6th International Conference on Astrodynamics Tools and Techniques

SENSOR FUSION ANALYSIS FOR HEO SPACE DEBRIS USING BAS³E

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Darmstadt

OUTLINE

- INTRODUCTION TO BAS3E SIMULATION BENCH
- TEST SCENARIOS DEFINITION
- VISIBILITY ANALYSIS
- ORBIT DETERMINATION RESULTS
- CONCLUSION

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- **INTRODUCTION TO BAS3E SIMULATION BENCH**
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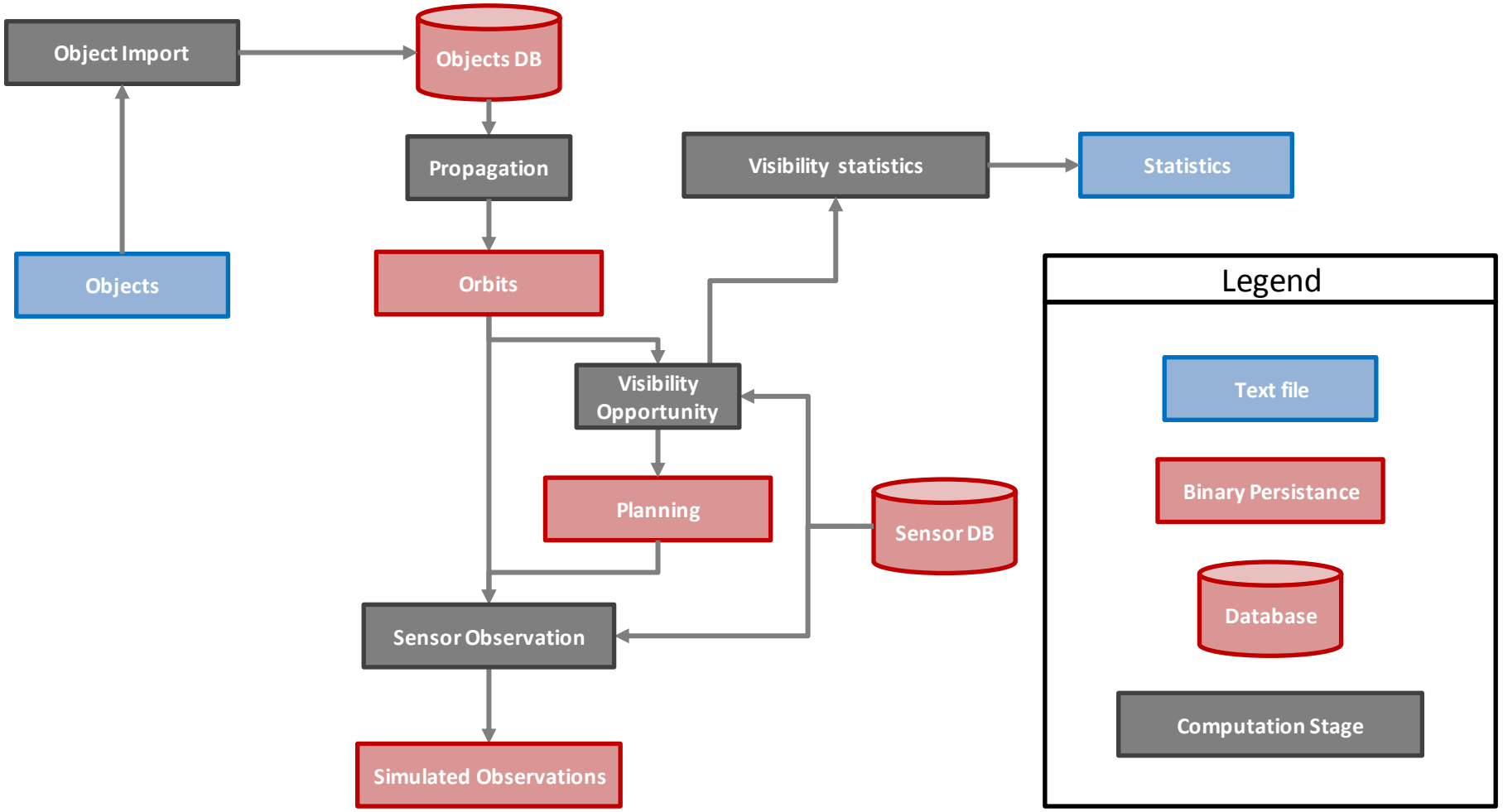
BAS³E SIMULATOR

- BAS³E is a CNES tool that enables the analysis of the performance of space surveillance networks (on-ground or space-based) as well as the algorithms involved in the catalogue maintenance, analysis and planning systems
- Simulator architecture and MMI under Eclipse RCP
- Based on CNES-own JAVA flight dynamics libraries
- Parallel computing
- Executed on CNES clusters

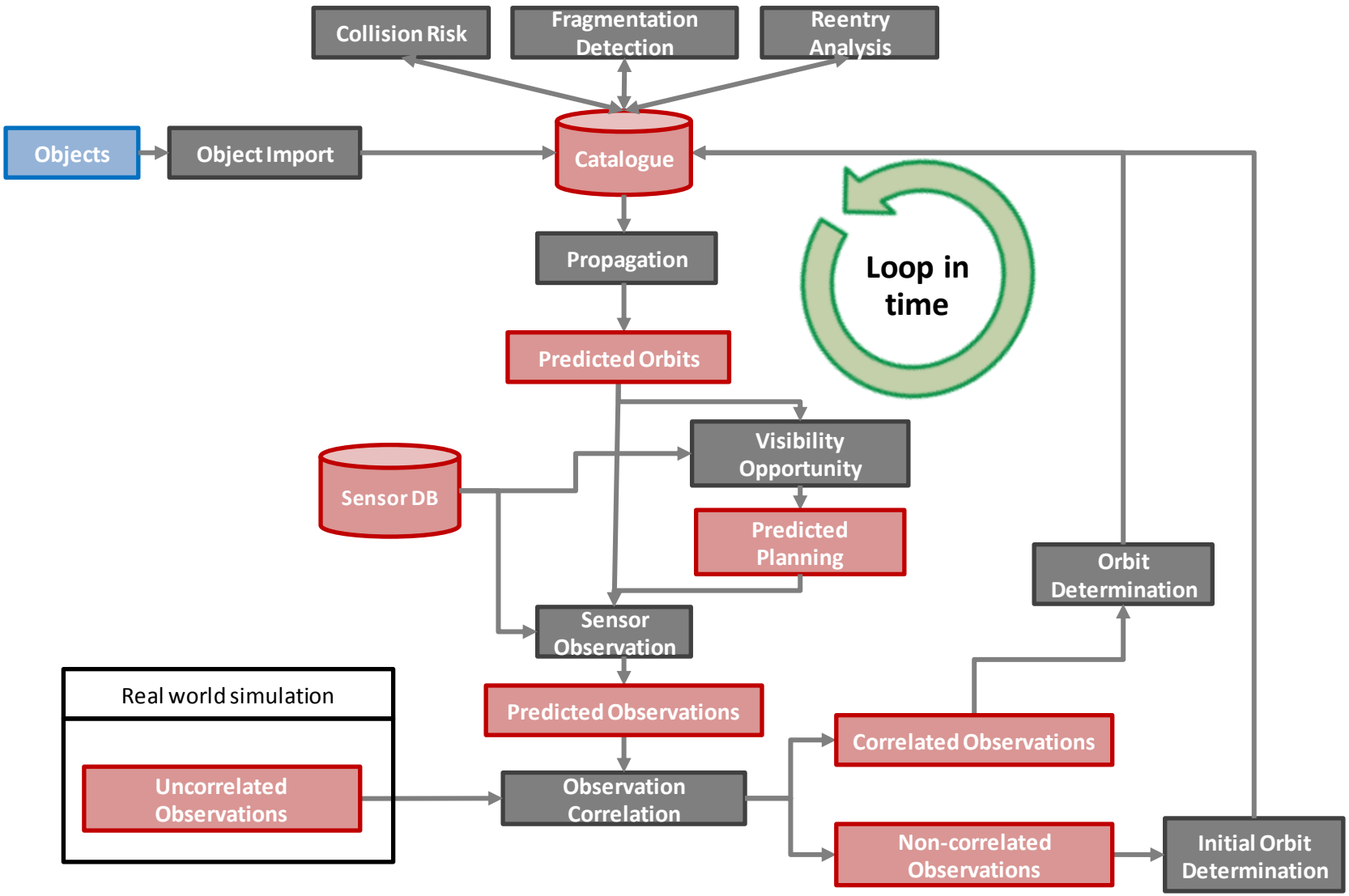
Need of simulating thousand of space debris objects

- Independent computation stages linked by different persistence means:
  - SQL Databases : object DB, sensor DB, …
  - Binary files databases: ephemeris files, observations files, …
  - ASCII files

STAGES LINKAGE – REAL WORLD



STAGES LINKAGE – SSA SYSTEM



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OBJECTS POPULATION

- Objects list comes from 2009 ESA-MASTER population database of objects larger than 10 cm in or crossing the LEO region> 20 000 objects
- Constraints on maximal perigee altitude (600 km) and minimal apogee altitude (10000 km)

eccentricity > 0.4

Number of objects : 2139

- Propagation to obtain reference/predicted orbits:

Objects (%)

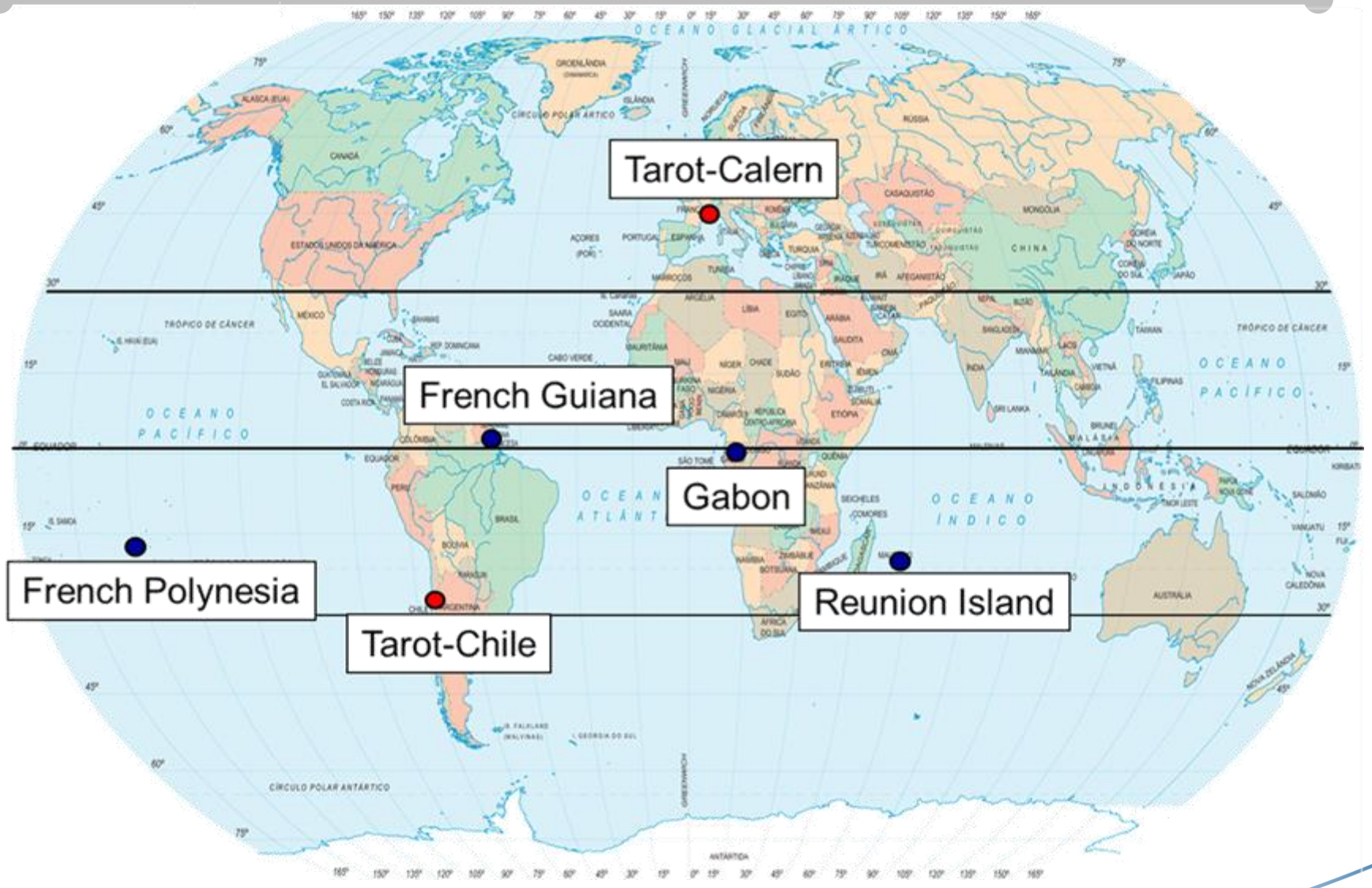
In real world simulation

- Earth potential up to 12th order and 12th degree.
- Drag force with MSIS2000 model for atmospheric density.
- Luni-solar perturbations.
- Solar Radiation Pressure.

In SSA system simulation

- Earth potential up to 6th order and 6th degree.
- Drag force with MSIS2000 model for atmospheric density.
- Luni-solar perturbations.

SENSORS LOCATION



TYPE OF SENSORS

Telescopes (one only type)

- Measurement noise: 3,0 mdeg
- Time between observations: 30 s
- Visibility constraints:
  - Object elevation(0-90 deg)
  - Object distance(> 20 000 km)
  - Night: Sun-Zenith angle(113-180 deg)
  - Illumination: object illuminated by the Sun

Radars (two types)

- Measurement noise : see table
- Time between observations : 5 s
- Visibility constraints :
  - Object elevation (0-90 deg)
  - Object distance (100 - 2 000 km)

Noise	Distance Radar (DIS)	Doppler Radar (DOP)
Angular measurement	10.0 mdeg	10.0 mdeg
Range/Range rate measurement	10 m	1 m/s

- Sensor Location
- Type of sensor

SENSOR NETWORKS

Name	Composition
0T4R	French Guiana + Reunion Island + French Polynesia + Gabon
2T0R	TAROT
2T1R	TAROT + French Guiana
2T2R	TAROT + French Guiana + Reunion Island
2T3R	TAROT + French Guiana + Reunion Island + French Polynesia
2T4R	TAROT + French Guiana + Reunion Island + French Polynesia + Gabon

Plus a suffix indicating the type of radar, for instance, 0T4R-DOP

Total number of sensor networks : 11

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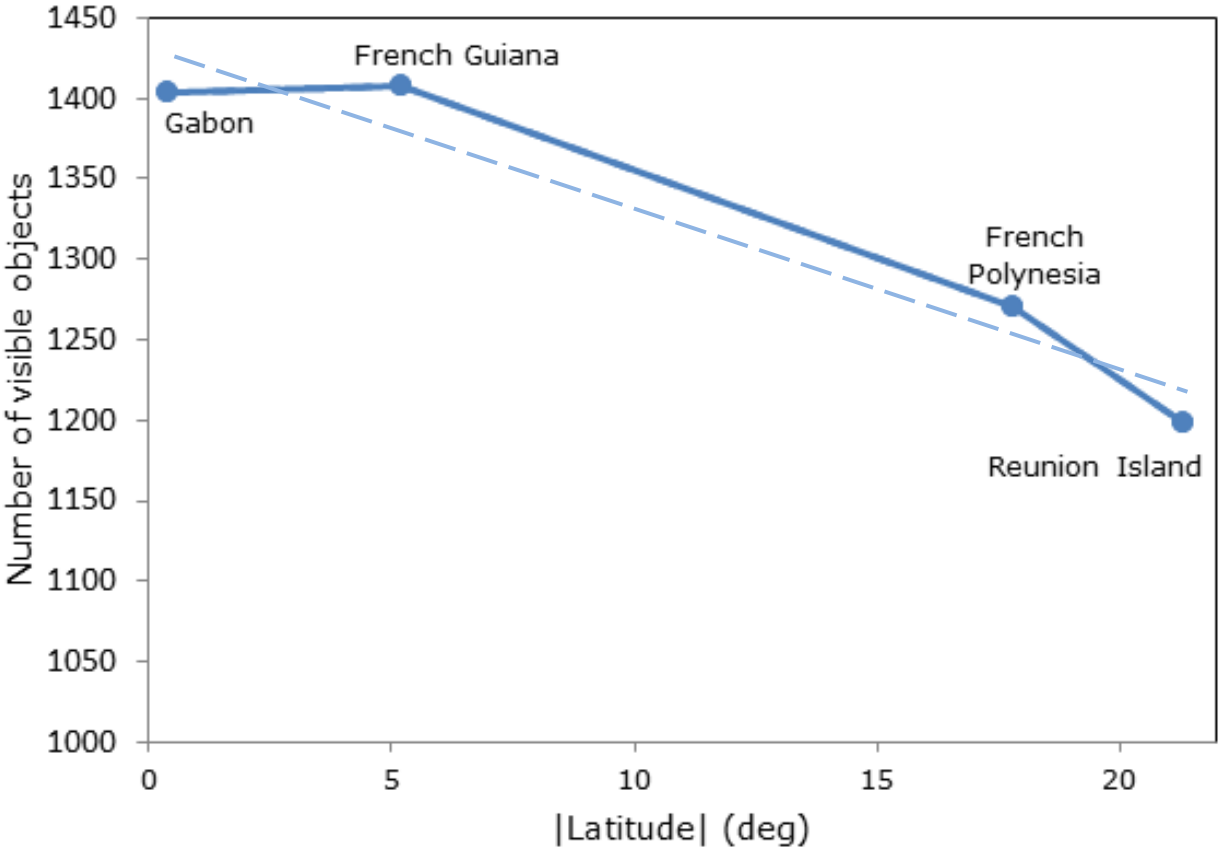
VISIBILITY STATISTICS

- **Visibility opportunities**: how many objects? How often?
- **Visibility duration**: how long?
- **Sensor load**: how many objects simultaneously?

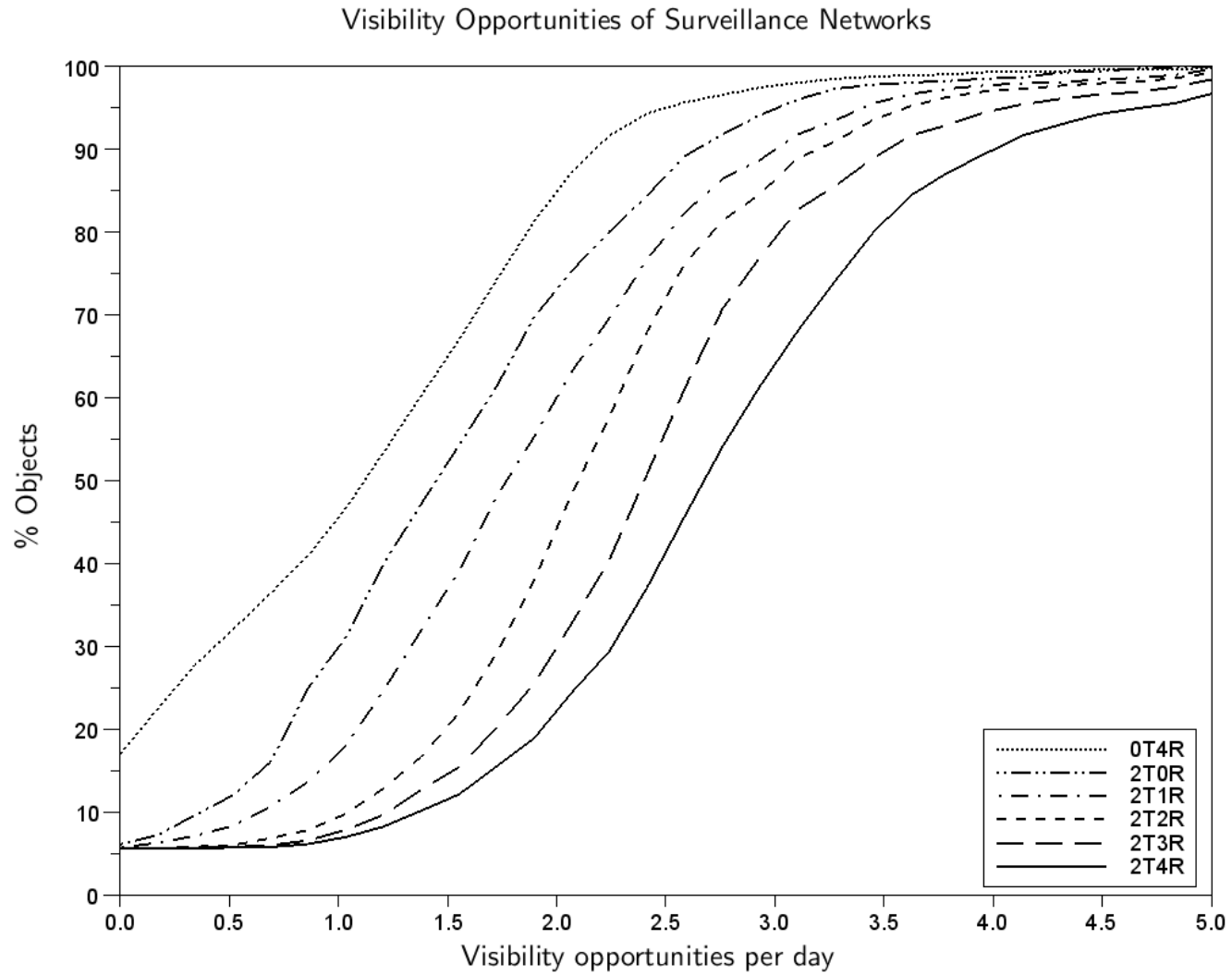
We present visibility statistics for the 2139 objects population within a 6 days timespan

VISIBILITY OPPORTUNITIES - RADARS

Latitude dependence

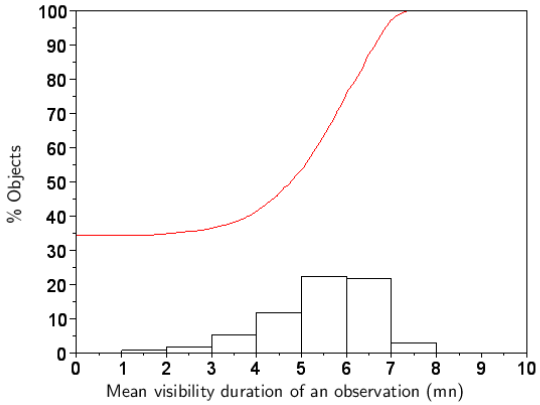


VISIBILITY OPPORTUNITIES - NETWORKS

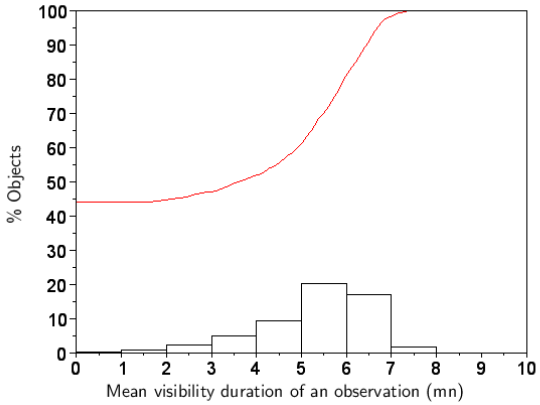


VISIBILITY DURATION

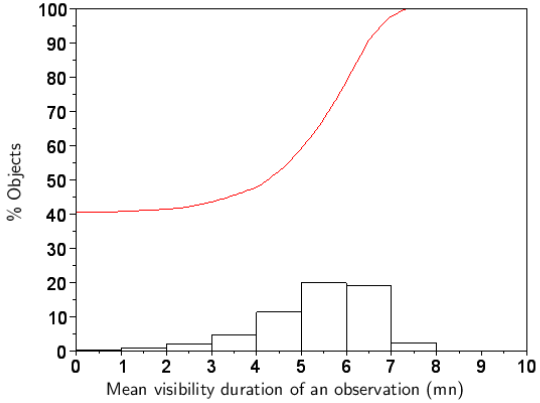
French Guiana



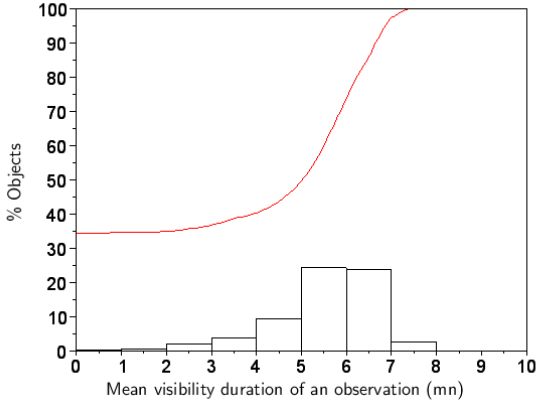
Reunion Island



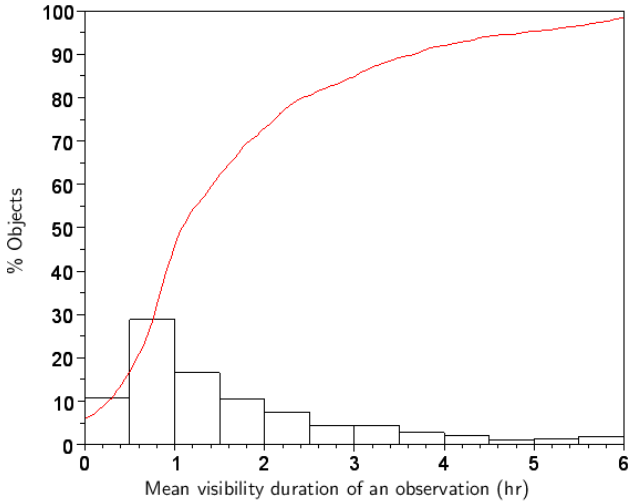
French Polynesia



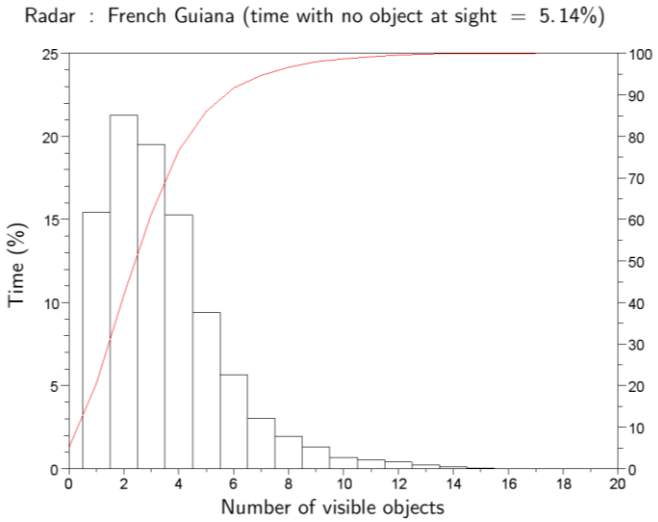
Gabon

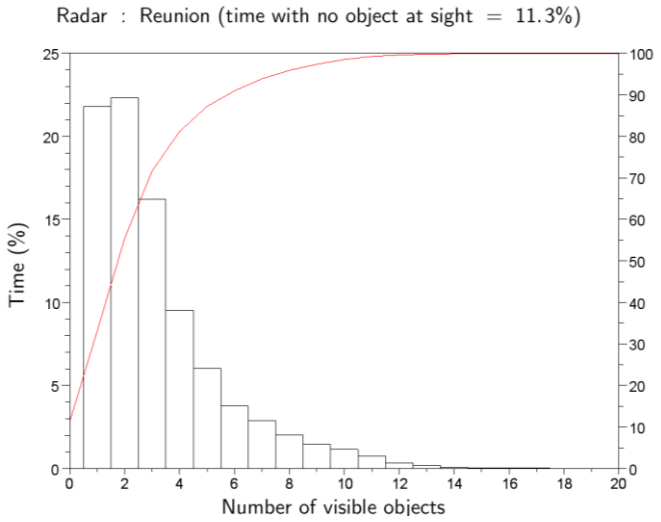


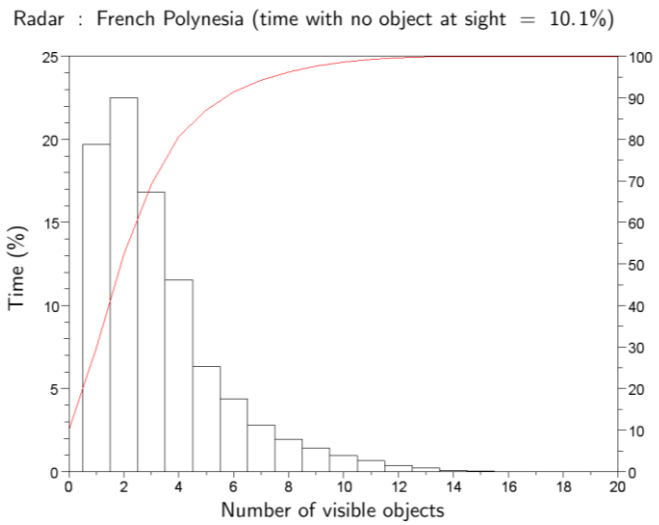
Telescopes

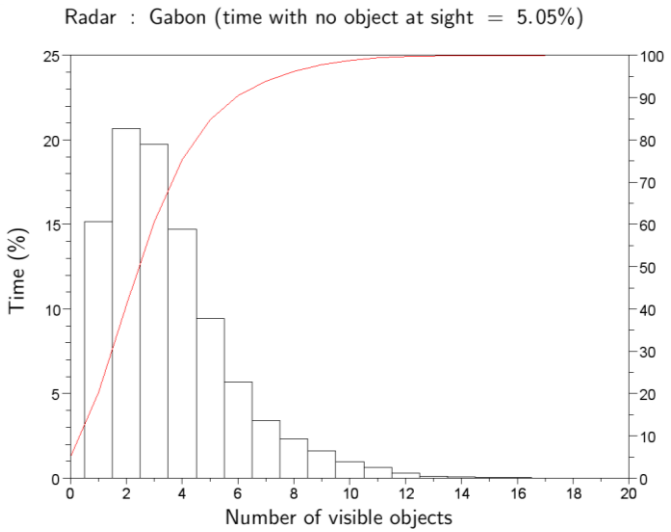


SENSOR LOAD - RADARS





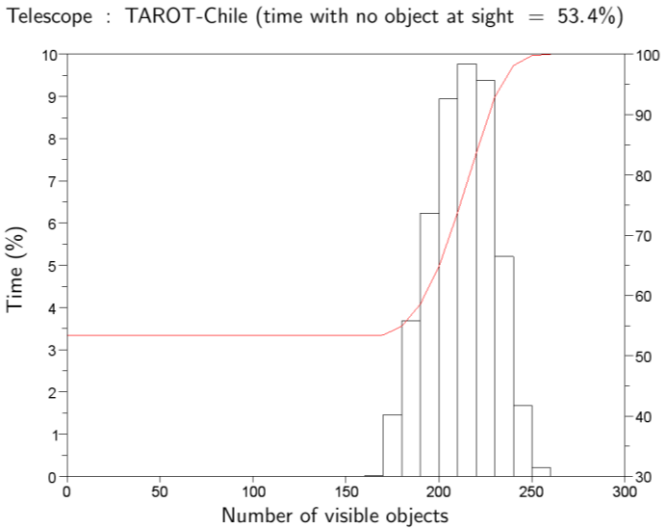


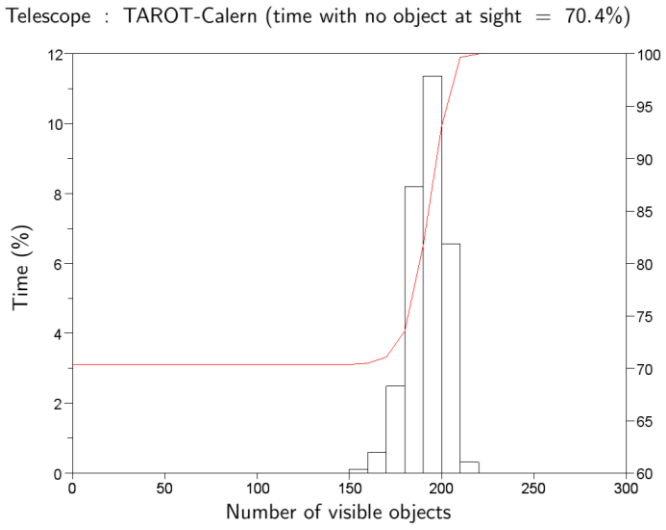


20 – 30% of the time radars are observing one object or none: normal load

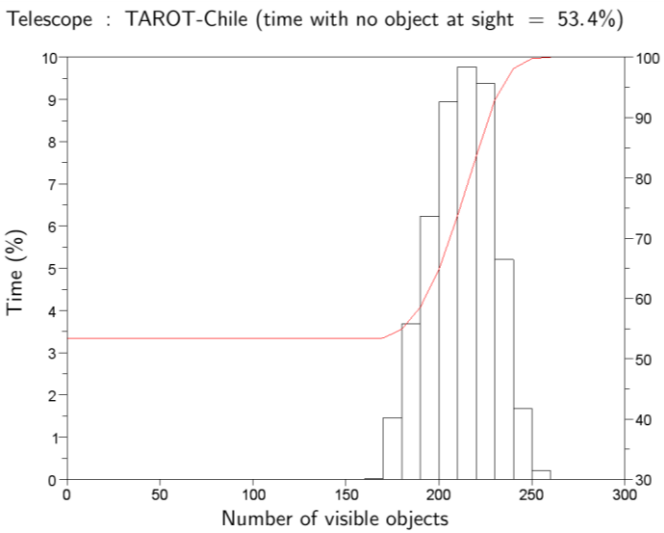
➔ Importance of the sensors planning algorithm (this year's new feature)

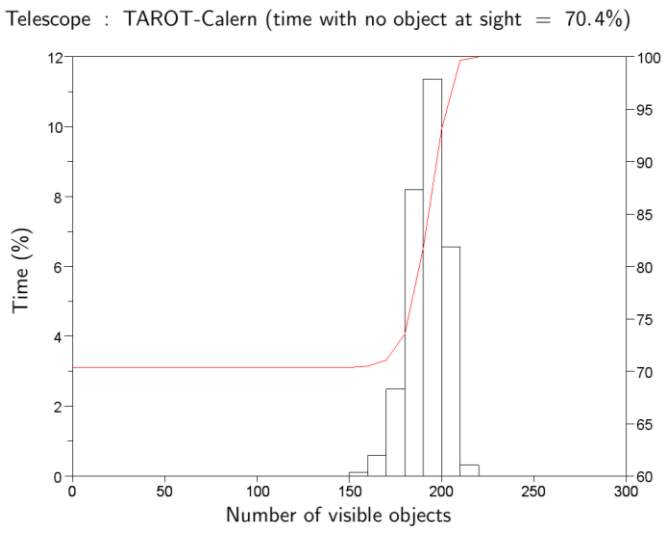
SENSOR LOAD – TELESCOPES

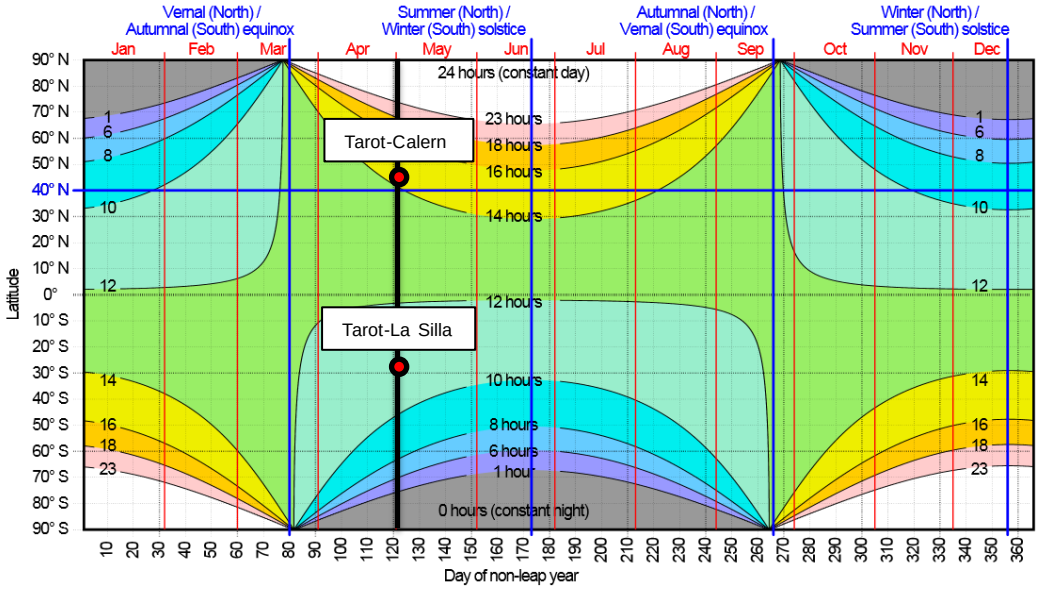




SENSOR LOAD – TELESCOPES







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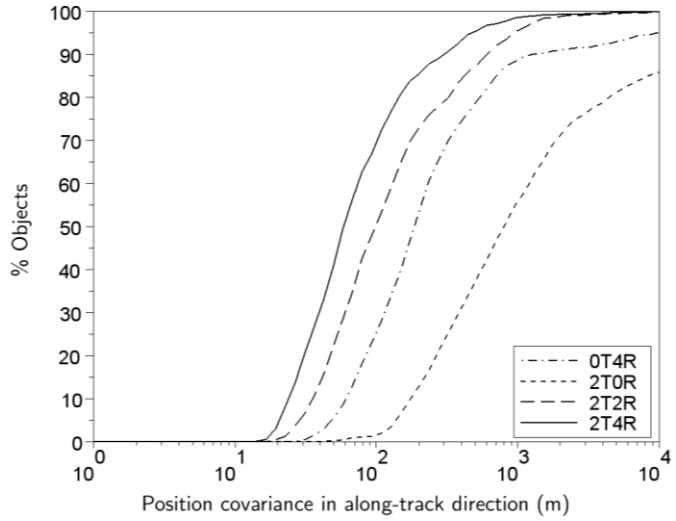
ORBIT DETERMINATION WITH LSM

- Time span of orbit determination : 6 days
- Initial state vector of space debris objects is not perturbed
- Initial covariance in TNW frame :
  - Position sigma vector = (10 km, 5 km, 5 km) et
  - Velocity sigma vector = (10 m/s, 5 m/s, 5 m/s)
- Simplified dynamical model w.r.t. the model used in the real world simulation
- Estimation of a dynamical parameter related to the drag force
- Orbit determination using :
  - Least squares method (LSM) : results follow
  - Extended Kalman Filter (EKF) : similar results to LSM

FINAL COVARIANCE IN ALONG-TRACK DIRECTION

LSM (6 days) - Doppler case



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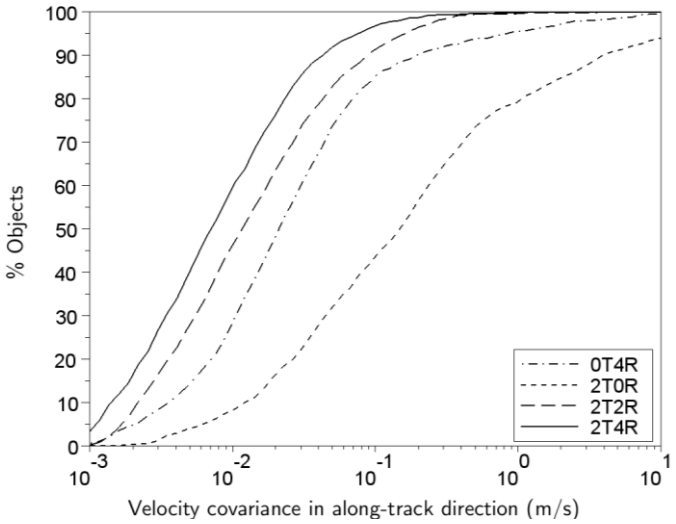
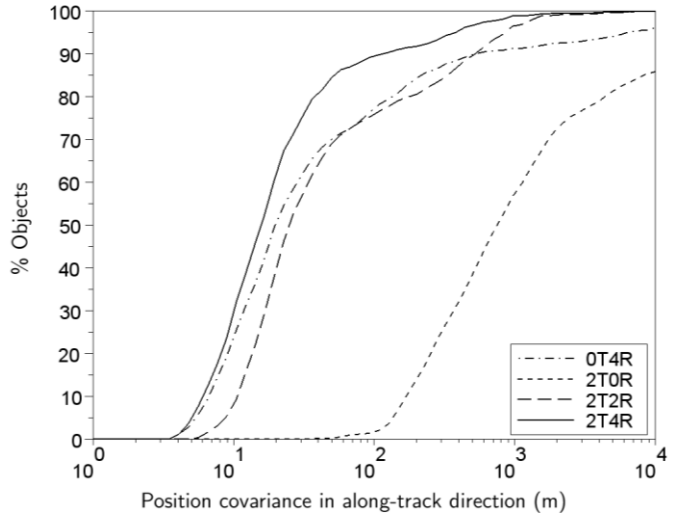
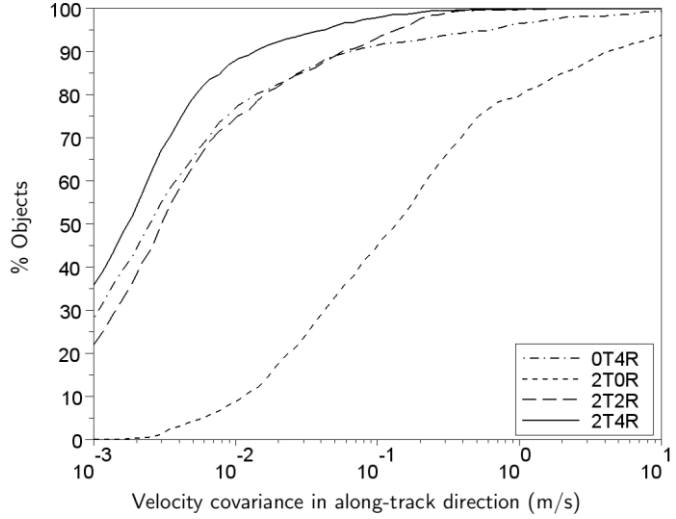


LSM (6 days) - Distance case



LSM (6 days) - Distance case



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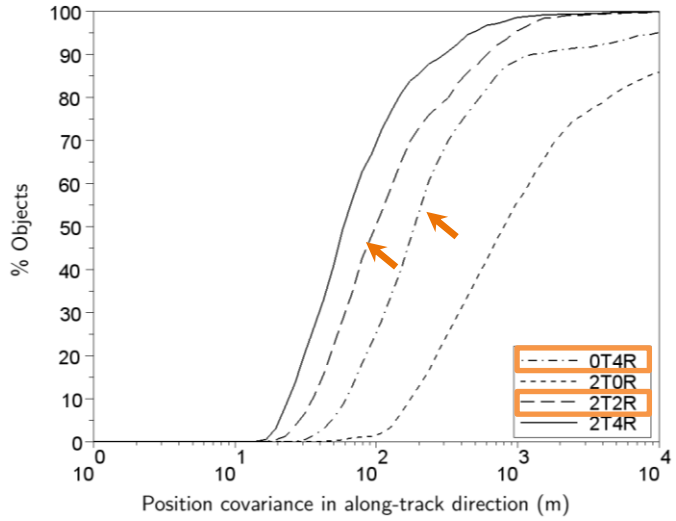
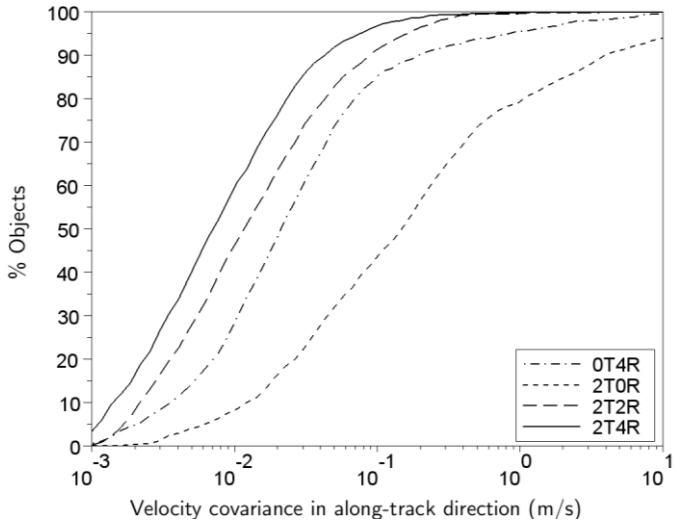


LSM (6 days) - Doppler case



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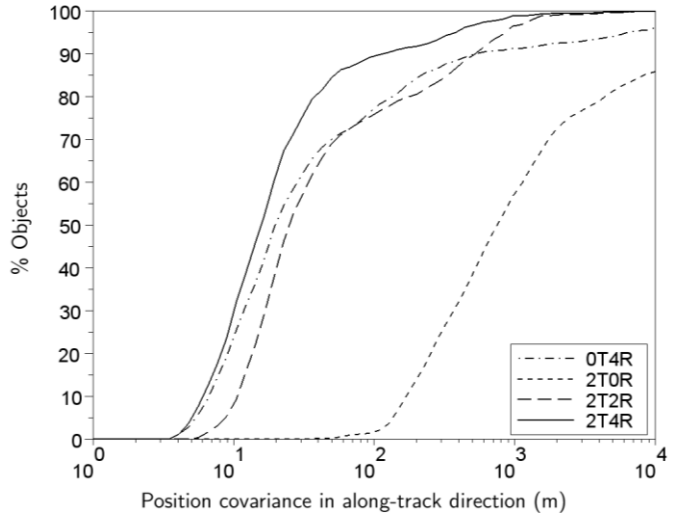

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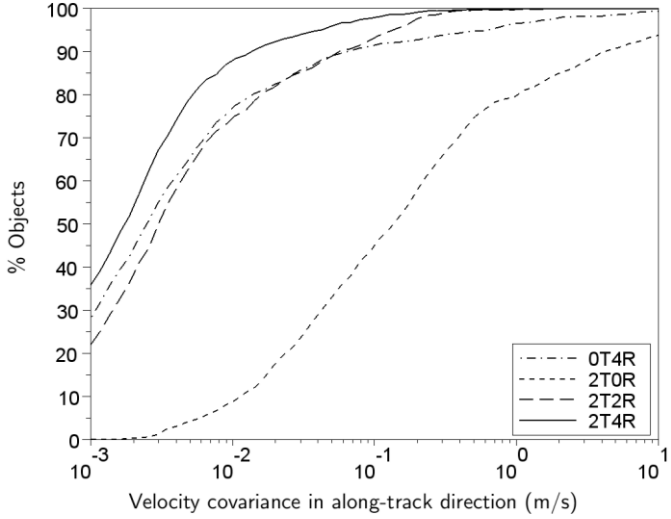
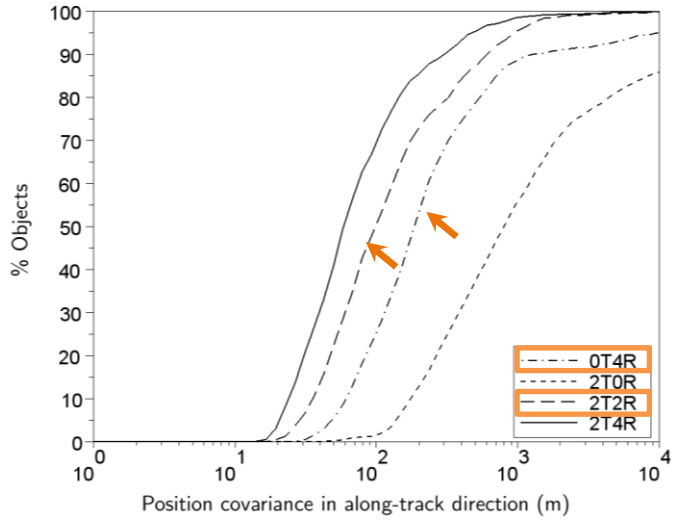


FINAL COVARIANCE IN ALONG-TRACK DIRECTION

LSM (6 days) - Doppler case



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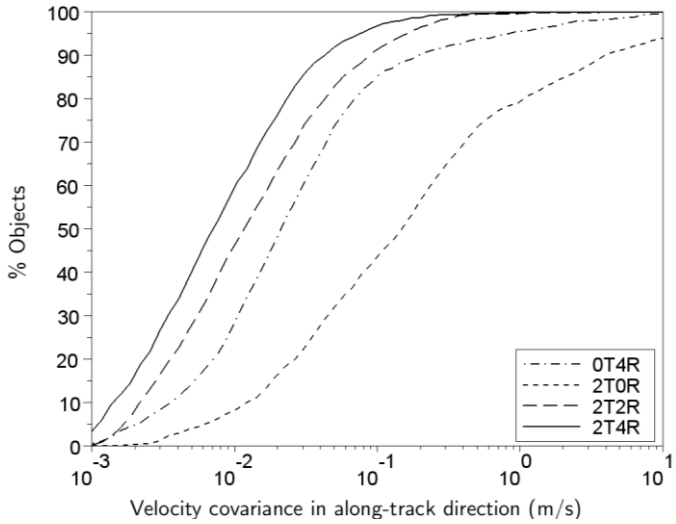
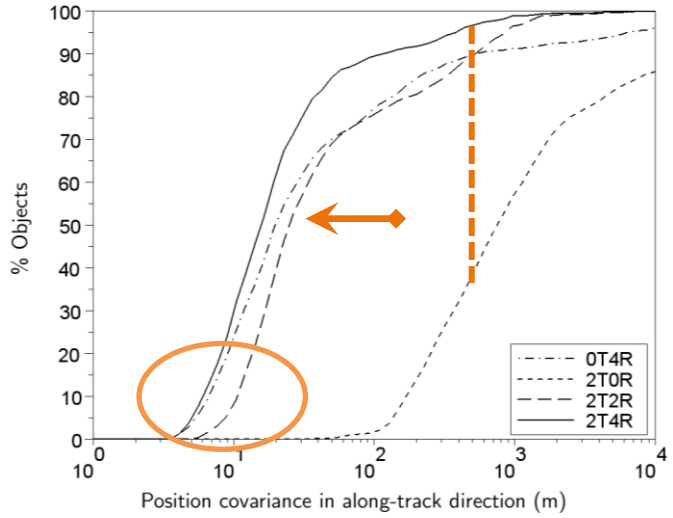
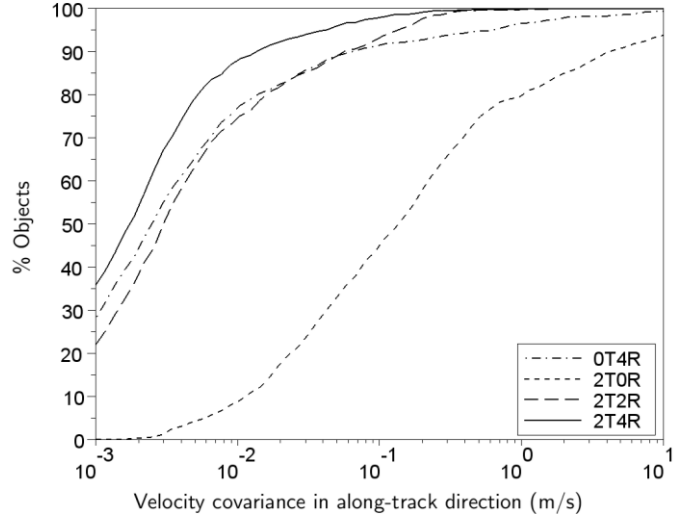


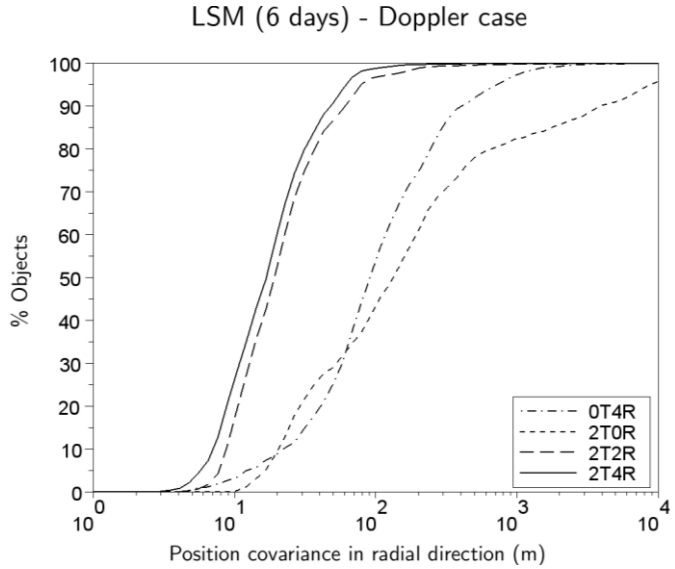
LSM (6 days) - Distance case

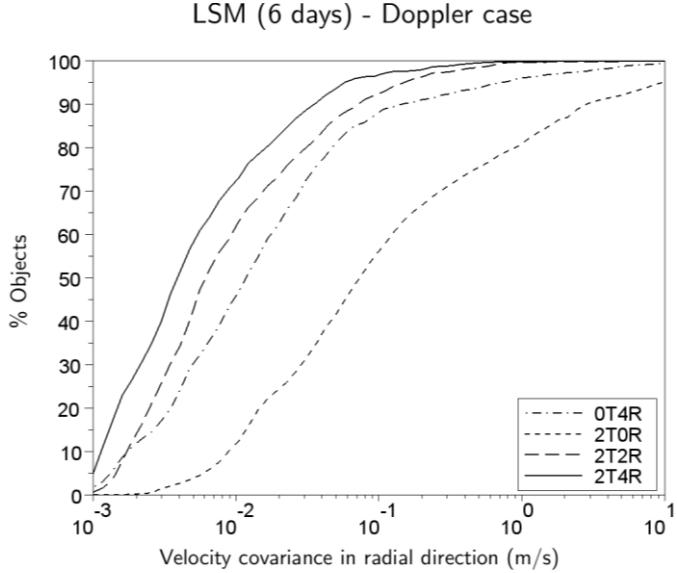


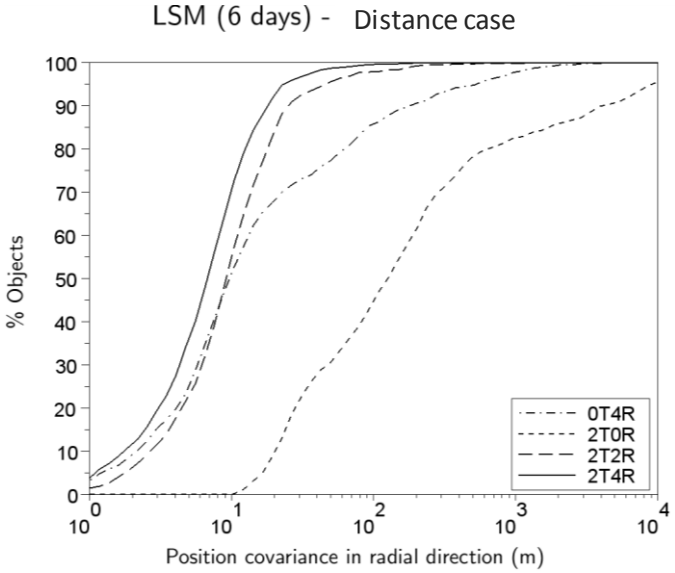
LSM (6 days) - Distance case

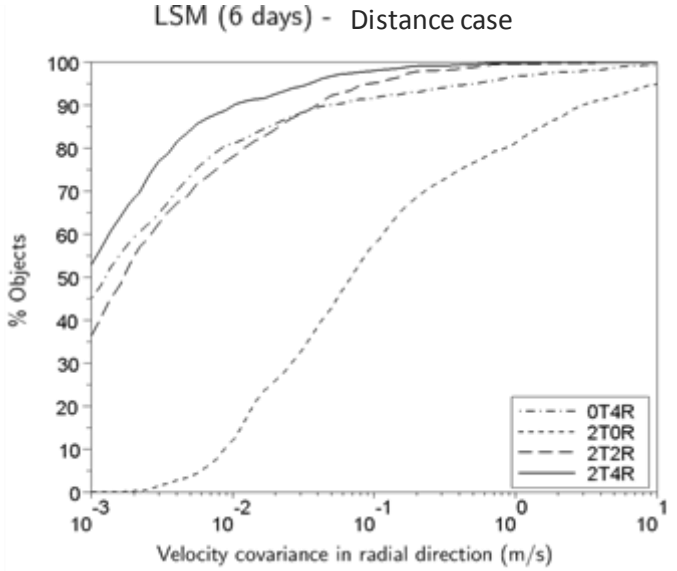


FINAL COVARIANCE IN RADIAL DIRECTION

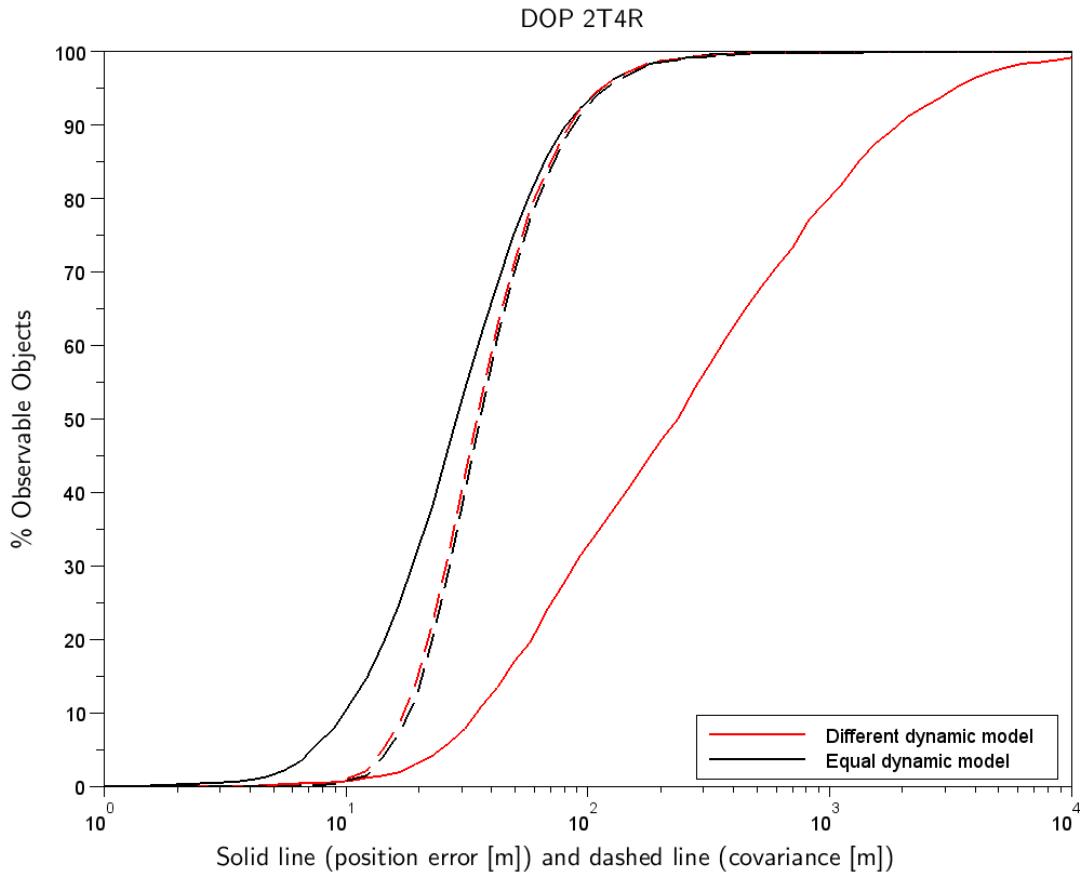








COVARIANCE REPRESENTATIVITY



Dynamical model must be close to real one for the covariance to be representative of the error → need for estimating more dynamical parameters of poorly-known forces.

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CONCLUSIONS

- BAS3E is a modular and flexible tool that enables to perform a large variety of simulations for analyzing the capabilities and performance of space surveillance systems in different scenarios.

- Sensor data fusion presents advantages with respect to the use of single-type sensor networks for the orbit determination of HEO objects. In particular:
  - Number of accessible objects is increased,
  - Possibility of observations on perigee (drag coefficient estimation) and apogee (sun radiation pressure coefficient estimation) → Improves covariance representativity,
  - Covariance in 2T2R cases is in general better than in 0T4R case.