DESIGN OF OPTIMAL OBSERVATION STRATEGY FOR RE-ENTRY PREDICTION IMPROVEMENT OF GTOs UPPER STAGES

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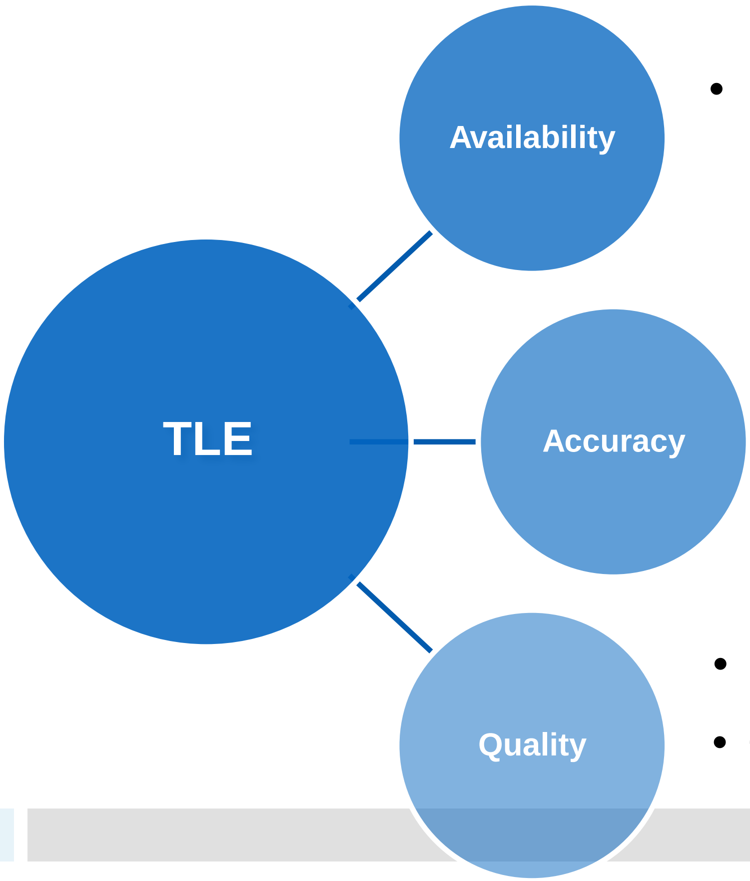
"ITT AO/1-8155/15/D/SR Technology for Improving Re-Entry Predictions of European Upper Stages through Dedicated Observations"

- Improvement based on Two Line Elements (TLE)



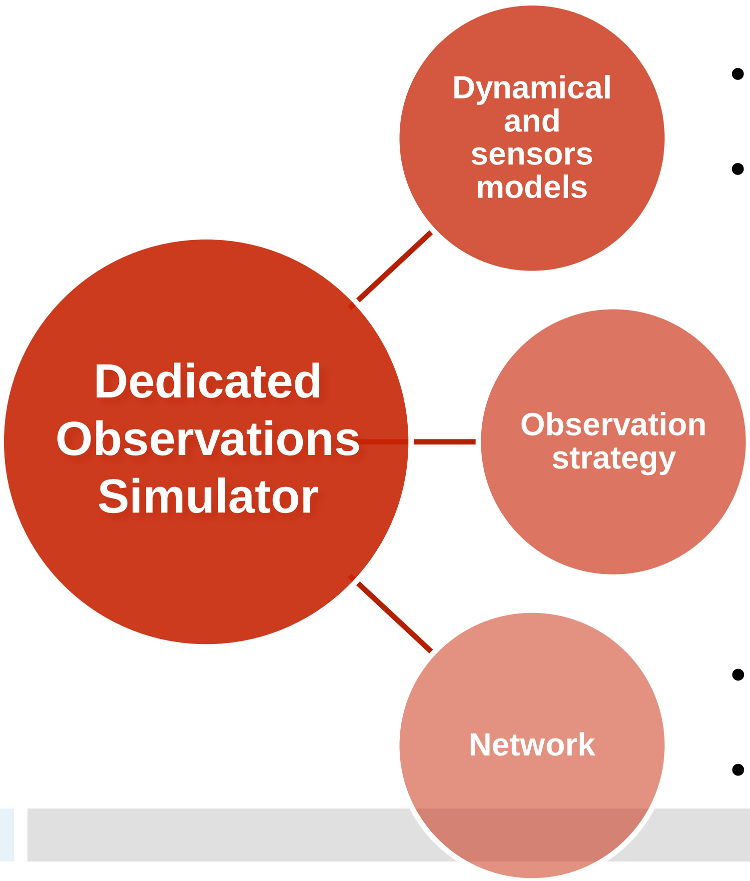
- Public data source available from USSTRATCOM

- Typically low
- Without uncertainty information (i.e. covariance matrix)

- Not homogeneous
- Complex estimation of BC and SRPC (need of filtering techniques)

POTENTIAL APPROACHES

- Improvement through dedicated observations



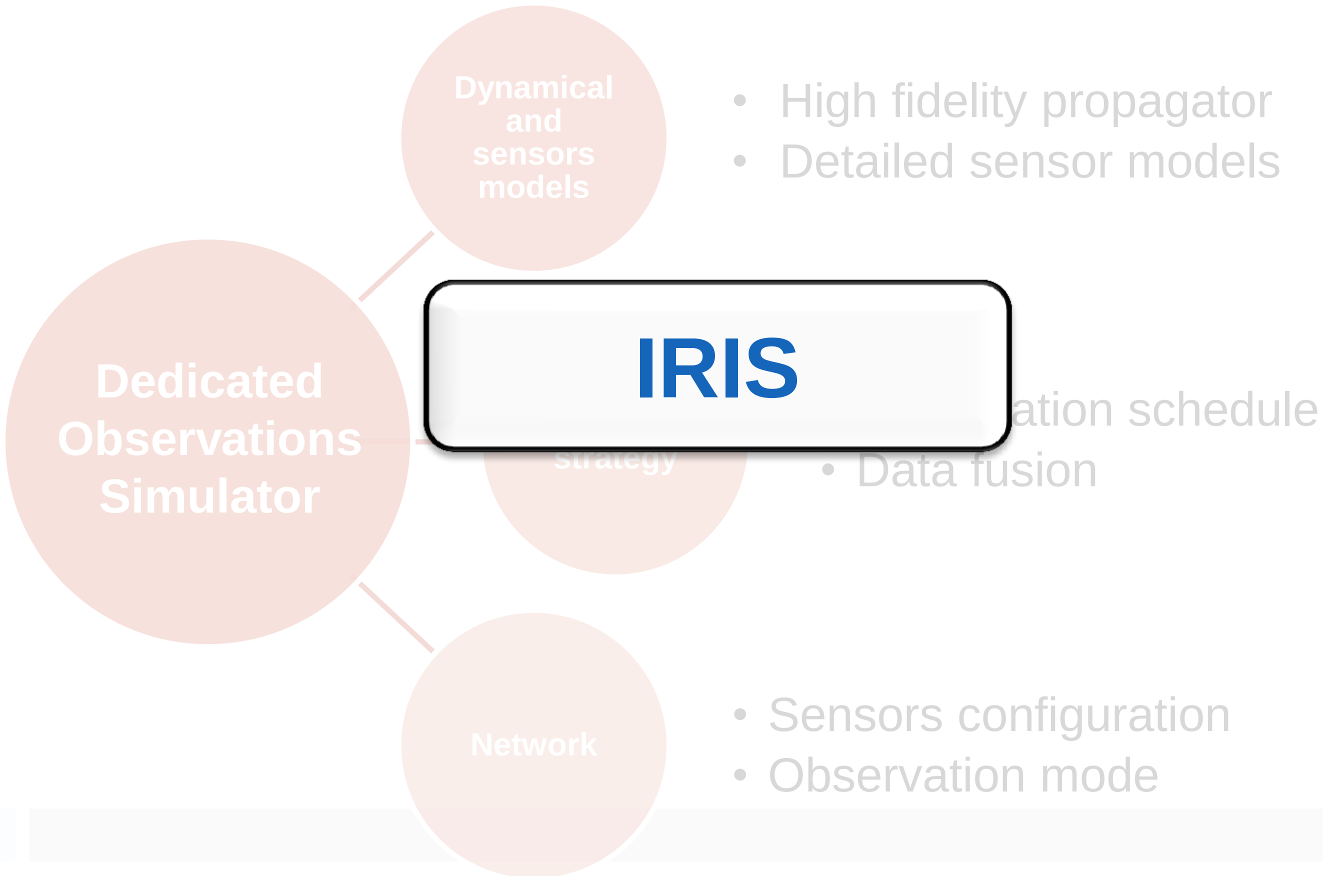
- High fidelity propagator
- Detailed sensor models

- Observation schedule
- Data fusion

- Sensors configuration
- Observation mode

Potential Approaches

- Improvement through dedicated observations

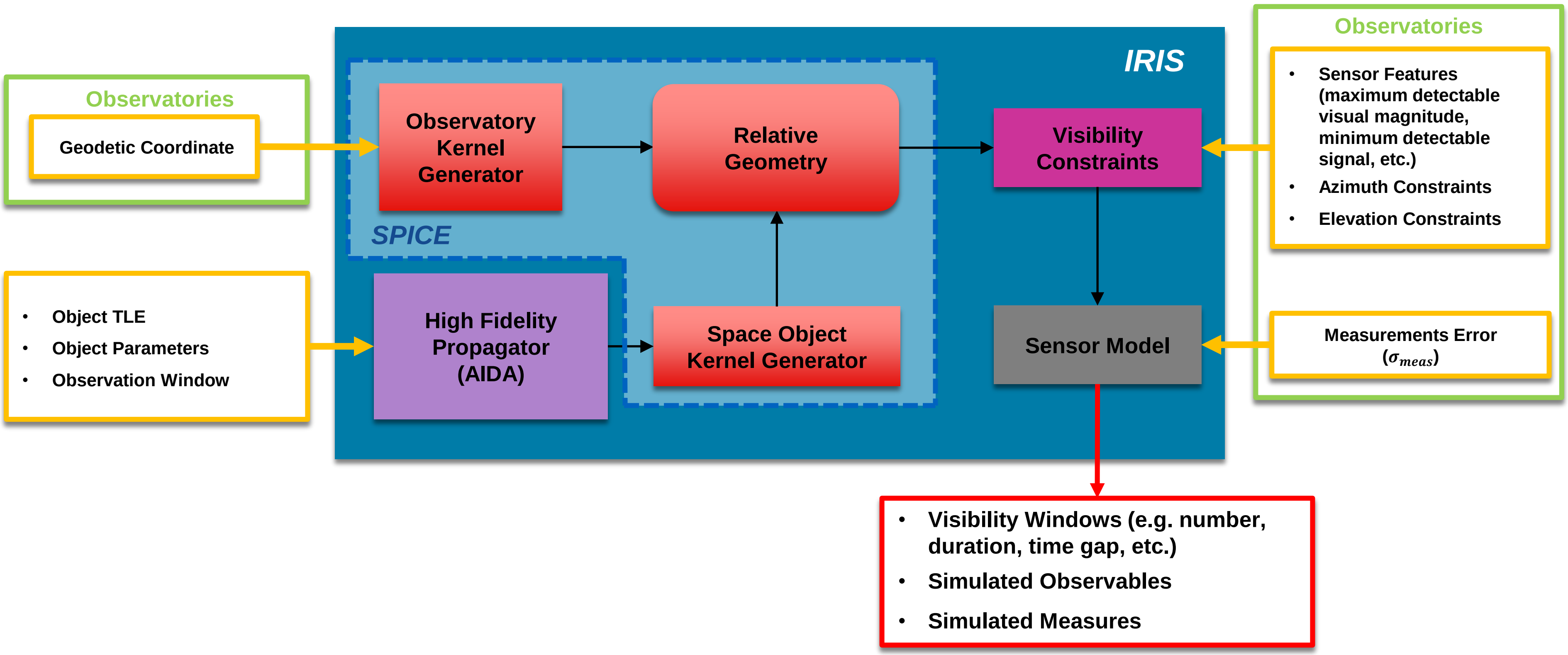


IRIS

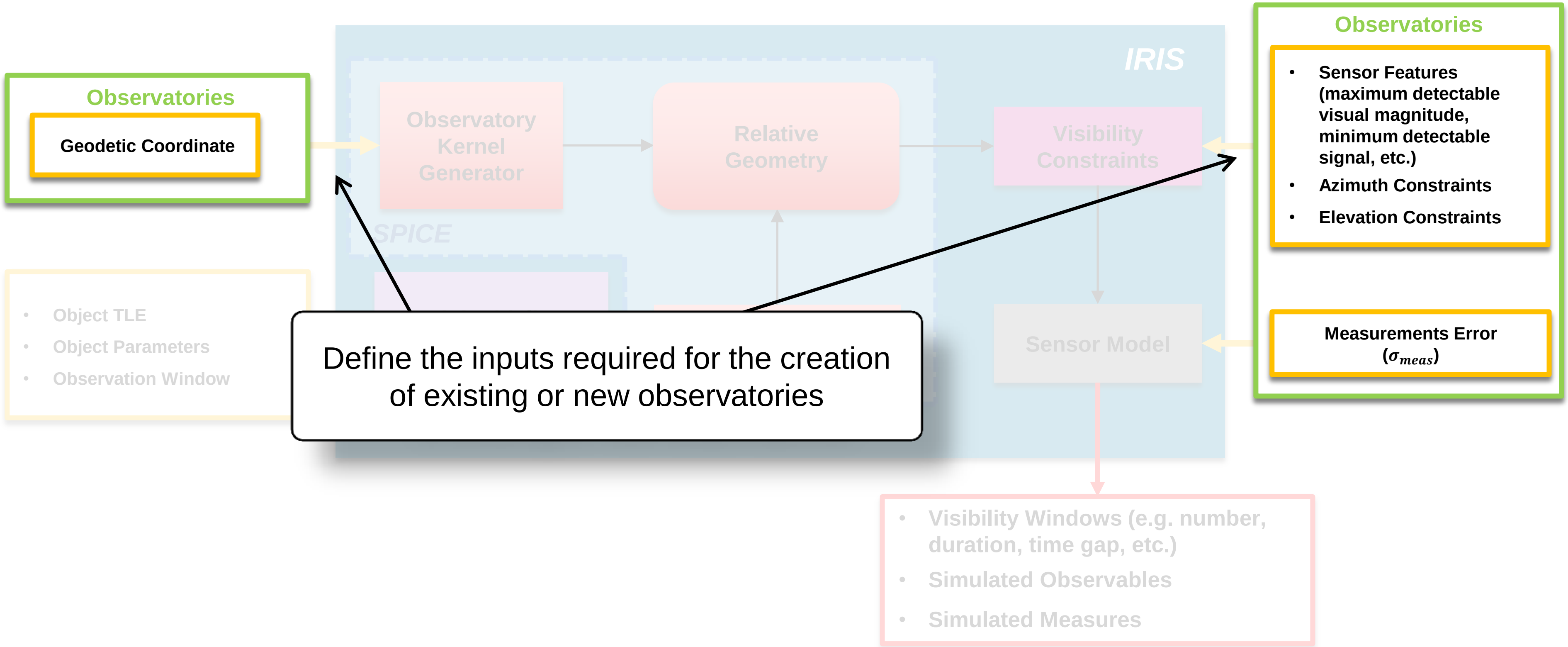
- **Goals:**
  - Accurate simulation of observation campaigns through existing and ideal sensors
  - Computation of visibility windows, observables, ground track coverage etc.
  - Design of observation strategies for the improvement of re-entry predictions

IRIS Architecture

- Fully implemented in Matlab

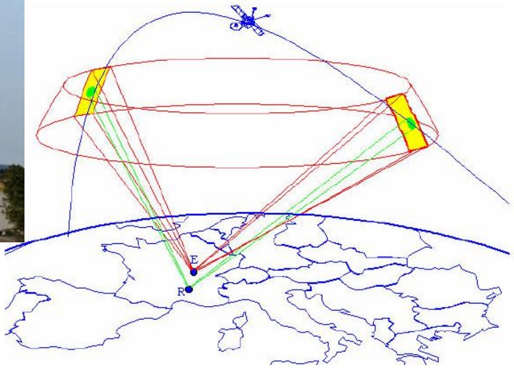


- Observatory class

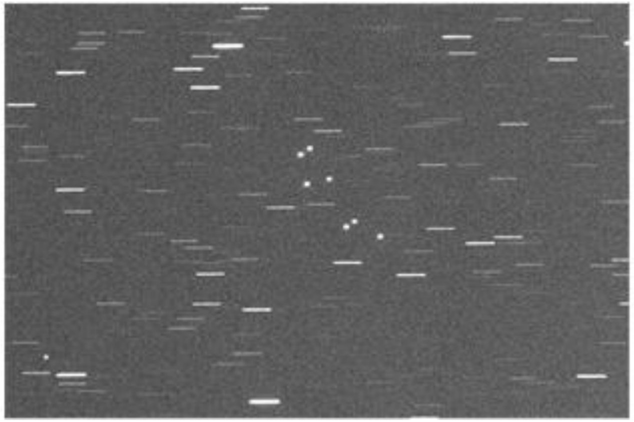


Observatory Class

- Active systems such as the radar and LADAR (Lidar radar) illuminate space objects with radio (VHF/UHF) or laser beams: d^{-4} dependency

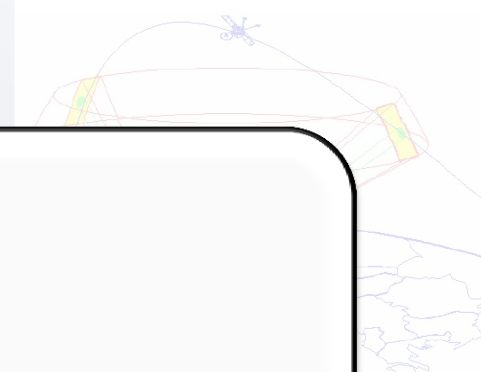


- Passive systems such as optical sensors which use the SUN as source of illumination: d^{-2} dependency



OBSERVATORY CLASS

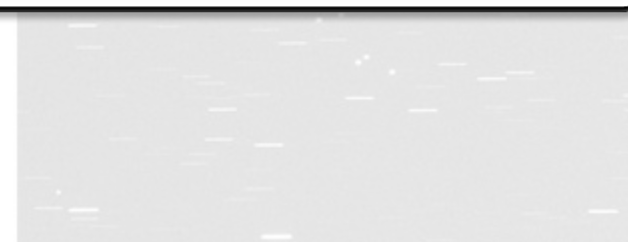
- Active systems such as the radar and LADAR (Lidar radar) ill…



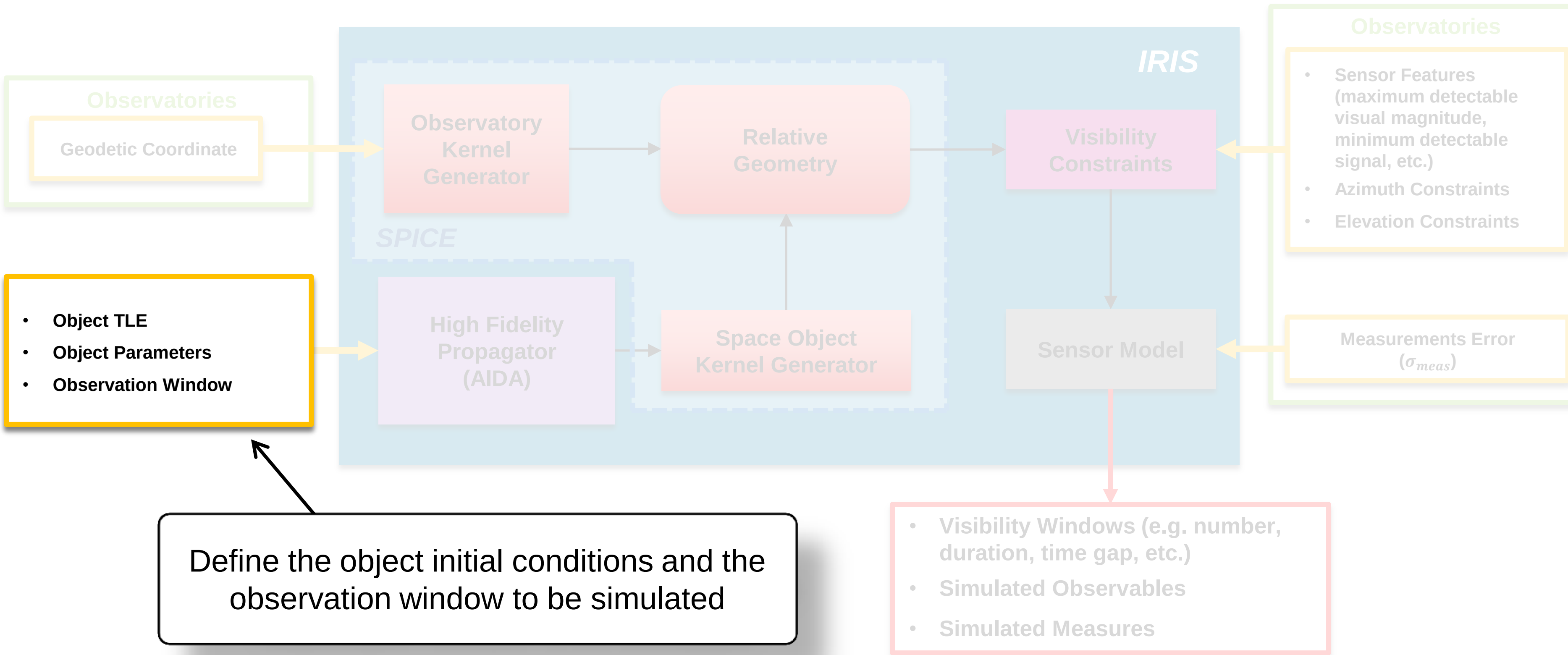
Ideal observatories can also be defined:

- Laser sensors
- Infrared sensors
- …

- … sensors which use the SUN as source of illumination: d^{-2} dependency

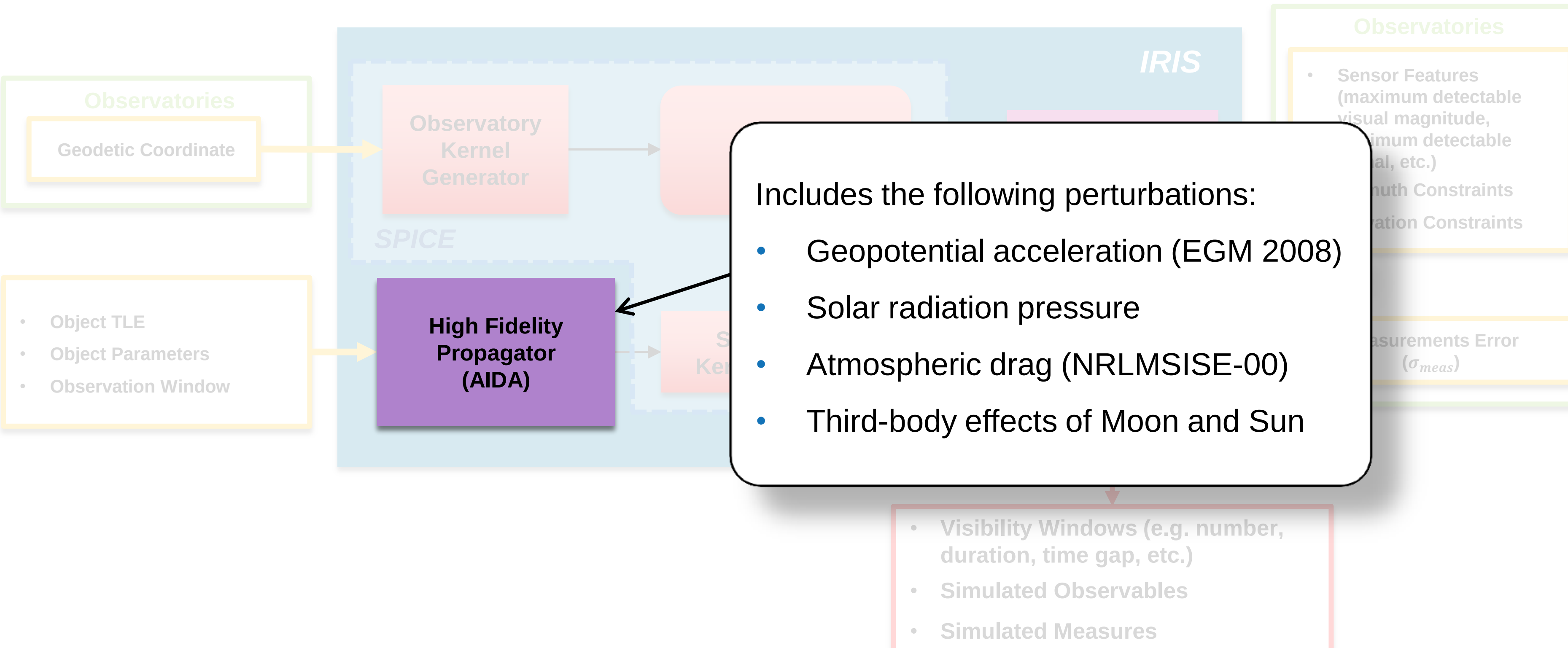


- Object class



IRIS Architecture

- High fidelity propagator (AIDA) module

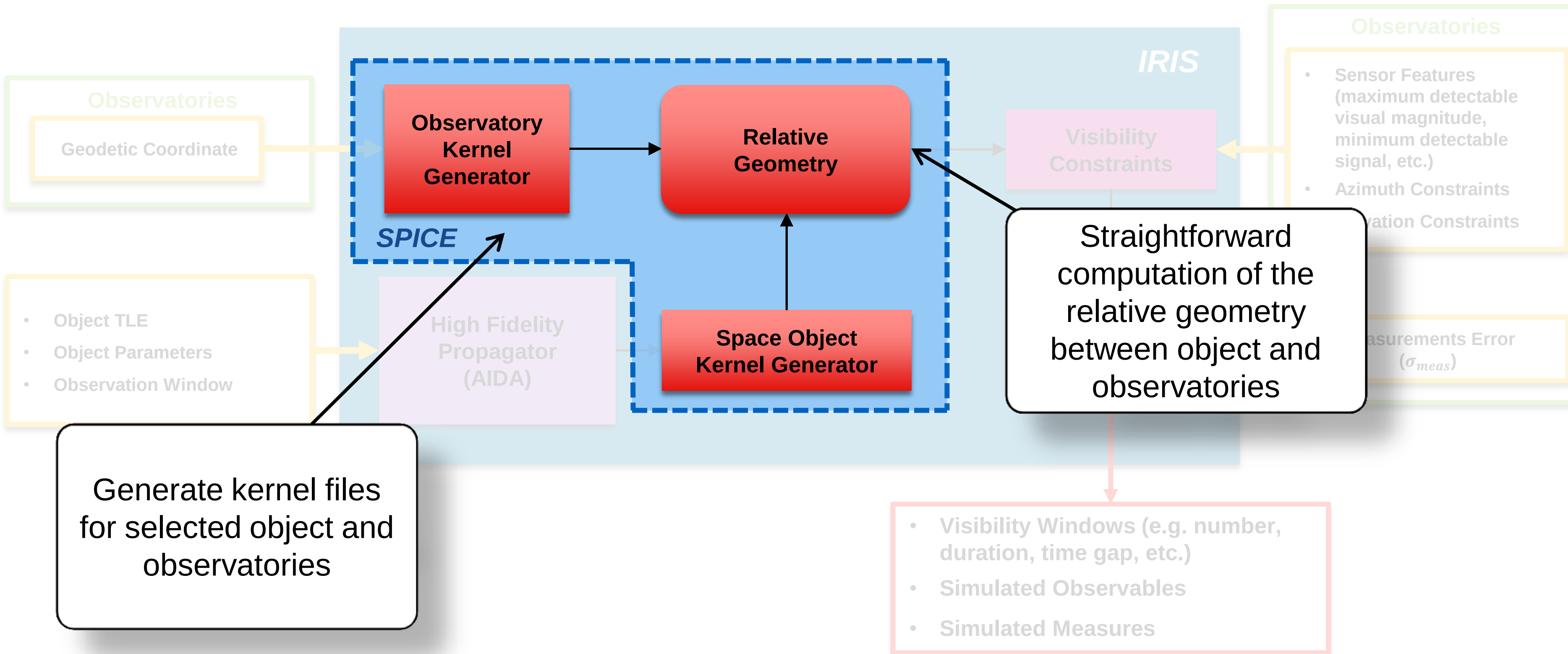


Includes the following perturbations:

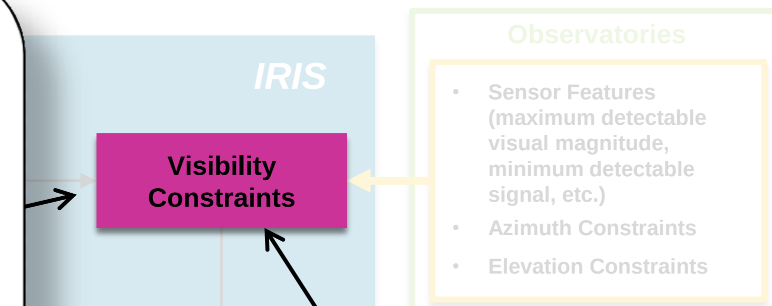
- Geopotential acceleration (EGM 2008)
- Solar radiation pressure
- Atmospheric drag (NRLMSISE-00)
- Third-body effects of Moon and Sun

IRIS ARCHITECTURE

- SPICE module



- Visibility module



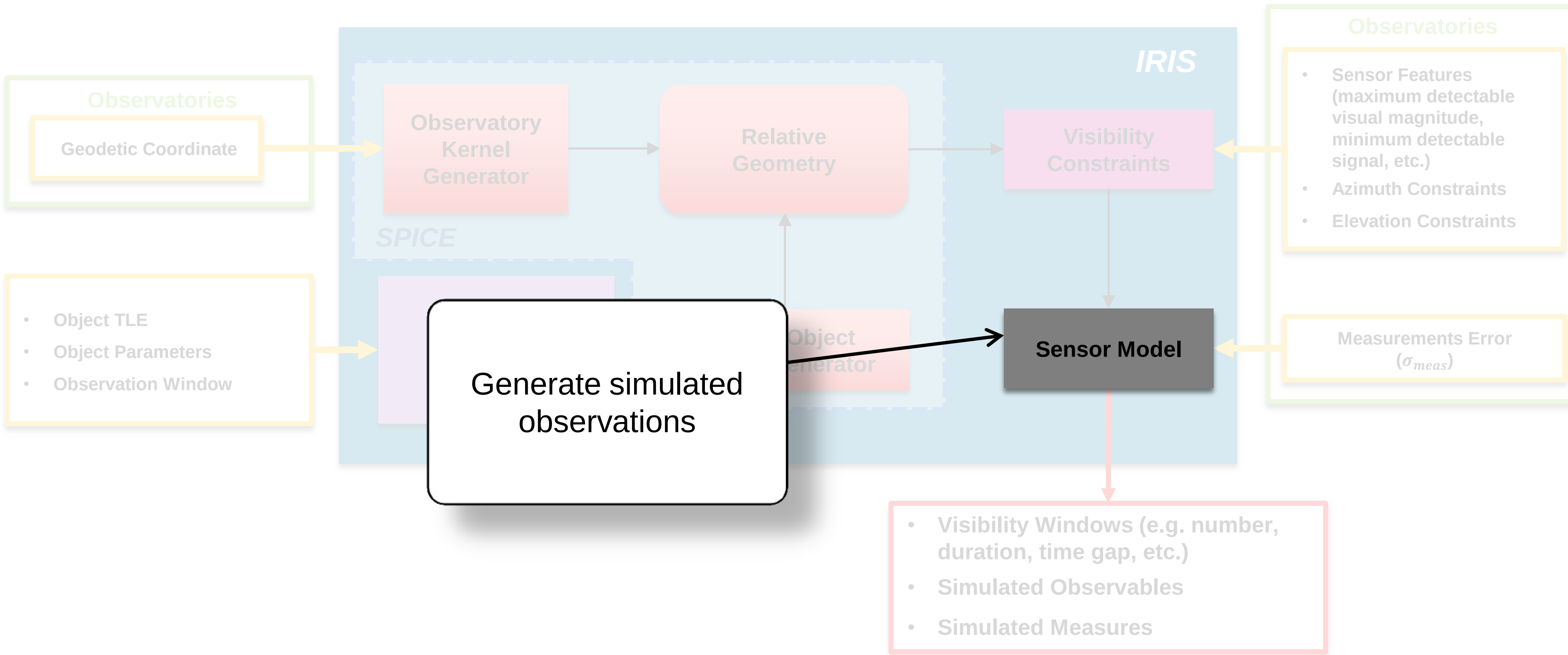
Optical Observatory

- Geometrical Constraints
  - The object has to be detectable from sensor location
- Illumination Constraints
  - Object must be illuminated by the Sun
  - Object brightness must exceed that of the background sky by a certain margin
  - Dark background during observations
  - Observation must occur during the night
- Cloud Coverage Constraint
  - The sky has to be clear to perform the measurement
- Angular Velocity Constraints
  - Object velocity doesn't exceed a maximum value

Radar Observatory

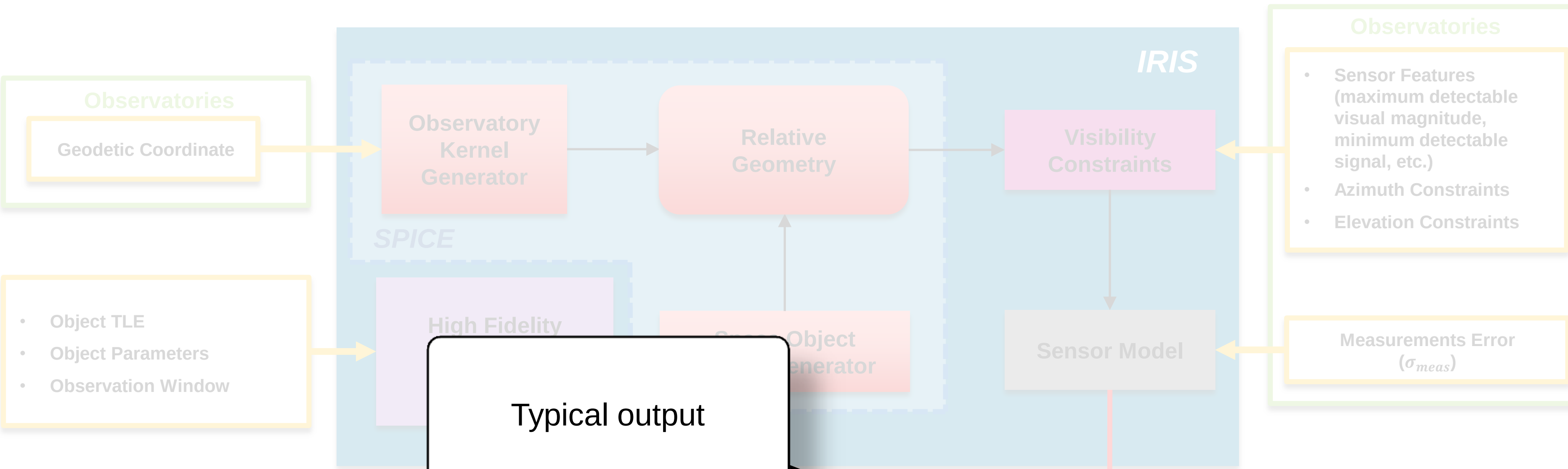
- Geometrical Constraints
  - The object has to be detectable from sensor location
- Received Power Constraints
  - The received power has to be higher than the minimum detectable signal

- Sensor module



IRIS ARCHITECTURE

- Output

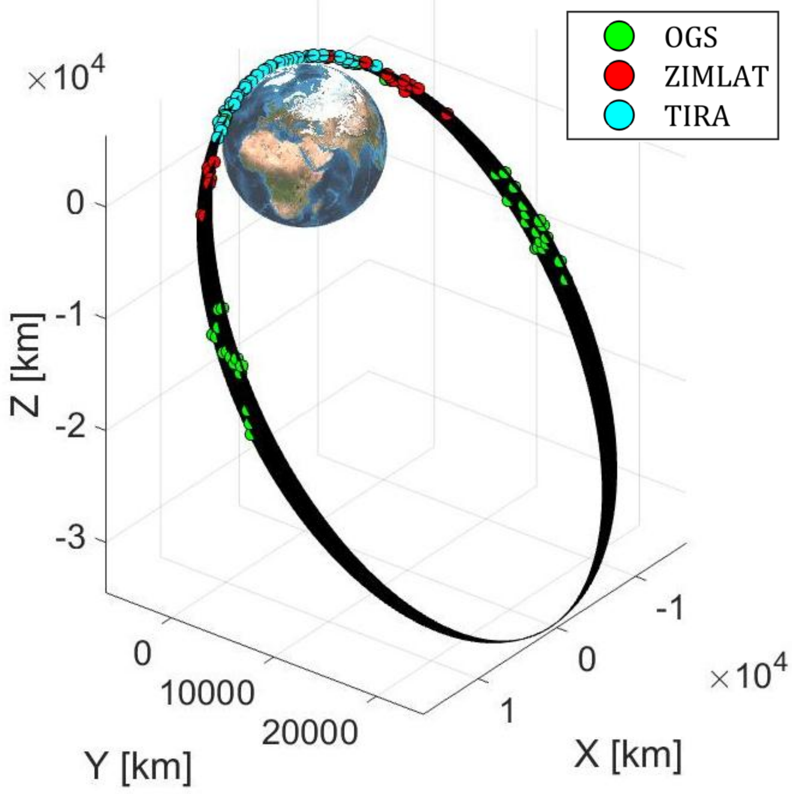


Typical output

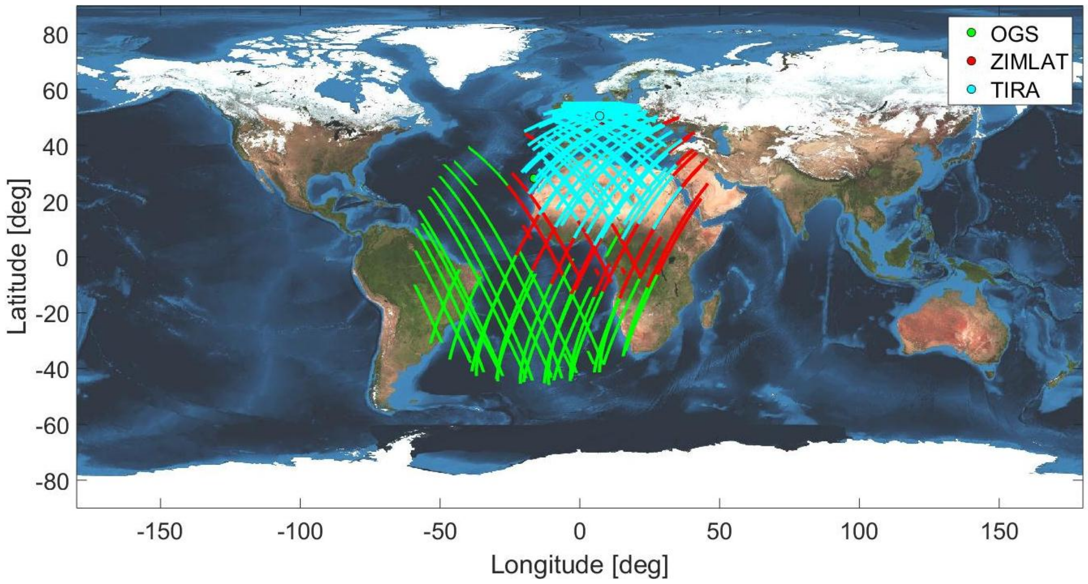
- **Visibility Windows (e.g. number, duration, time gap, etc.)**
- **Simulated Observables**
- **Simulated Measures**

OUTPUT

Measures along the orbit



Ground Track of the observable



- Observational data represent the inputs for the design of optimal observation strategies

Optimization Approach

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- Automatic method for observation strategy design

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Optimization Approach

- Automatic method for observation strategy design
- Strategy design problem as a multi-objective optimization problem:

$$\boldsymbol{X}_{opt} = [1,0,0,1,\dots,0,0,1] \quad \boldsymbol{X}_{opt} \in \Re^{N_{Obs}}$$

$$\boldsymbol{f}(\boldsymbol{X}_{opt}) = [f_1(\boldsymbol{X}_{opt}) \quad f_2(\boldsymbol{X}_{opt})] = [N_{Obs} \quad max(\lambda_i)]$$

$$Cov = (H^T W H)^{-1}$$

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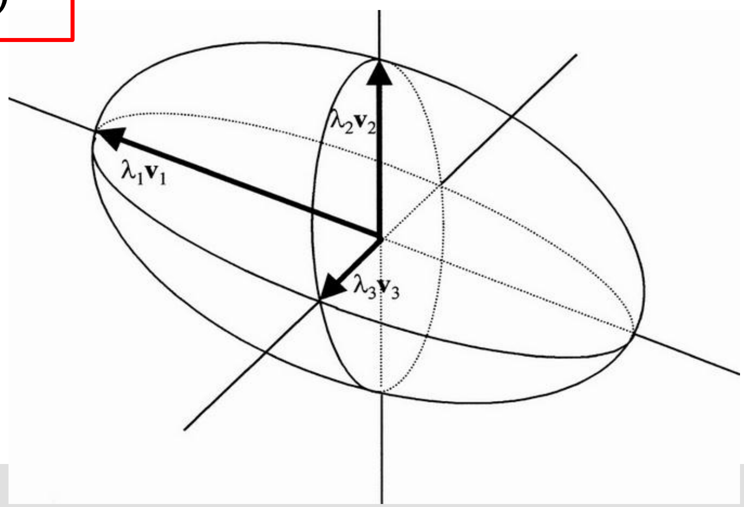
Spectral decomposition

$$max(\lambda_i)$$



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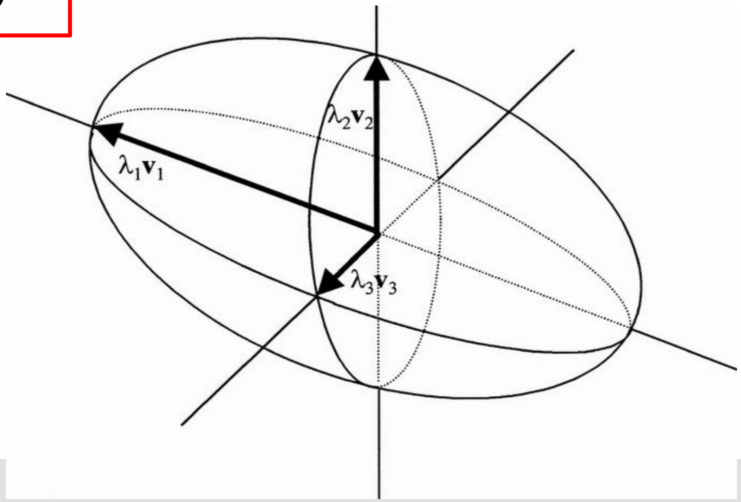

1) Other possibilities?

→ det(*Cov*), tr(*Cov*), ...

OPTIMIZATION APPROACH

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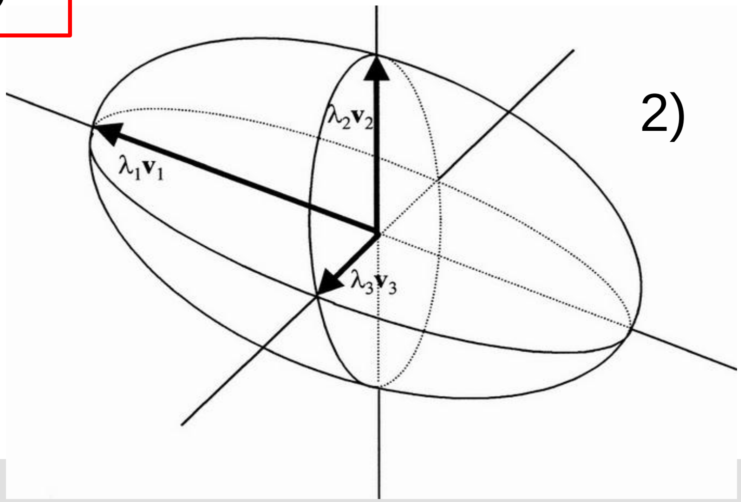
Spectral decomposition

$max(\lambda_i)$



1) Other possibilities?

→ det(*Cov*), tr(*Cov*), ...

2) Relation with re-entry prediction?

→ Assessment of improvement is required

$$Cov = (H^T W H)^{-1}$$

Jacobian matrix

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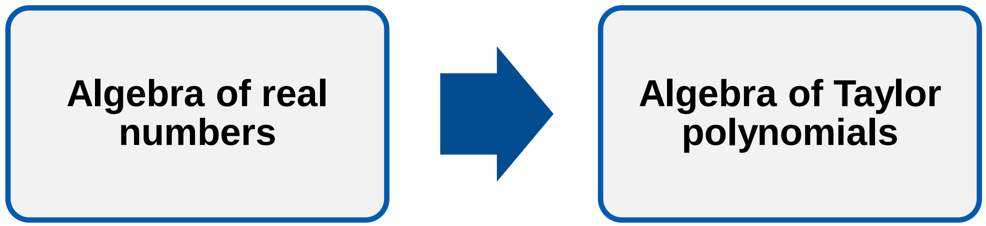
Jacobian matrix

Jacobian matrix can be computed through Differential Algebra (DA)

DIFFERENTIAL ALGEBRA

- Substitution of classical real algebra with a new algebra of Taylor polynomials



- Any function of *n* variables is expanded into its Taylor polynomial up to an arbitrary order *k*
- Unlike standard automatic differentiation tools, the analytic operations of differentiation and antiderivation are introduced

Differential Algebra

Pros

- Jacobian computed at machine precision
- Efficient computation of J for any dynamical and sensor models
- No finite differences or variational equations used
- Reduction of computational efforts

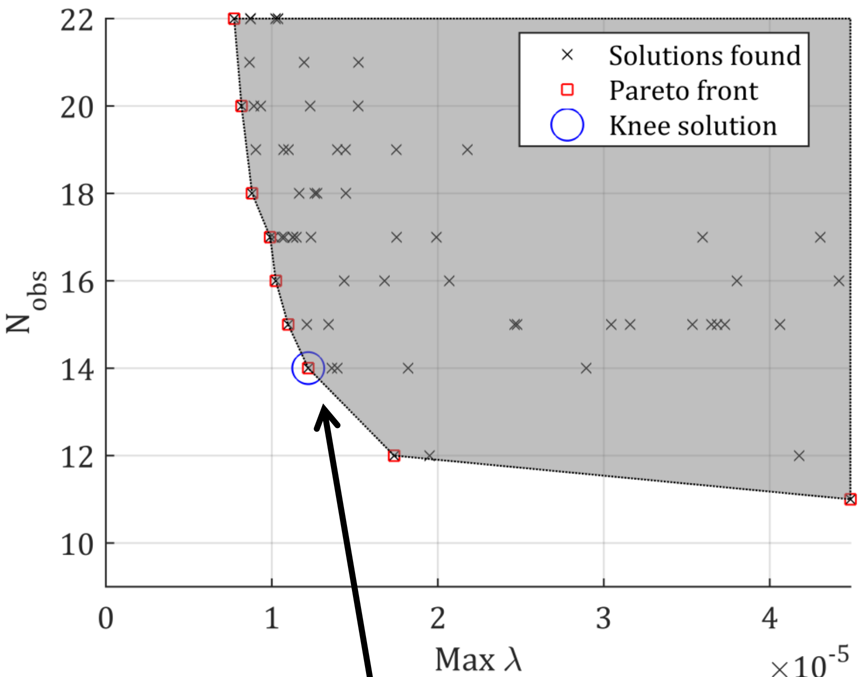
CPU Time	
MATLAB (finite differences)	~200 s
DA	~15 s

Cons

- Need of a DA framework: DAST

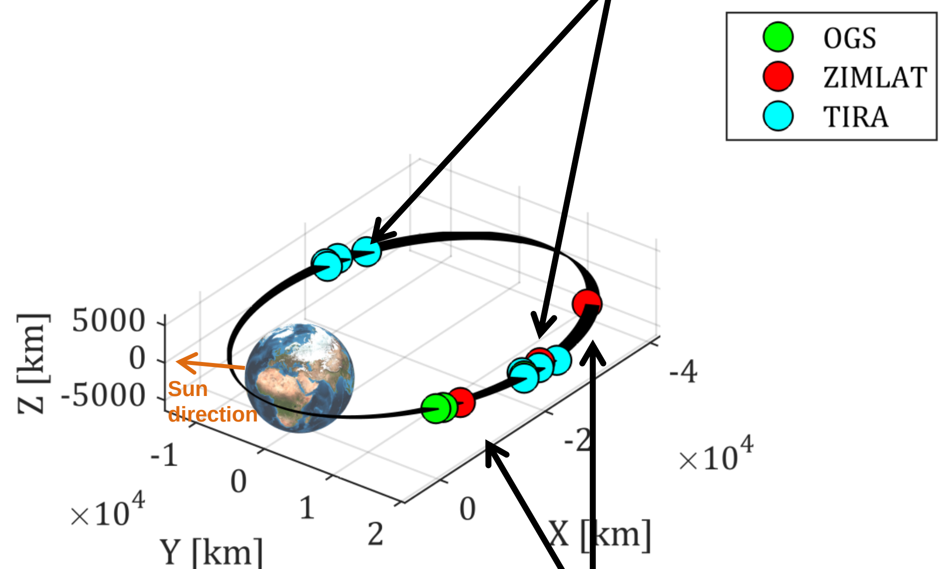
In C++, interface through Mex files

➤ *Ariane 5 Second Stage (37239)*



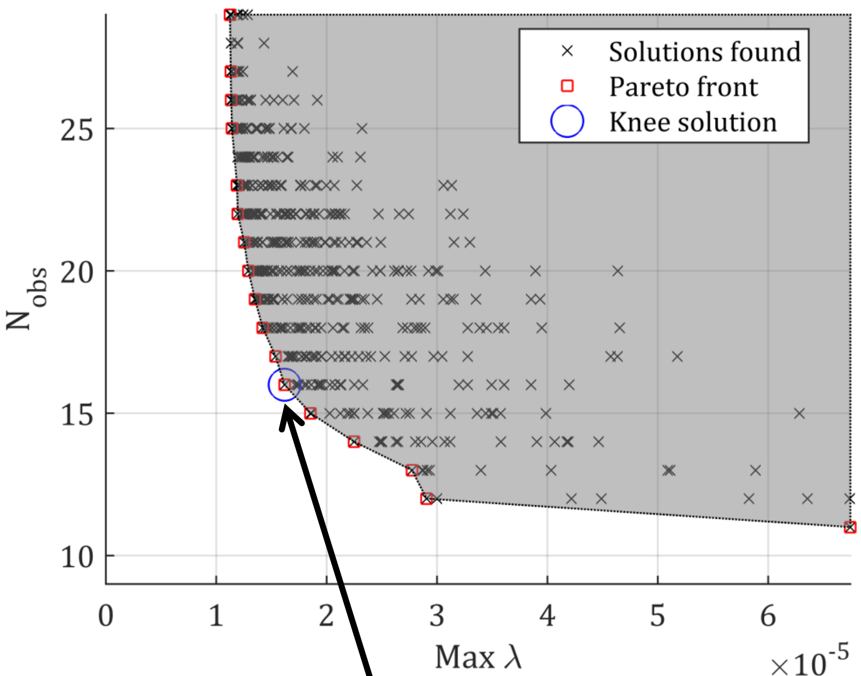
The knee-solution corresponds to $N_{obs} = 14$

Radar measurements are taken at quite large distance from the perigee and close to the maximum available bound for this type of sensors



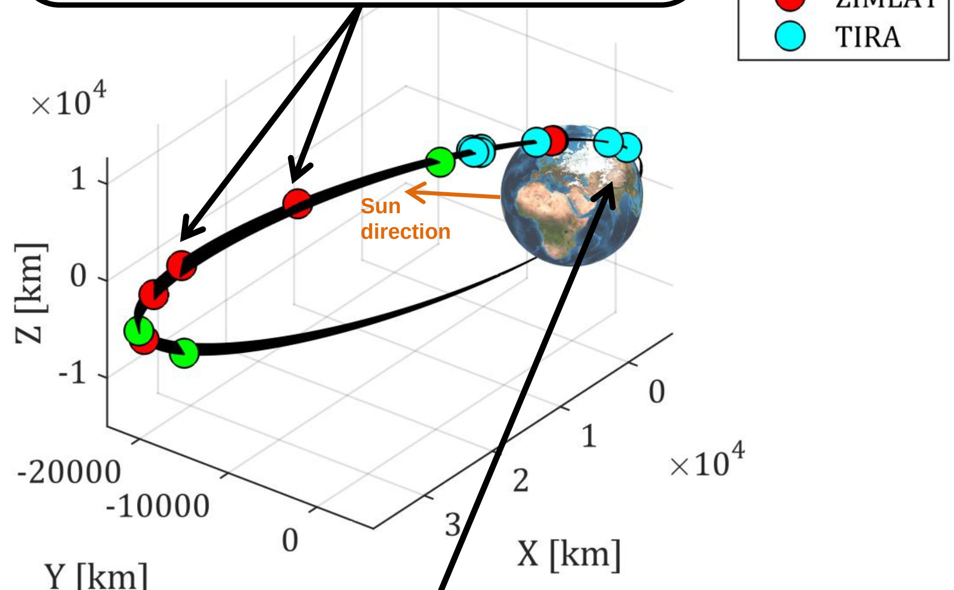
Optical observations are all on the same side of the orbit because of the position of the Sun relative to the observed object

CZ-3A Third Stage (37949)



The knee-solution corresponds to $N_{obs} = 16$

OGS and ZIMLAT produce the most of measurements when the object moves around the orbit apogee, whereas TIRA can observe the object when it is close to orbit perigee



TIRA provide measures only when the sub-satellite point is on north hemisphere. This is mainly due to high inclination of orbit ($i_0 = 55°$) combined with the high latitude of TIRA sensor

Conclusions

- A high accuracy observation simulator (IRIS) has been developed
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  - Accurate simulation of observation campaigns through existing and ideal sensors
  - Computation of visibility windows, observables, ground track coverage etc.
- An optimization approach can be used to obtain the optimal observation strategy for given object and sensors network
- Study not yet completed...
  - No evidence of common patterns that can be used as guidelines for the definition of a general optimal strategy
  - Other approaches are currently under investigation
  - Covariance analyses

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