Dropdown**

NEOSAT FDS – Example

Orbit
Propagation

Satellite:
Set

Run
Cancel
Validate

Select Bulletin
Propagator & Force Models

Bulletin selection

Initial Epoch: 2017-01-09T10:38:35
Get Bulletin

Initial orbital bulletin: 20161101_194500.odp

Equinoctial Elements

Original values (Osculating Keplerian Elements)

Parameter	Value	Unit
a	42166.258900000001	km
ex	-0.00016792771750327406	
ey	0.00010490129500693452	
ix	0.0023545724860406982	
iy	-0.0012987164334971667	
I	57.784251999999974	deg

Bulletin File Type : Ephemeris

Source Frame: TOD

Source Format: Osculating Keplerian Elements

Source Position Angle: MEAN

Source Parameters Type: OSCULATING

Display frame: TOD

Display format: Select format

Initial bulletin position angle: MEAN

Orbital parameters type: OSCULATING

Mass: 3000 kg

Output Format Selection

Output ephemeris format: Equinoctial Elements

Orbital parameters type: OSCULATING

Output position angle: MEAN

Propagation datetime range

Start Date: 2017-11-23T17:48:50

End Date: 2017-11-23T17:53:50

Outputs

Data
Plots
Files

Final Orbital Bulletin

Parameter	Value
Final Date : 2017-11-23T17:53:50.000	
a [km]	42199.55562081987
ex	-0.00011930825219286988
ey	0.00007550613574174191
ix	0.0018945923477726827
iy	0.004159462925481746
I [deg]	63.20616550920809

Satellite final mass [kg]: 3000

File format: Equinoctial Elements

Frame: TOD

Position Angle: MEAN

Parameters Type: OSCULATING

Orekit in NEOSAT FDS

General Functionalities

Orbits

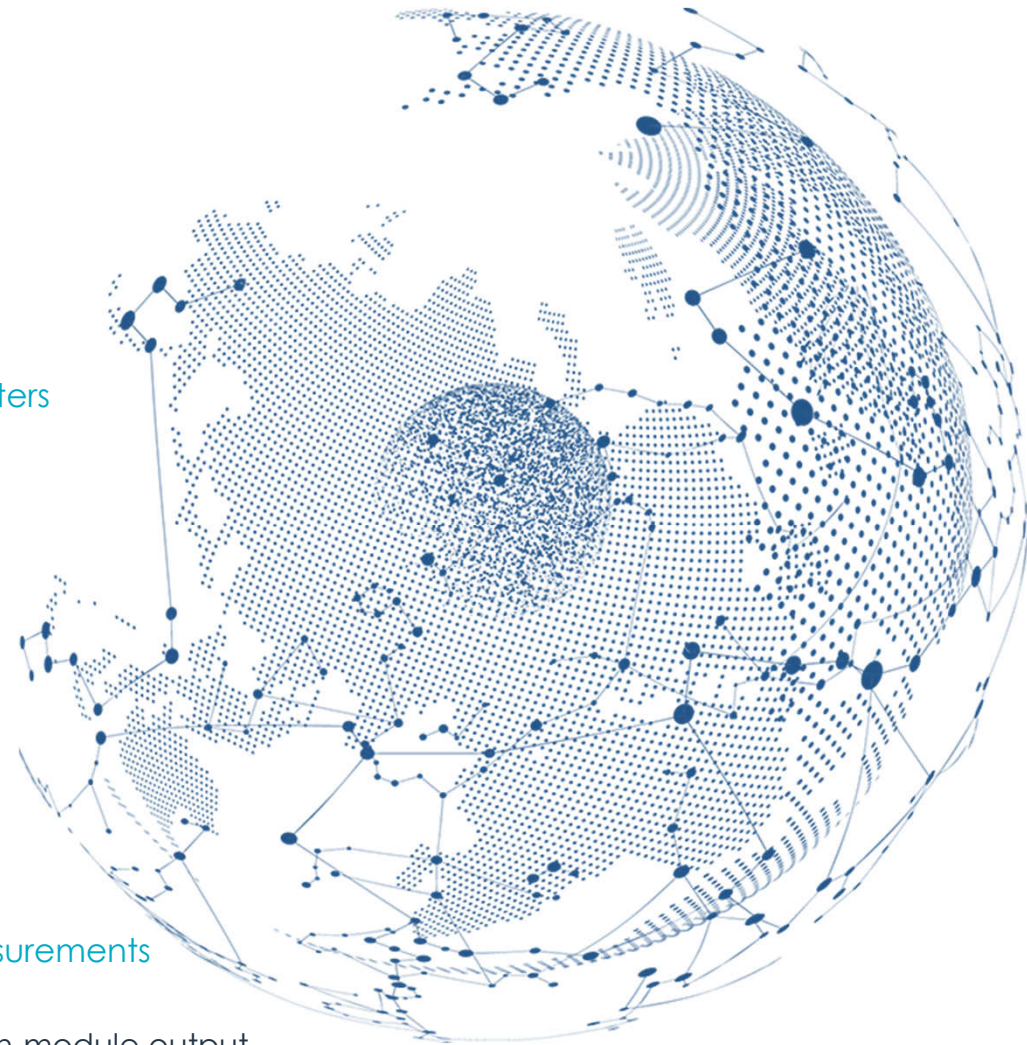
- 🌐 Type: Equinoctial, Cartesian, Keplerian, Flight parameters
- 🌐 Frames: IERS 2010 Conventions
 - 🌐 Inertial: EME2000, TOD, Veis...
 - 🌐 ECEF: ITRF2008, WGS84
 - 🌐 Topocentric Frames for ground stations

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

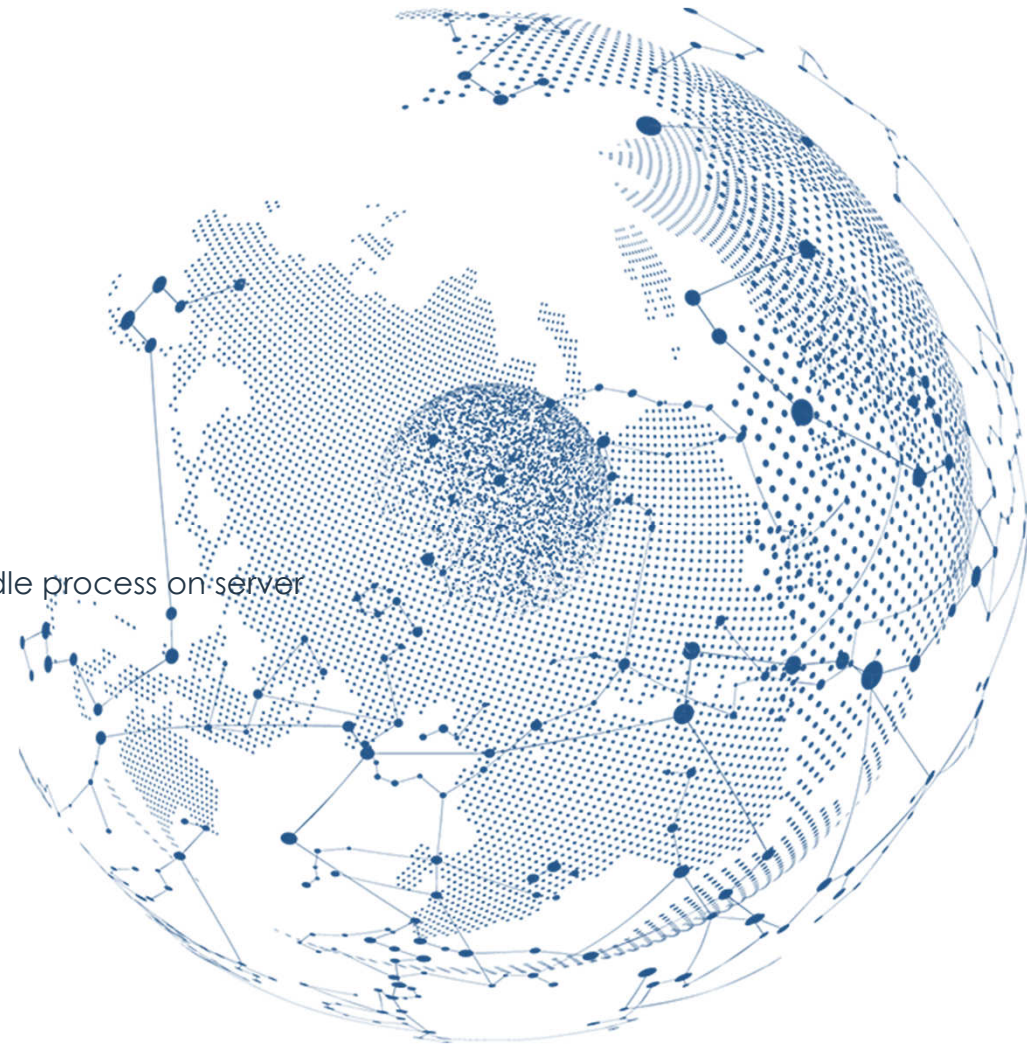
Orbit Determination

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



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

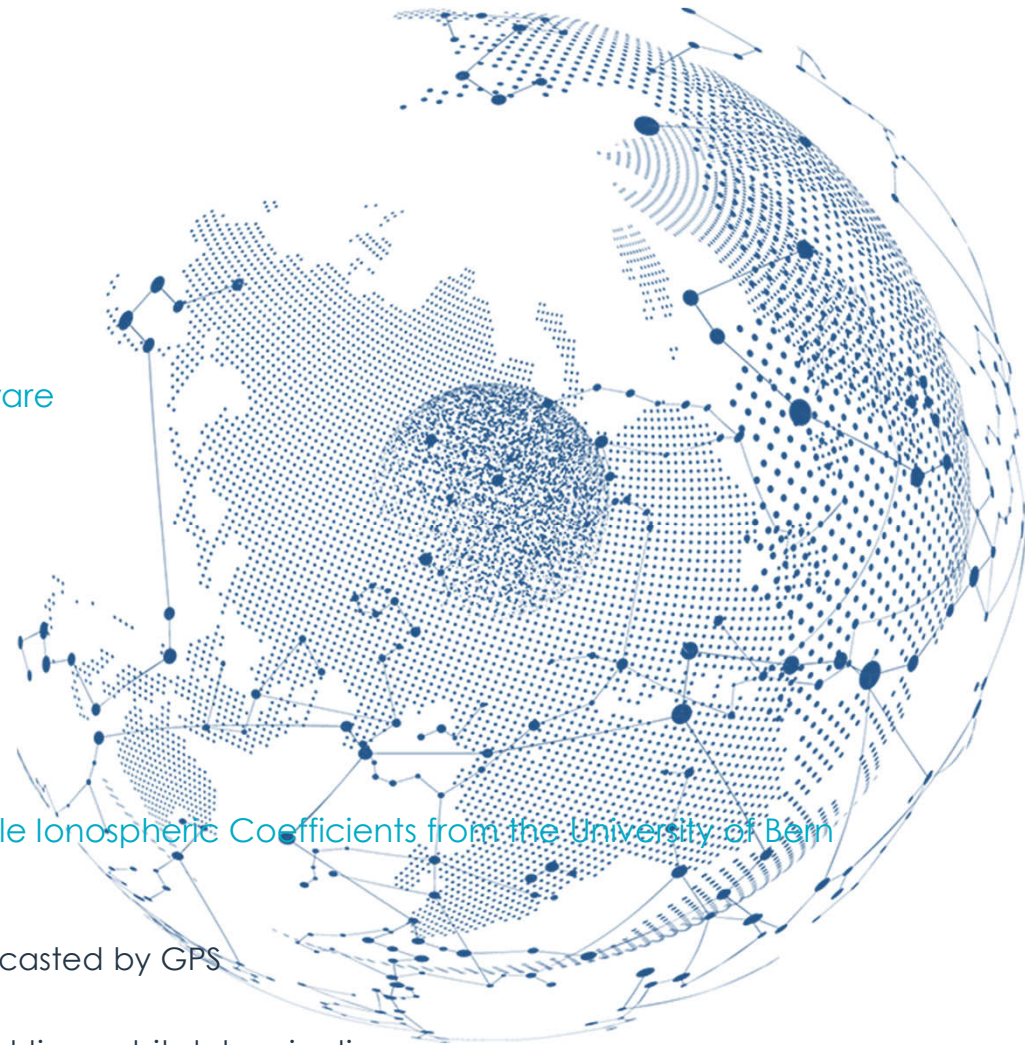
- 🚀 Developed in Orekit then added to NEOSAT FDS software

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!

