ITTI Orbits

End-To-End Procedure for satellite Orbit Catalogue

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ITTI

- **SME – ca. 80 people**
- Main activities:
  - developement of **customised software solutions**
  - **applied R&D** activities in the area of ICT
- Space domains:
  - Space Situational Awareness
    - NEO (Near Earth Objects)
    - SST (Space Surveillance and Tracking)
  - Software supporting ground segment activities:
    - AIT (Assembly, Integration and Testing)
    - EGSE (Electrical Ground Support Equipment)
  - Spacecraft data handling technologies (e.g. SpaceWire)
- Member of international and national bodies e.g. Polish Space Industry Association (ZPSK)

AGENDA

- **Idea** – SST, orbital catalogue
- **Development** – modules, technical spec., software readiness
- **First tests:**
  - Objective
  - Methodology
  - Input: original orbit elements, measurements, parameters
  - Output: orbit elements with uncerteinty, estimated position
- **Validation** in E2EPOC Project
- **Q&A**

SST

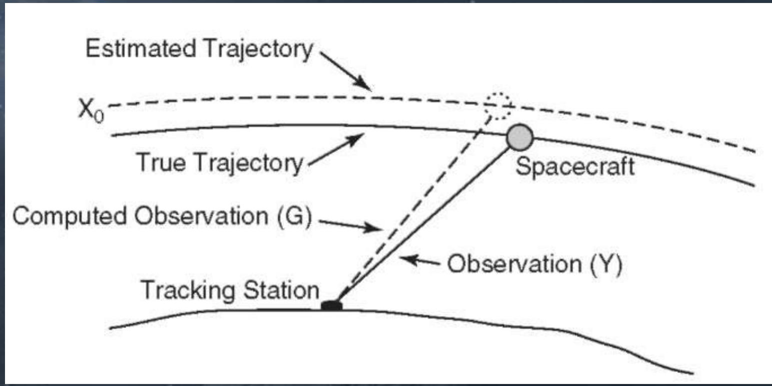
- Thousands of artificial objects around Earth need survaillance: Collision Avoidance, In-orbit Fragmentation, Re-entry
- To track movement we predict – good orbital catalogue is needed
- It is expected more and more accurate prediction
  - Observation – more we observe – better orbits we have
  - Computation – accurate orbit determination and propagation is needed
- Is an open source software an answer?

ORBIT IMPROVEMENT

Based on optical observations only – angular measurements

Process:

- Import TLE (all objects)
- For selected objects:
  - OBSERVE: schedule and perform observations => FITS
  - MEASURE: pre process FITS and make astrometry => measurments
  - COMPUTE: improve orbit (first time convert TLE to osculating elements)
  - UPDATE orbital catalogue



DATA SCHEME

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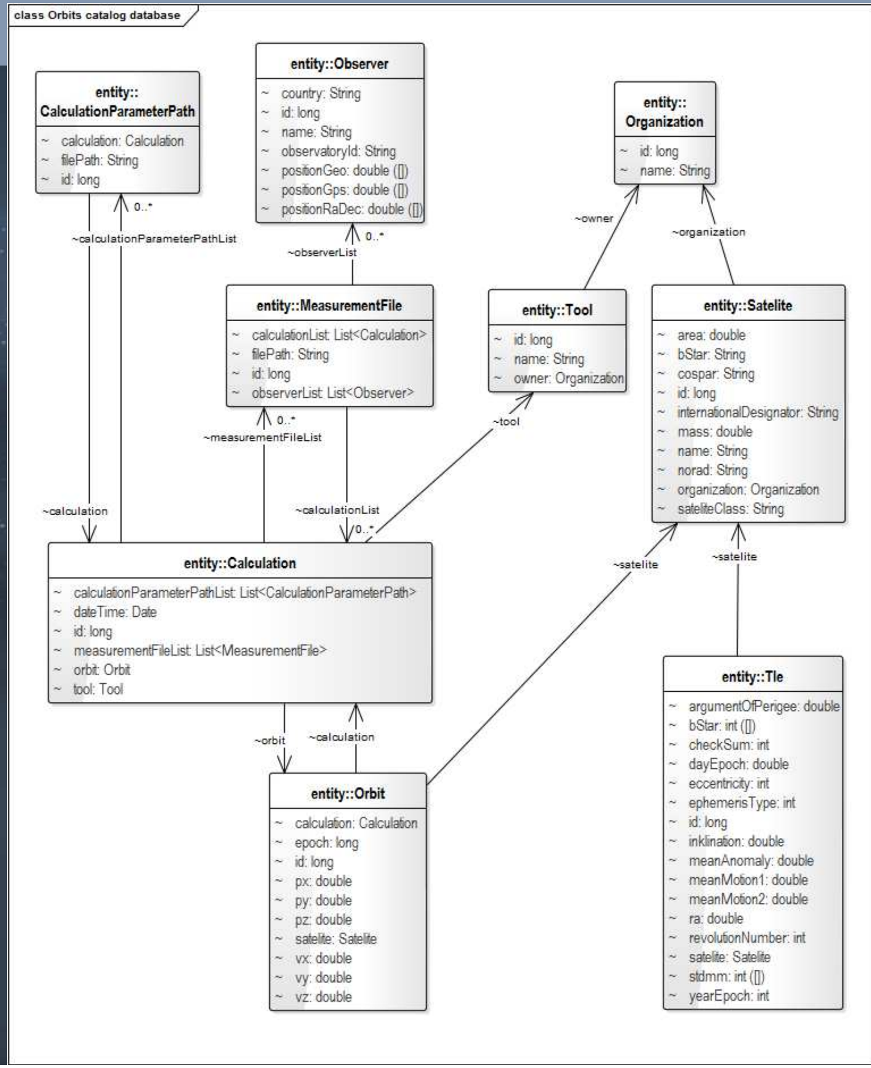
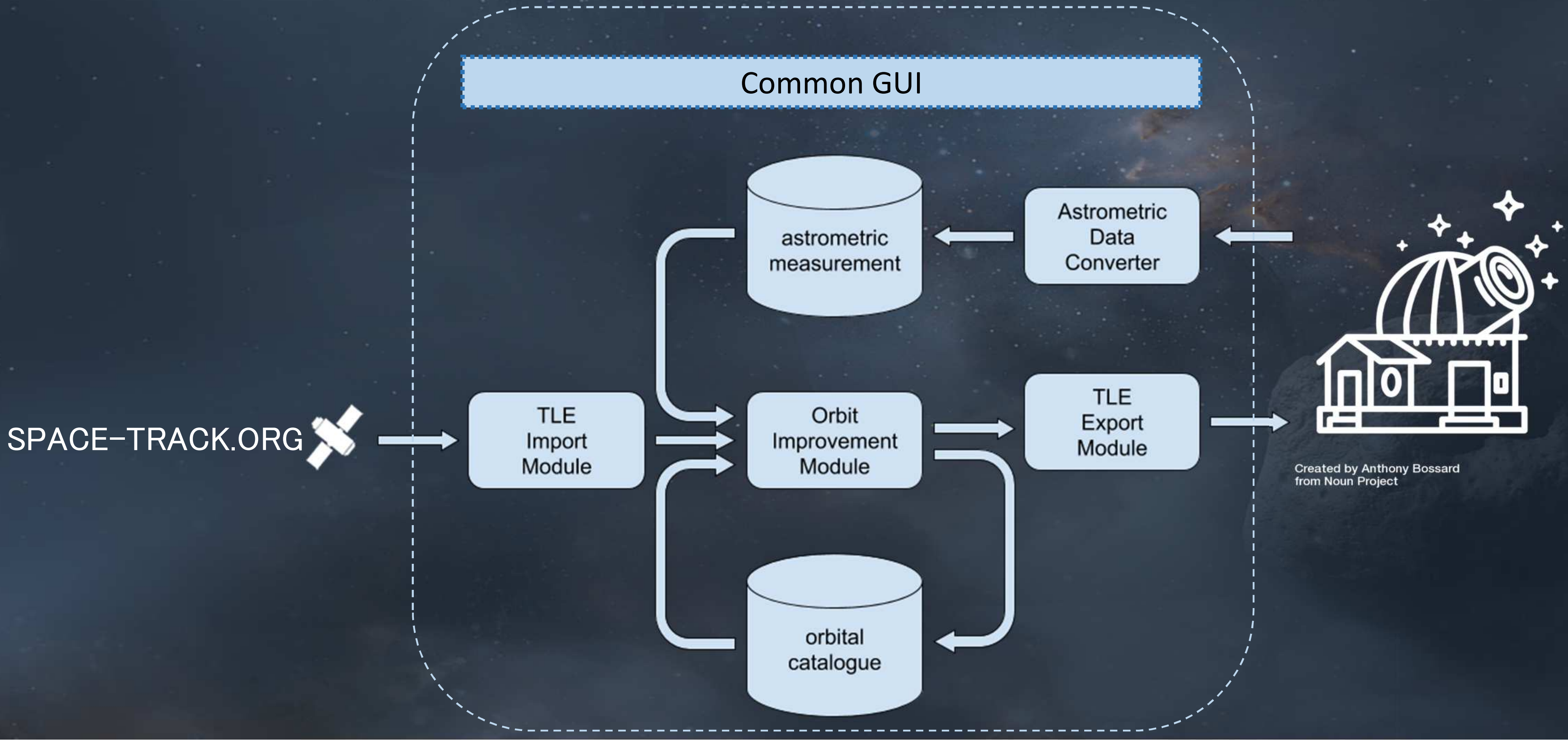
- Orbit (stored in the form of PV – state vectors)
  - Satellite – belongs to an Organisation
  - Calculation – made using a Tool with Parameters
  - MeasurementFile – acquired from an Observer



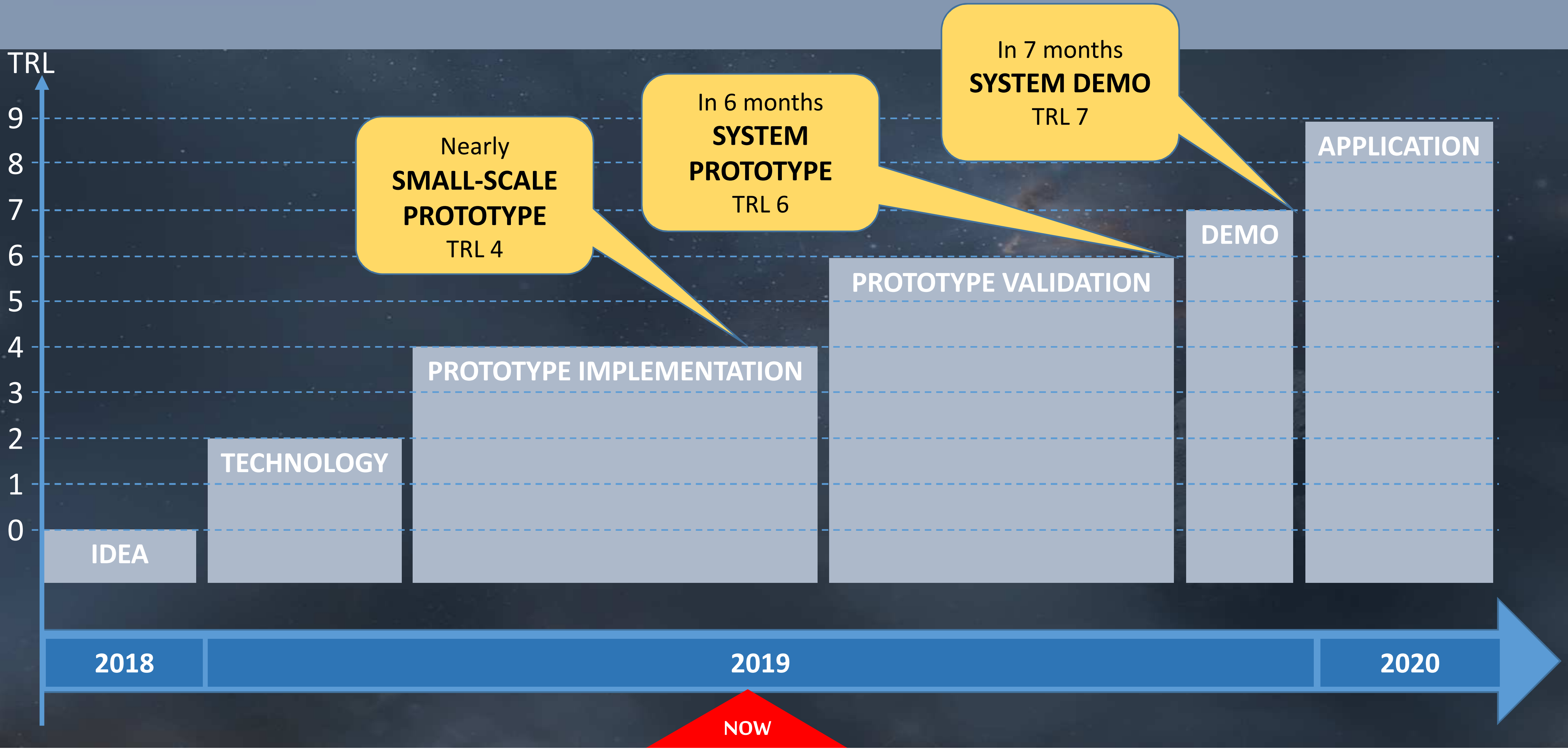
ARCHITECTURE



FACT SHEET

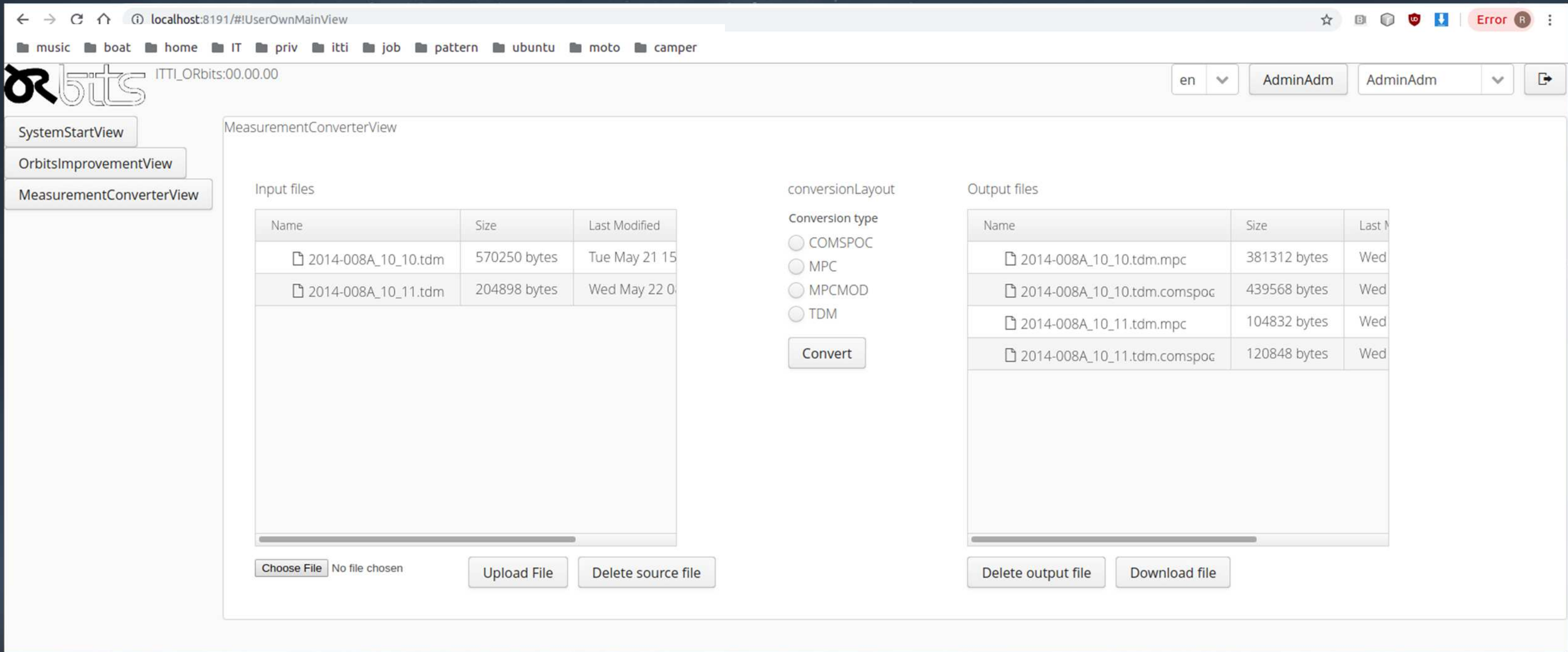
MODULE	OIM Orbit Improvement Module	ADC Astrometric Data Converter	TIM TLE Import Module	TEM TLE Export Module
FUNCTIONALITY	Improvement of the orbital data basing on the optical observation	Cross-conversion among observation measurement format (TDM, ComSpOC, MPC, MPCMOD)	Downloading of TLE data from SPACE TRACK service	Exporting of orbital data in TLE format
APPLICATION TYPE	Web-based app			
LANGUAGE/TECHNOLOGY	Java, Spring, Vaadin			
INSTALLATION	maven, gradle, docker			
MAN-MACHINE INTERFACE	Common GUI			
REMOTE DEPENDENCIES	Orekit v. 9.3			
INTEGRATION TECHNOLOGY	Rest API			
LICENSE	Proprietary			
DATA INTERFACES	Files, DB tables	Files, DB tables	Files, DB tables	Files
INTERNET CONNECTION	Not required	Not required	Required	Not required

READINESS



TRL
9
8
7
6
5
4
3
2
1
0
Nearly SMALL-SCALE PROTOTYPE TRL 4
In 6 months SYSTEM PROTOTYPE TRL 6
In 7 months SYSTEM DEMO TRL 7
IDEA
TECHNOLOGY
PROTOTYPE IMPLEMENTATION
PROTOTYPE VALIDATION
DEMO
APPLICATION
2018
2019
2020
NOW

GUI UNDER CONSTRUCTION



ORBITS

WEB ACCESS MOCKUP

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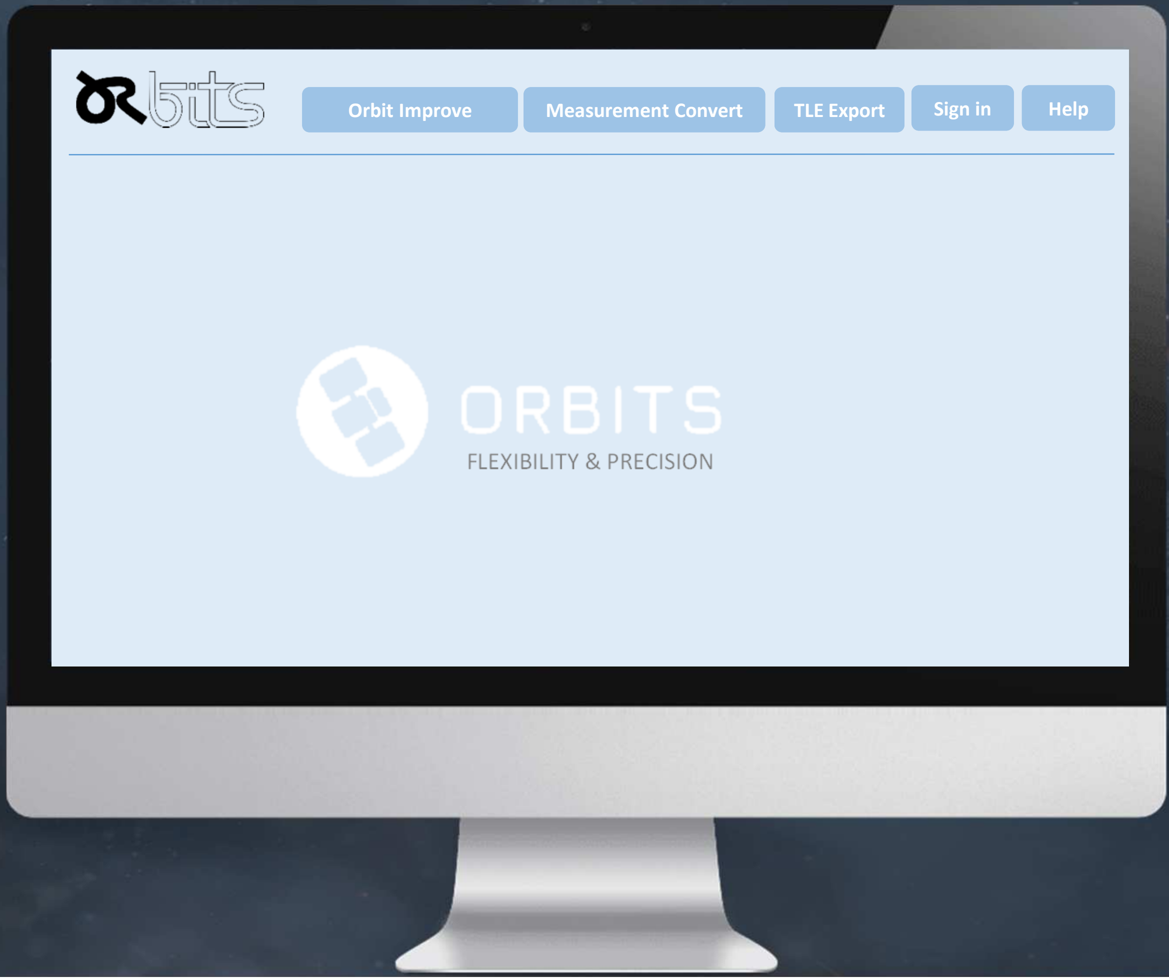
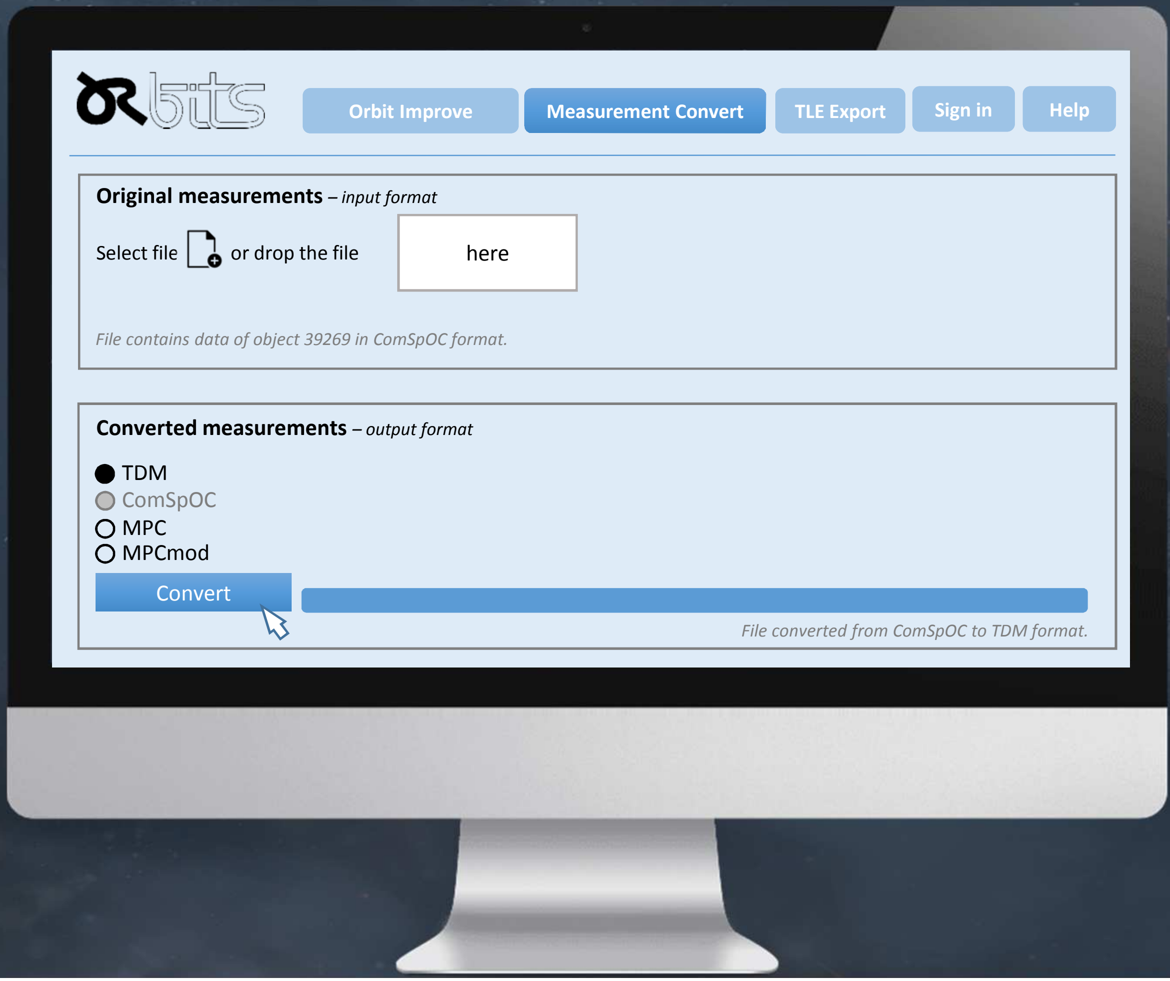
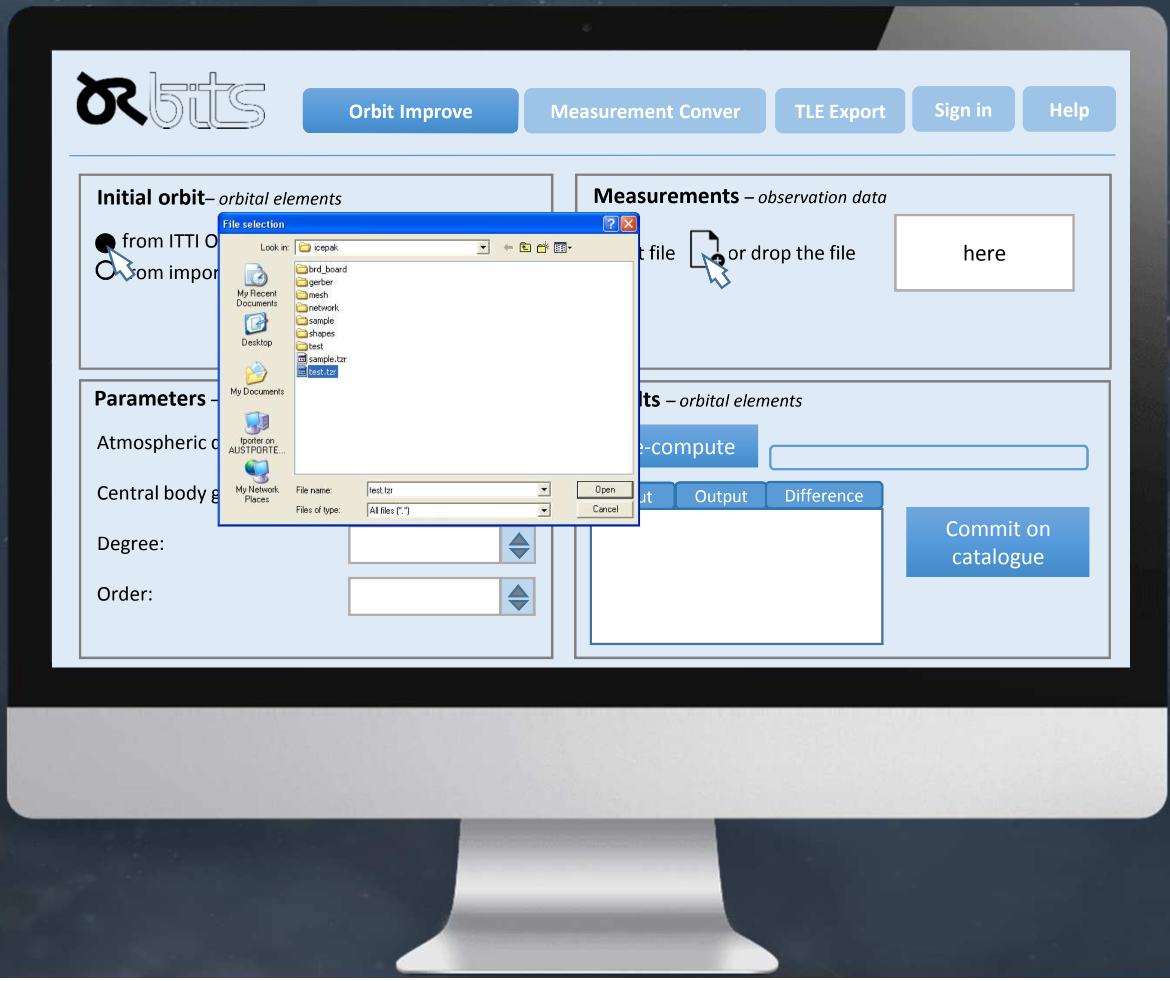


Measurments Conversion – 1/2

Measurments Conversion – 2/2



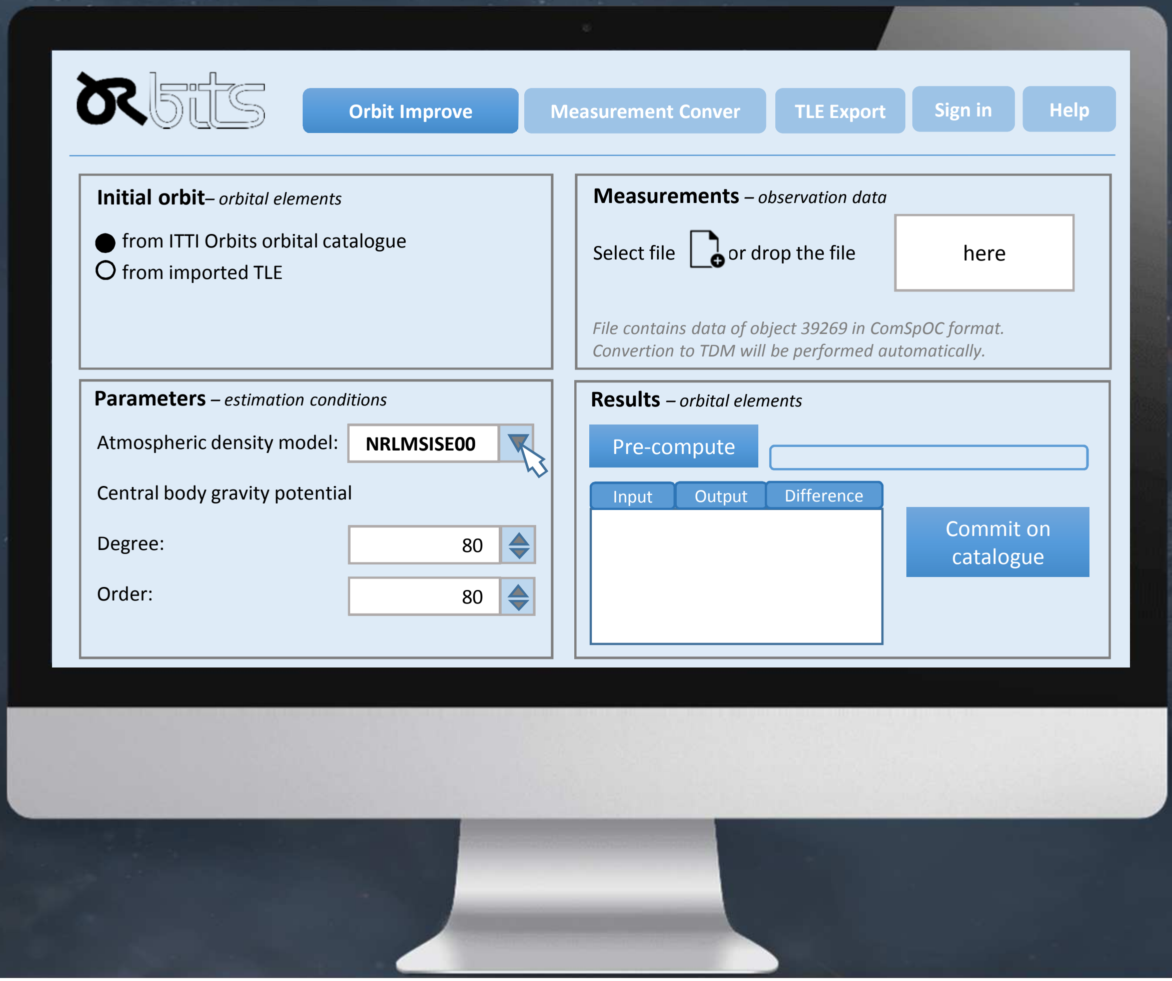
ORBIT IMPROVEMENT 1/4



ORBITS

ORBIT IMPROVEMENT 2/4

iTTi



ORBITS

Orbit Improvement 3/4

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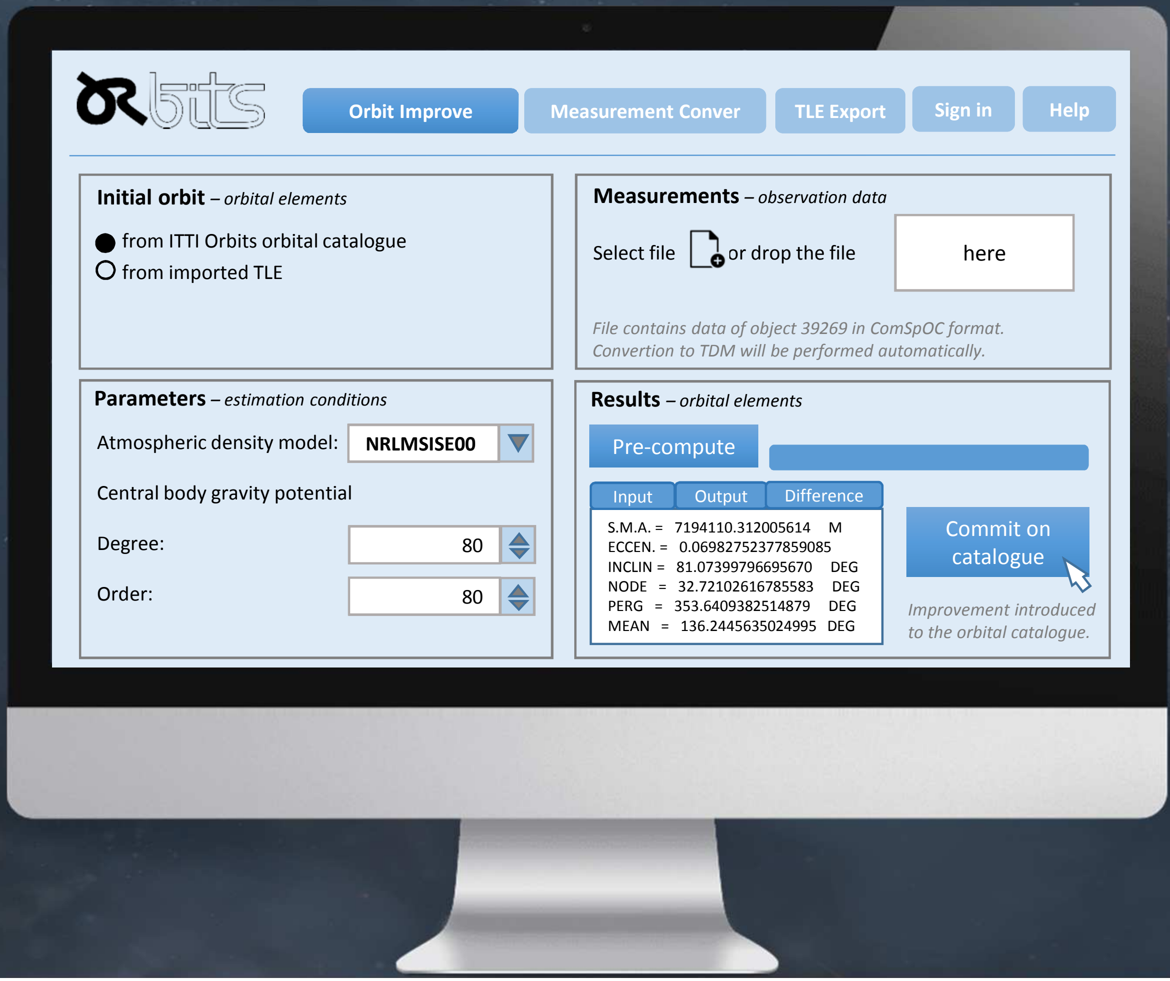
ORBIT IMPROVEMENT 4/4



TESTING OBJECTIVES

- Testing to prove:
  - COMPLETENESS – all required data for satellite orbit catalogue derivable
  - EFFECTIVENESS – can be applied for orbit determination and propagation
  - ACCURACY – uncertainty of results on acceptable level

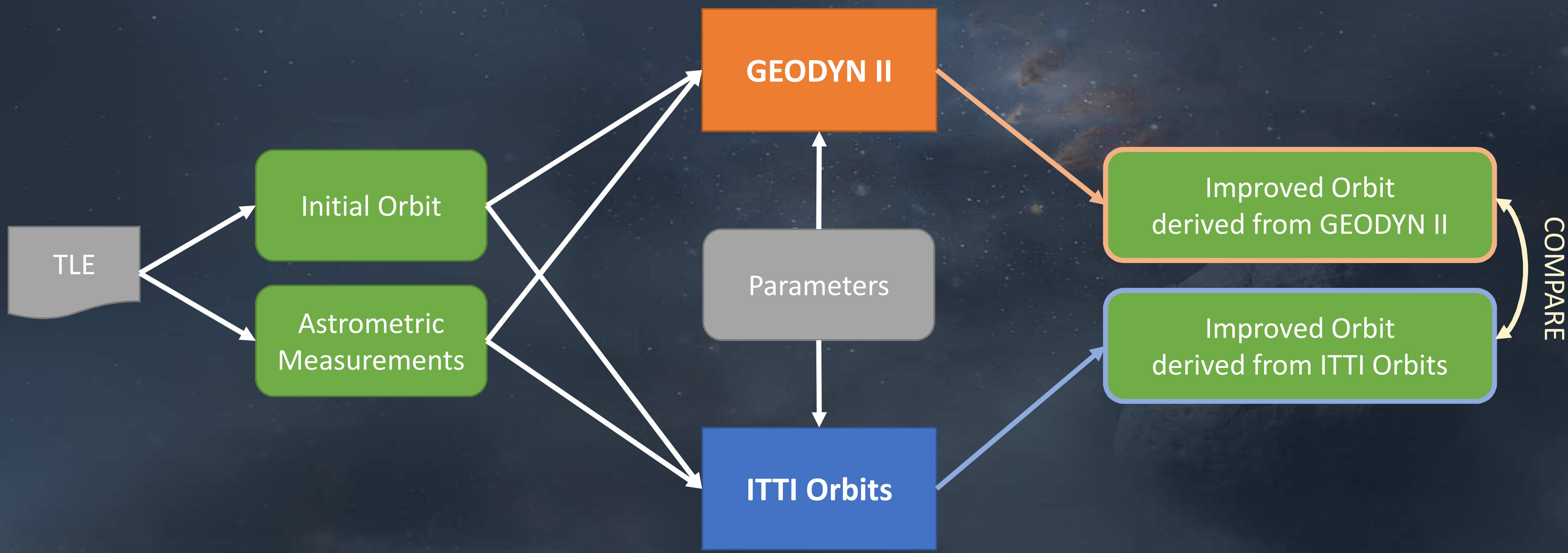
TESTING METHODOLOGY (1/2)

- **Subject:** ITTI Orbits an application based on Orekit v. 9.3 library
- **Method:**
  - comparison of results of ITTI Orbits and the benchmark tool
  - assess accuracy
- **Benchmark:** Geodyn II – a benchmark tool
- **Objects:**

POPACS-2 (USA) id: 39269
Solar influence on upper atmosphere density
Weight 1.5 kg 10-cm sphere
Launched 29 Sep 2013 – LEO
Alt. perigee: 327 km Alt. apogee: 1,313 km
Inclination: 81.0 ° Period: 101.1 min
Semi major axis: 7190 km

NAVSTAR 69/GPS 2F-5 (USA) id: 39533
Navigation Satellite
Weight 1620 kg area 52 m^2
Launched 21 Feb 2014 – MEO
Alt. perigee: 20 081 km Alt. apogee: 20 296 km
Inclination: 53.9 ° Period: 717.9 min
Semi major axis: 26559 km

TEST CASE


GEODYN II
Initial Orbit
TLE
Astrometric Measurements
Parameters
Improved Orbit derived from GEODYN II
Improved Orbit derived from ITTI Orbits
COMPARE
ITTI Orbits

POPACS-2
INPUT

Initial orbit

Orbit Elements	Initial orbit
Epoch	*2018-10-10 07:00:00 UTC*
Semimajor axis	a = 7191568 m
Eccentricity	e = 0.069910
Inclination	i = 81.01571°
Long. of ascending node	Ω = 32.9631°
Argument of perigee	ω = 353.5483°
Mean anomaly	M= 126.322°

Astrometric Measurements:

- 6 night of observation: 24 May – 3 Jun 2018
- Observed 710 images
- 710 measurments in TDM format

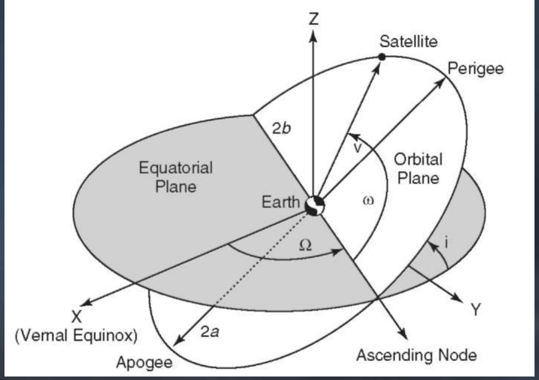
Created by Anthony Bossard from Noun Project

Parameters

Influence	Parameter	GEODYN II	ITTI Orbits
Properties	Mass	1 kg	**1 kg**
Atmosphere	Model	JAACHIA9999	NRLMSISE00
	Area	0.003 m2	0.003 m2
Gravity – Earth	Degree	80	**80**
	Order	80	**80**
Gravity – Sun	Correction	Yes	**Yes**
Gravity – Moon	Correction	Yes	**Yes**
Ocena Tides	Correction	No	**No**
Solid Tides	Correction	No	**No**
Solar Radiation Pressure	Area	0.003 m2	**0.003 m2**
Relativity	Correction	No	**No**
Terrestrial Thermal Radiation	Correction	No	**No**

POPACS-2
OUTPUT OLD

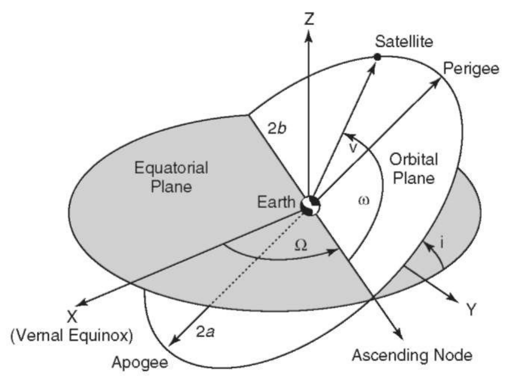
Orbit Elements	GEODYN II	Standard Deviation	ITTI Orbits	Difference	Accuracy
Semimajor axis	a = 7 194 110 m	± 116 m	a = 7 191 570 m	2540 m	D < 23σ
Eccentricity	e = 0.0698273	± 0.0000583	e = 0.071295	0.001468	D < 25σ
Inclination	i = 81.07399°	± 0.00413 °	i = 81.07636°	0.00237 °	D < σ
Long. of ascending node	Ω = 32.72102°	± 0.00524 °	Ω = 32.72686°	0.00583 °	D < 2σ
Argument of perigee	ω = 353.64069°	± 0.32247°	ω = 354.498°	0.857 °	D < 3σ
Mean anomaly	M= 136.245°	± 0.346 °	M = 125.039°	11.206 °	D < 33σ



POPACS-2

OUTPUT

Orbit Elements	GEODYN II	Standard Deviation	ITTI Orbits	Difference	Accuracy
Semimajor axis	a = 7 194 110 m	± 116 m	a = 7 194 116 m	6 m	D < σ
Eccentricity	e = 0.0698273	± 0.0000583	e = 0.070855	0.001028	D < 18σ
Inclination	i = 81.07399°	± 0.00413 °	i = 81.07661°	0.00261 °	D < σ
Long. of ascending node	Ω = 32.72102°	± 0.00524 °	Ω = 32.72530°	0.00427 °	D < σ
Argument of perigee	ω = 353.64069°	± 0.32247°	ω = 354.528°	0.887 °	D < 3σ
Mean anomaly	M= 136.245°	± 0.346 °	M = 135.183°	1.062 °	D < 4σ



NAVSTAR 69
INPUT

ORBITS

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Initial orbit

Orbit Elements	Initial orbit
Epoch	*2018-05-24 03:52:51 UTC*
Semimajor axis	a = 26 558 953 m
Eccentricity	e = 0.003634
Inclination	i = 54.02754°
Long. of ascending node	Ω = 264.1146°
Argument of perigee	ω = 190.285°
Mean anomaly	M= 248.707°

Astrometric Measurements

- 2 nights of observation: 10-11 Oct 2018
- Observed 3615 images
- 3615 measurments in TDM format

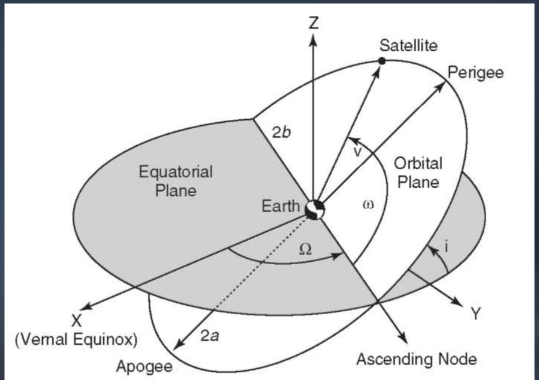
Parameters

Influence	Parameter	GEODYN II	ITTI Orbits
Properties	Mass	1630 kg	**1630 kg**
Atmosphere	Model	JAACHIA9999	NRLMSISE00
	Area	52 m2	52 m2
Gravity – Earth	Degree	80	**20**
	Order	80	**20**
Gravity – Sun	Correction	Yes	**Yes**
Gravity – Moon	Correction	Yes	**Yes**
Ocena Tides	Correction	No	**No**
Solid Tides	Correction	No	**No**
Solar Radiation Pressure	Area	52 m2	**52 m2**
Relativity	Correction	no	**No**
Terrestrial Thermal Radiation	Correction	no	**No**

NAVSTAR 69

OUTPUT

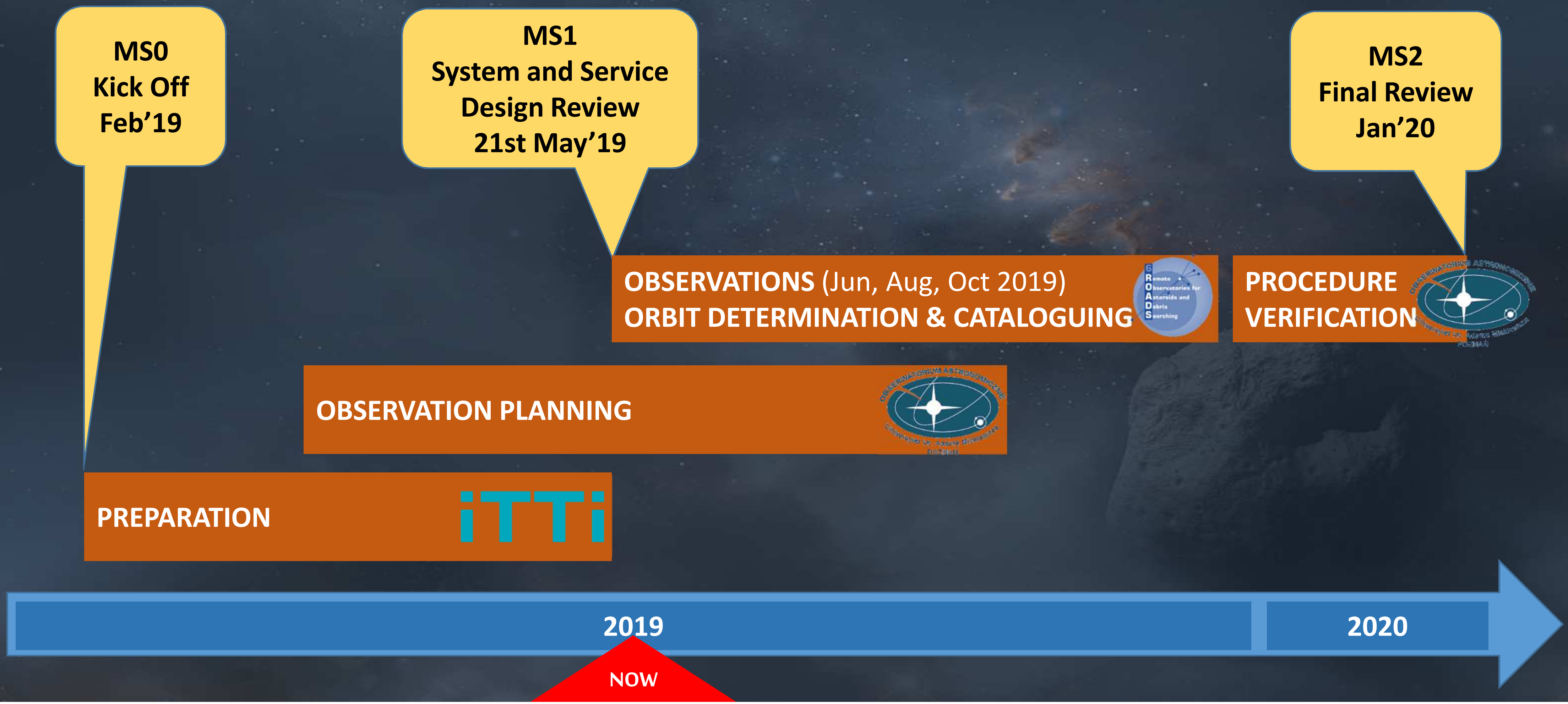
Orbit Elements	GEODYN II	Standard Deviation	ITTI Orbits	Difference	Accuracy
Semimajor axis	a = 26 558 928 m	± 31 m	a = 26 558 912 m	16 m	D < σ
Eccentricity	e = 0.003661	± 0.000043	e = 0.003751	0.000090	D < 3σ
Inclination	i = 53.91037°	± 0.00073 °	i = 53.91342 °	0.00305 °	D < 5σ
Long. of ascending node	Ω = 263.8538°	± 0.0037°	Ω = 263.859 °	0.0051 °	D < 2σ
Argument of perigee	ω = 190.216°	± 0.307°	ω = 191.515 °	1.299 °	D < 4σ
Mean anomaly	M= 248.893°	± 0.303°	M = 247.546 °	1.347 °	D < 5σ



E2EPOC – BASICS

- Opportunity to use ITTI Orbits for orbit determination on real observational data
- Project funded by European Space Agency
- **Title:** End-To-End Procedure for satellite Orbit Catalogue from optical observation
- **Contractor:** 6ROADS – a observation company from Poland
- **Subcontractors:**
  - Astronomical Observatory of Adam Mickiewicz University in Poznań, Poland
  - ITTI, Polznań, Poland
- **Time:** Feb 2019 – Jan 2020
- **Objective:** to design and verify observation procedures for the Polish SST activities
  - To establish an experimental (TRL-5) sensors network simulating future operational SST network
  - To define and test end-to-end procedure of SST observations

E2EPOC - TIMELINE

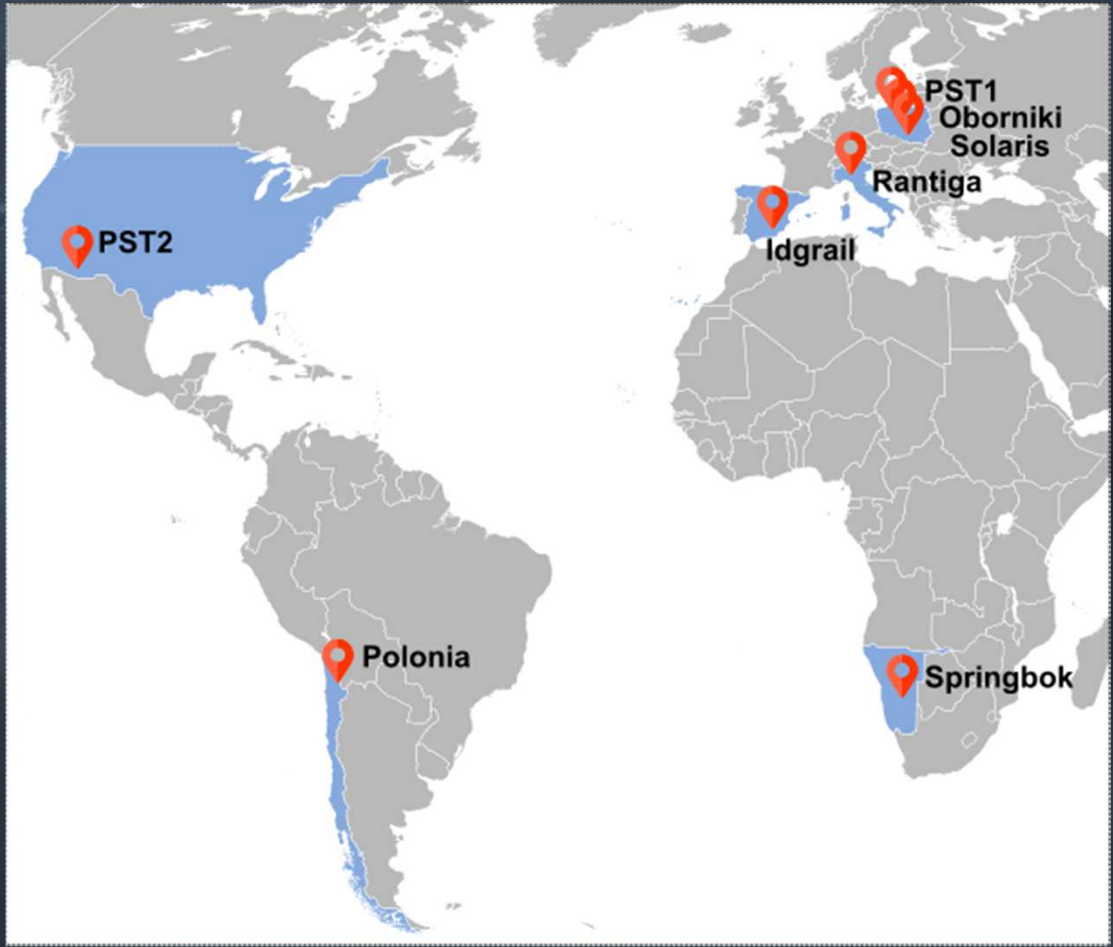


E2EPOC – SENSORS

ORBITS

E2E iTTi

Name	Location	Aperture	FoV	max framerate with 2s exposure time
PST1	Poland	0.5 m	1° × 1°	6 / min
PST2(RBT)	USA	0.7 m	0.16° × 0.16°	30 / min
Rantiga	Italy	0.4 m	1.38° x 1.38°	6 / min
Oborniki	Poland	0.4 m	1.38° x 1.38°	12 / min
Idgrasil	Spain	0.4 m	0.66° x 0.66°	6 / min
Solaris	Poland	0.3 m	0.53° x 0.33°	30 / min
Polonia	Chile	0.4 m	2.34° x 2.34°	12 / min
Springbok	Namibia	0.4 m	1.38° x 1.38°	12 / min



ORBITS

E2EPOC – OBSERVATION

E2E iTTi

- Date: July, September, November 2019
- Target objects: 42 space debris and rocket body at least as high as the Lageos orbit (ca. 6000m)
  - "easy-to-catch" objects – maximum numer of observable passes over all sensors in June 2019
  - typical objects – numer of passes equal to median – six targets from each: GEO, MEO and HEO
  - reference objects – GNSS satellites from the Galileo constellation (six additional targets on MEO) to enable direct comparison of observation and ephemeris

PARAMETERS
MODELS OF ATMOSPHERE

ORBITS

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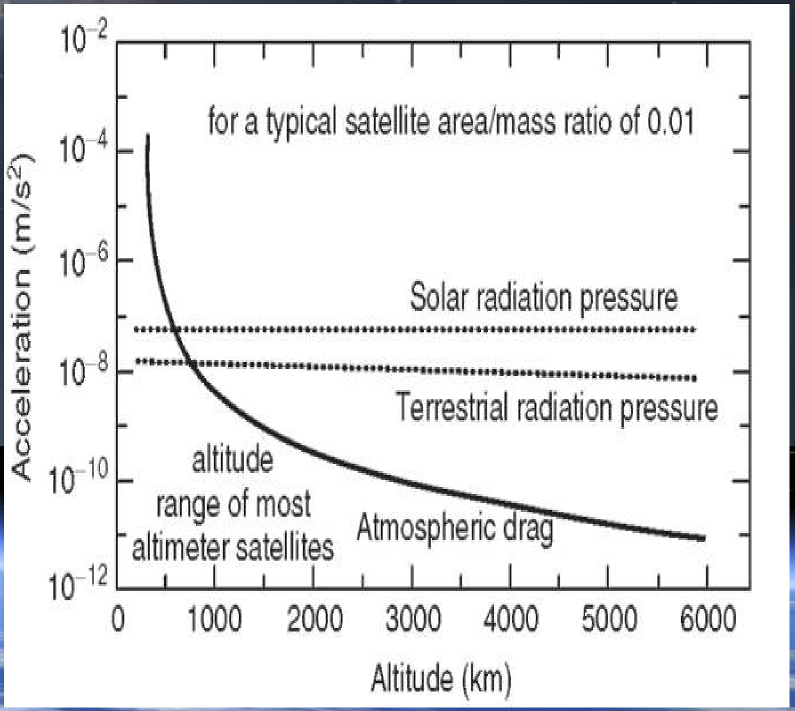
- **NRLMSISE00**
  (NRLMSISE00InputParameters parameters, PVCoordinatesProvider sun, BodyShape earth)
- **DTM2000**
  (safe, CelestialBodyFactory.getSun(), body)
- **HarrisPriester**
  (PVCoordinatesProvider sun, OneAxisEllipsoid earth)
- *JB2008*
  (JB2008InputParameters parameters, PVCoordinatesProvider sun, BodyShape earth)
- *SimpleExponentialAtmosphere*
  (BodyShape shape, double rho0, double h0, double hscale)



POSSIBLE EXTENSIONS

- Input Data Quality Assessment
- Data Source Evaluation
- Systematic Input Data Error Detection and Compensation
- Object Characterisation
- Dynamic 3D Geospatial Visualization – CesiumJS.org

We look for the cooperation opportunities with Orekit expert users and developers.
If you feel you can contribute to this effort contact me after the presentation.

THANK YOU

Presented: Andrzej Adamczyk
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Development and testing team
Prof. Edwin Wnuk, AO AMU
Julia Matysiak, ITTI/AO AMU
Robert Orczyk, ITTI

In presentations we used fragments of the following publications:

Jerome R. Vetter, *Fifty Years of Orbit Determination: Development of Modern Astrodynamics Methods*, Johns Hopkins APL Technical Digest, Volume 27, Number 3 (2007)

Precision Orbit Determination For Earth Observation Systems, http://what-when-how.com/space-science-and-technology/precision-orbit-determination-for-earth-observation-systems/