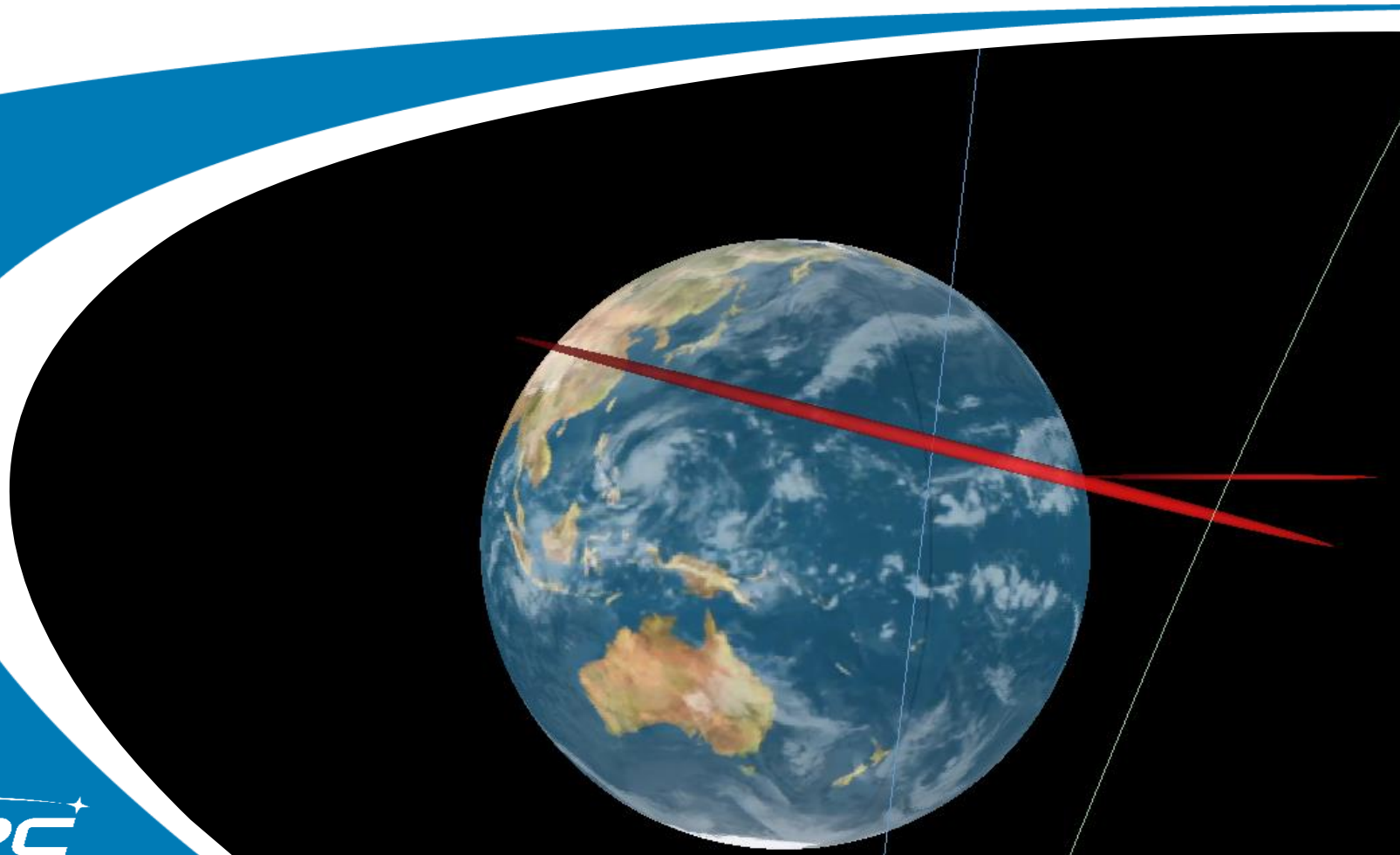
Assessing GEO Close Encounter Warnings for Spacecraft Operations

INTERNATIONAL WORKSHOP ON SPACE DEBRIS MANAGEMENT AND MITIGATION
November 9, 2018

Space Environment Research Centre Ltd., Weston Creek, Austalia

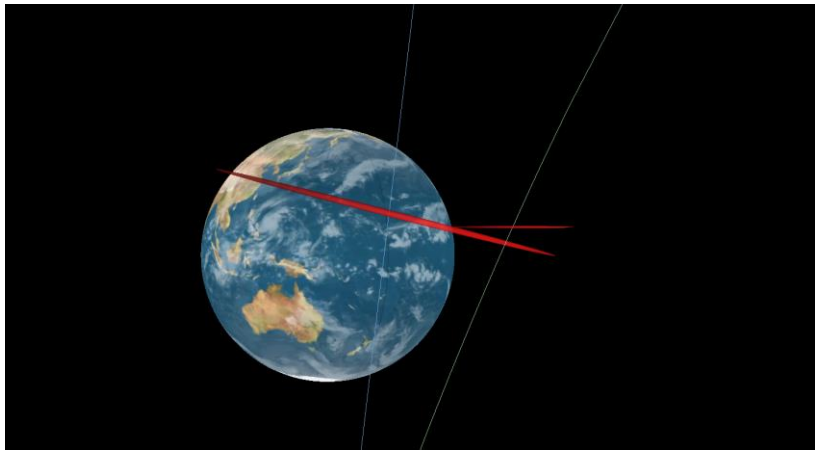


Main Contributors
Thomas La
Nathaniel McGrawth
Dr. Sven Flegel

Outline

- Fundamentals
- Visualisation
- Assessment
- Example Applications

New Tool developed at SERC



Conclusions from [Flegel, 2017 - International Astronautical Congress 2017]

GEO Encounters

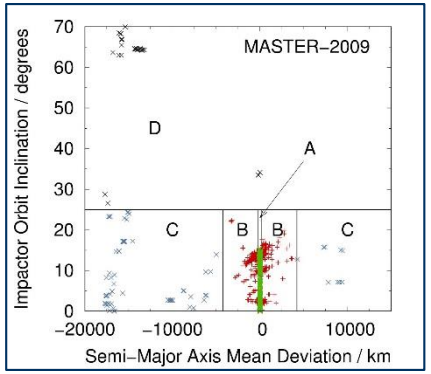
- Majority of GEO Close Encounters with GEO Libration (~61 %) and GEO Drift (~36 %) Objects
- Δv_{max} ~ 3 km/s & Δv_{min} < 1 m/s

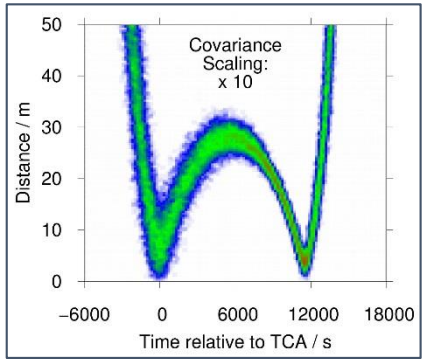
Collision Likelihood Metrics

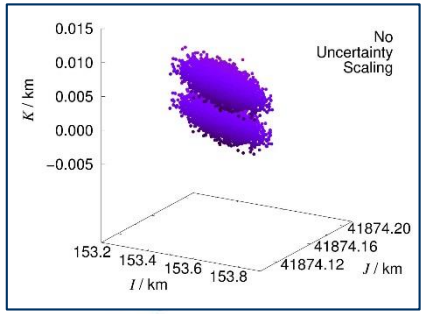
Metric	Pro	Con
Collision Probability	Accounts for uncertainty	Abstract
Miss Distance	Insight into event	Single value no account of uncertainty
Conflict Probability	*Not studied here*	

State Uncertainty Accuracy

- Idea: **Status** of collision likelihood metric should not be changed due to residual error
- Requirement difficult to impose in face of hard to predict perturbations which affect state & uncertainty during prediction span







Conclusions from [Flegel, 2017 - International Astronautical Congress 2017]

GEO Encounters

- Majority of GEO Close Encounters with GEO Libration (~61 %) and GEO Drift (~36 %) Objects
- Δv_{max} ~ 3 km/s & Δv_{min} < 1 m/s

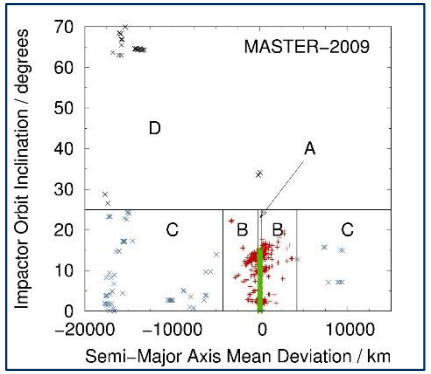
Collision Likelihood Metrics

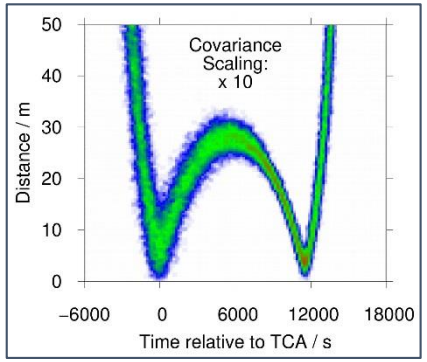
Metric	Pro	Con
Collision Probability	Accounts for uncertainty	Abstract
Miss Distance	Insight into event	~~Single value no account of uncertainty~~
Conflict Probability	*Not studied here*	

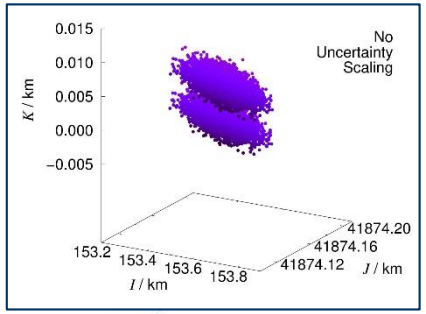
State Uncertainty Accuracy

- Idea: **Status** of collision likeli ged due to residual error
- Requirement difficult to imp turbations which affect state & uncertainty during predictio

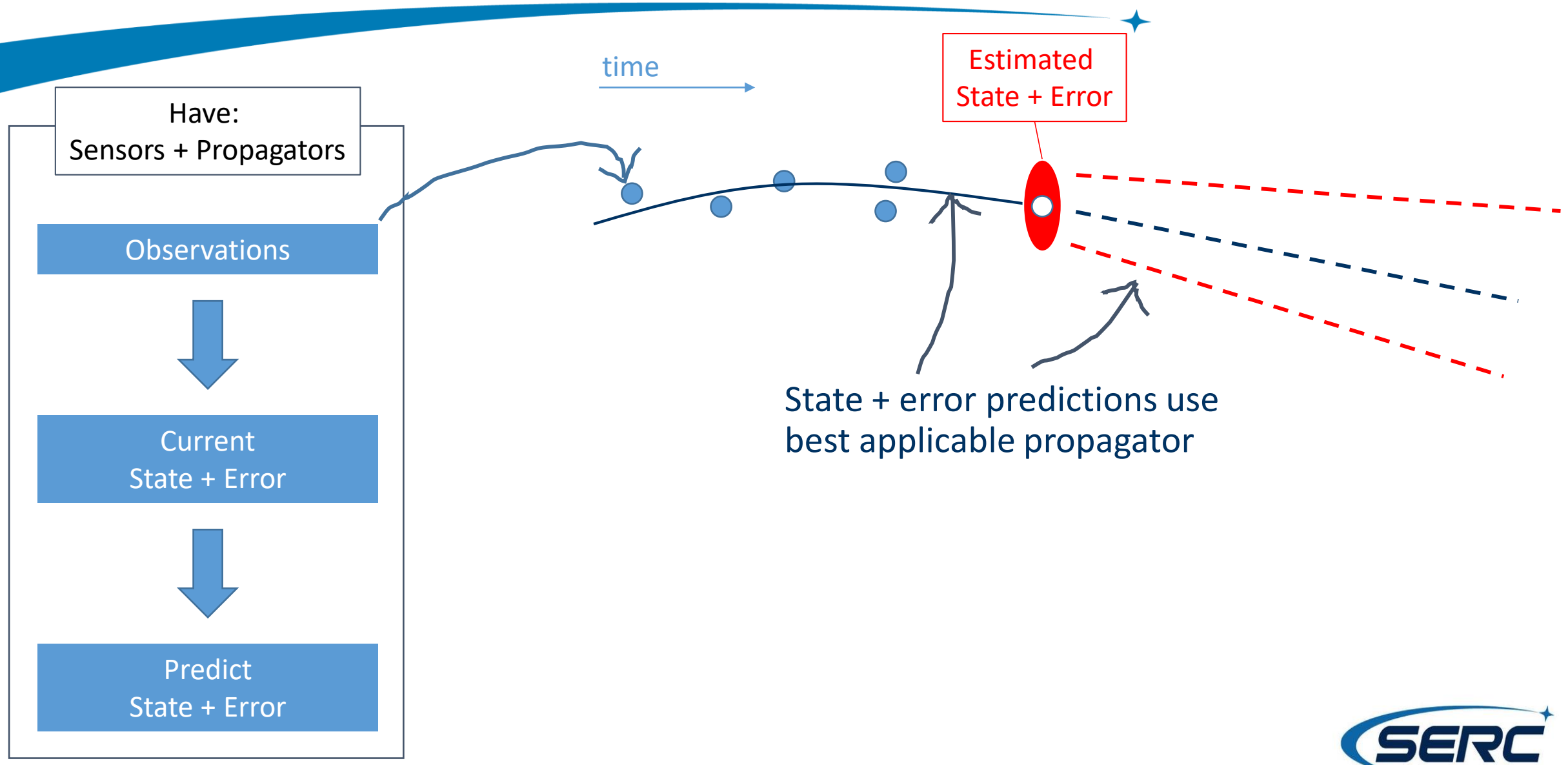
Uncertainty *can* be included







Fundamentals



Conjunction Data Messages

```
CCSDS_CDM_VERS                  =1.0
COMMENT                         =CDM_ID:1579154
CREATION_DATE                   =2016-02-24T03:16:29
ORIGINATOR                      =JSPOC
MESSAGE_FOR                     =LEO SAT 1
MESSAGE_ID                      =99999_conj_99998_2016056082403_05503
COMMENT MEETS EMERGENCY CRITERIA
TCA                             =2016-02-25T08:24:03.742
MISS_DISTANCE                   =254                    [m]
RELATIVE_SPEED                  =4088                   [m/s]
RELATIVE_POSITION_R             =128.7                  [m]
RELATIVE_POSITION_T             =-211.6                 [m]
RELATIVE_POSITION_N             =59.9                   [m]
RELATIVE_VELOCITY_R             =8.3                    [m/s]
RELATIVE_VELOCITY_T             =-1120.5                [m/s]
RELATIVE_VELOCITY_N             =-3932                  [m/s]
COLLISION_PROBABILITY           =4.306701e-05
COLLISION_PROBABILITY_METHOD    =FOSTER-1992
OBJECT                          =OBJECT1
OBJECT_DESIGNATOR               =99999
CATALOG_NAME                    =SATCAT
```

General Situation Information

[…]

[…]

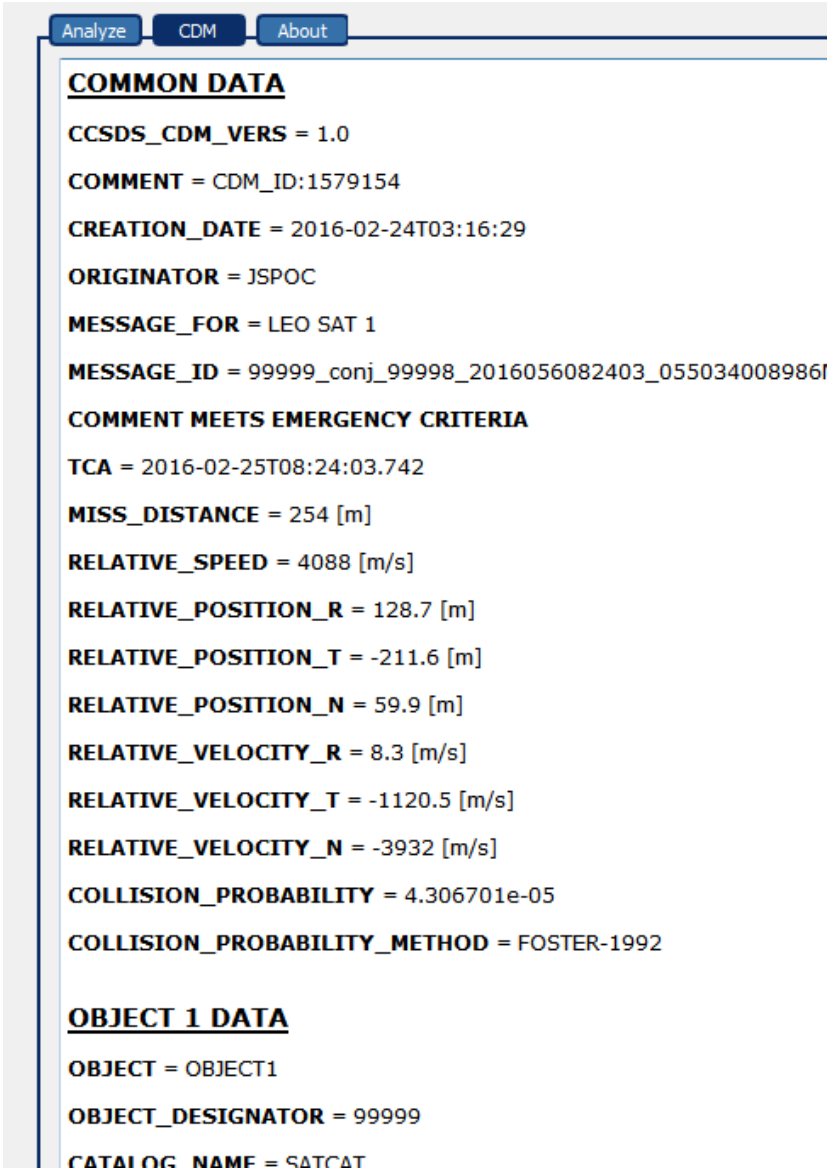
```
OBS_AVAILABLE                   =246
OBS_USED                        =245
RESIDUALS_ACCEPTED              =99.8                   [%]
WEIGHTED_RMS                    =1.109
COMMENT Apogee Altitude = 807   [km]
COMMENT Perigee Altitude = 804   [km]
COMMENT Inclination = 98.5  [deg]
AREA_PC                         =0.3084                 [m**2]
CD_AREA_OVER_MASS               =0.026403               [m**2/kg]
CR_AREA_OVER_MASS               =0.01192                [m**2/kg]
THRUST_ACCELERATION             =0                      [m/s**2]
SEDR                            =2.93988e-05            [W/kg]
X                               =504.999523             [km]
Y                               =1001.351516            [km]
Z                               =7094.906152            [km]
X_DOT                           =7.446012163            [km/s]
Y_DOT                           =-1.026940851           [km/s]
Z_DOT                           =-0.383622809           [km/s]
CR_R                            =72.84517               [m**2]
CT_R                            =10.78702               [m**2]
CT_T                            =1206.212               [m**2]
CN_R                            =1.219566               [m**2]
CN_T                            =-5.165142              [m**2]
CN_N                            =19.36692               [m**2]
CRDOT_R                         =-0.008242773           [m**2/s]
CRDOT_T                         =-1.183242              [m**2/s]
CRDOT_N                         =0.00225296             [m**2/s]
CRDOT_RDOT                      =0.001206133            [m**2/s**2]
CTDOT_R                         =-0.07541954            [m**2/s]
```

Object 1 position & Velocity

[…]

SERC Tool for close approach assessments

Simple formatting already provides better readability

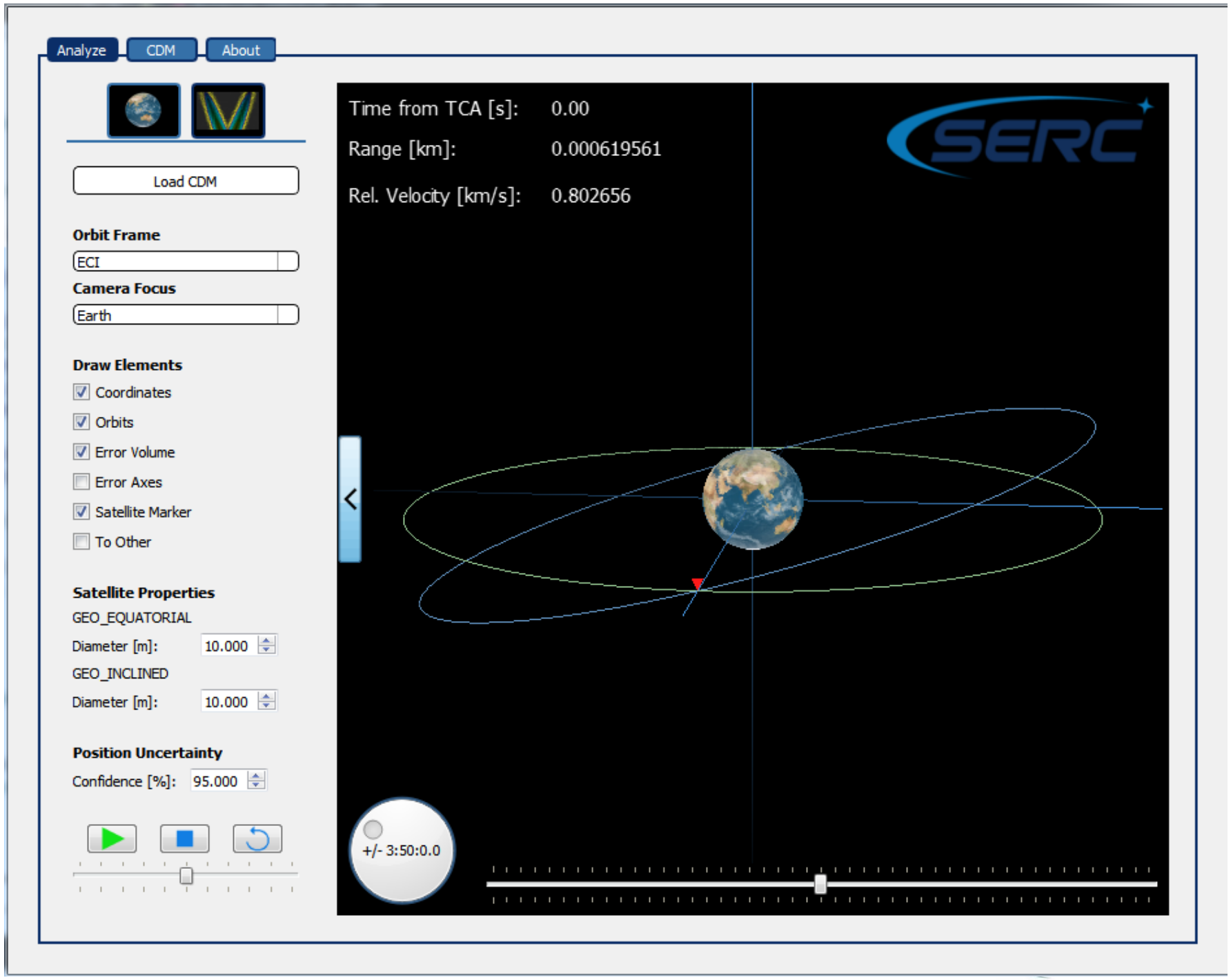


Visualisation

Orbits in ECI

High accuracy propagation
for states and errors at
Time of Closest Approach (TCA)

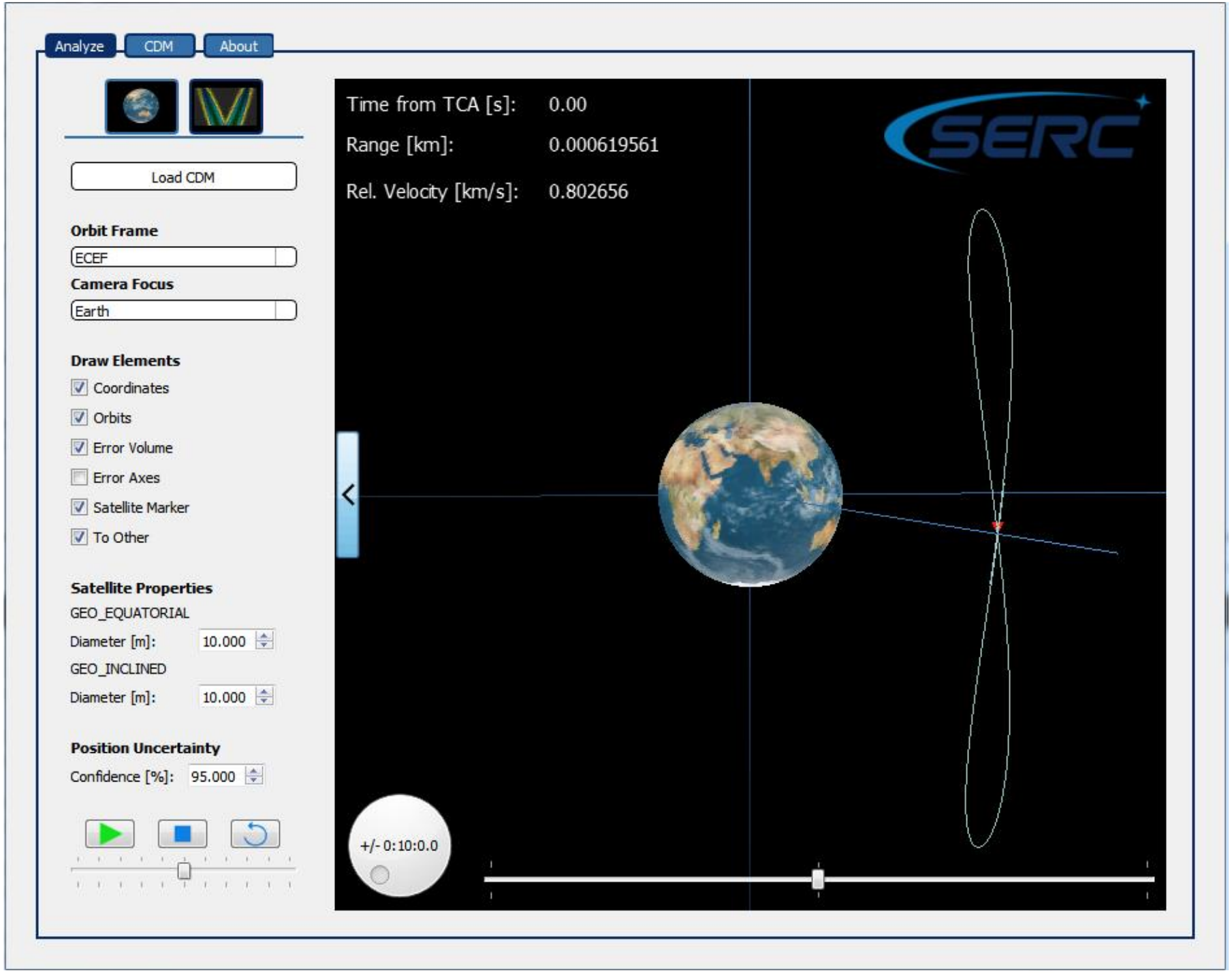
Lower fidelity propagation
for visualisation/assessment
around TCA



Visualisation

Orbits in ECEF

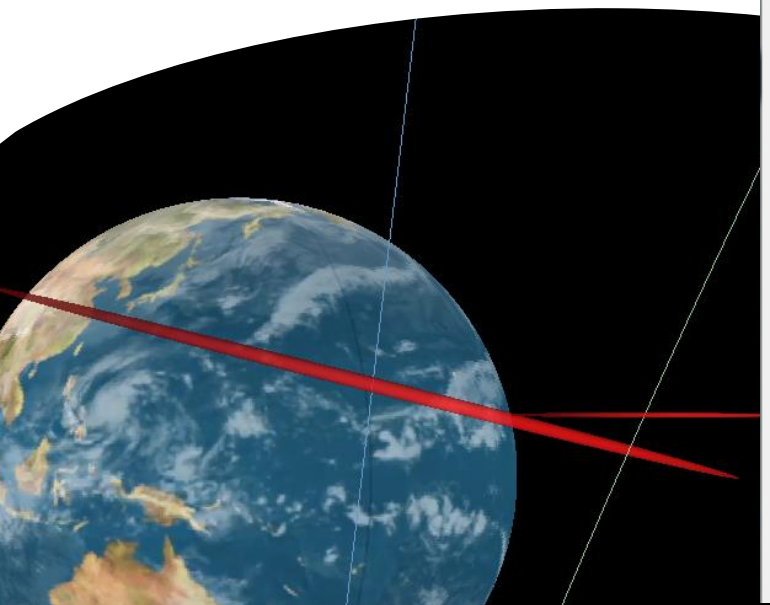
Orbits in geostationary
better understood
in Earth co-rotating frame

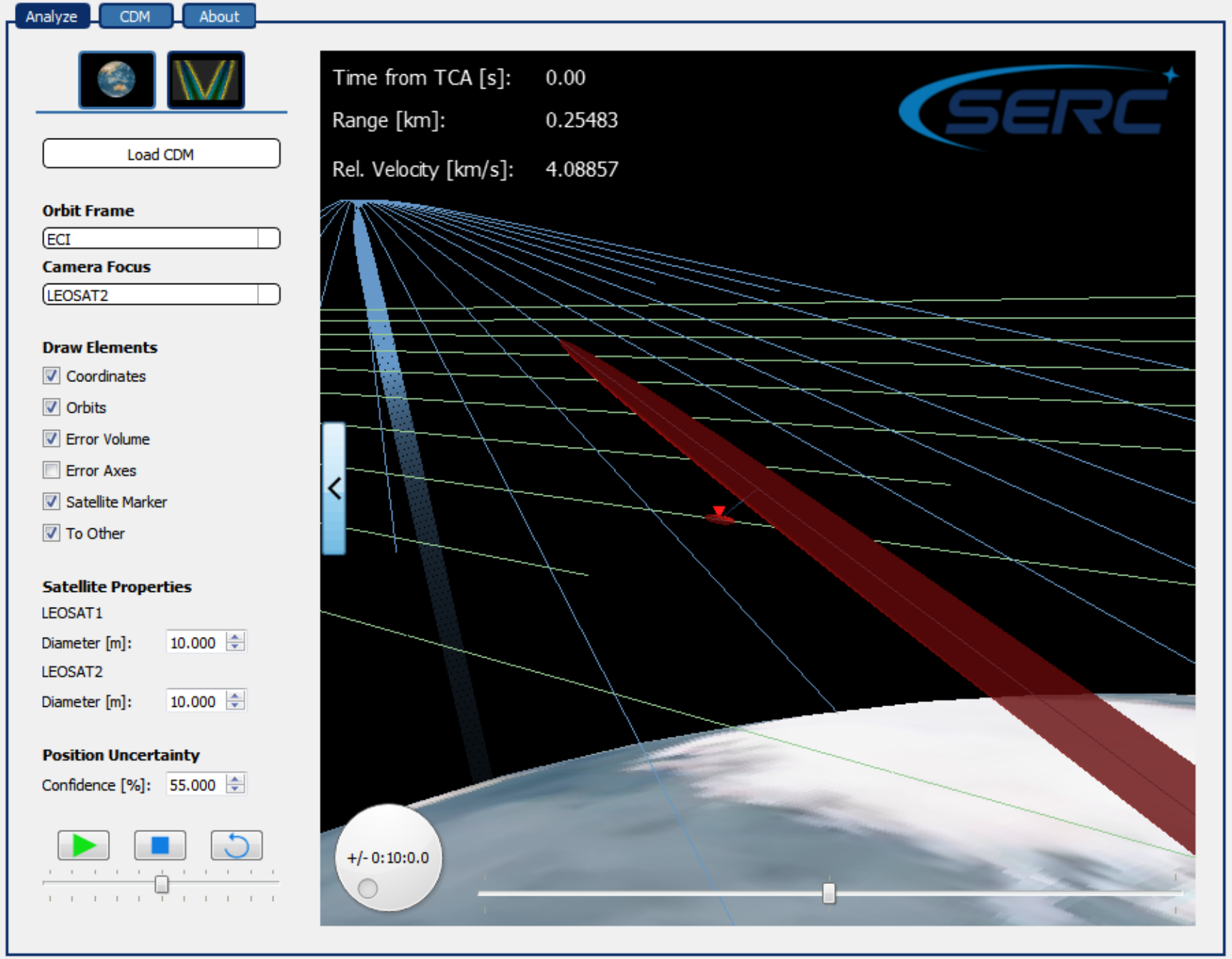


Visualisation

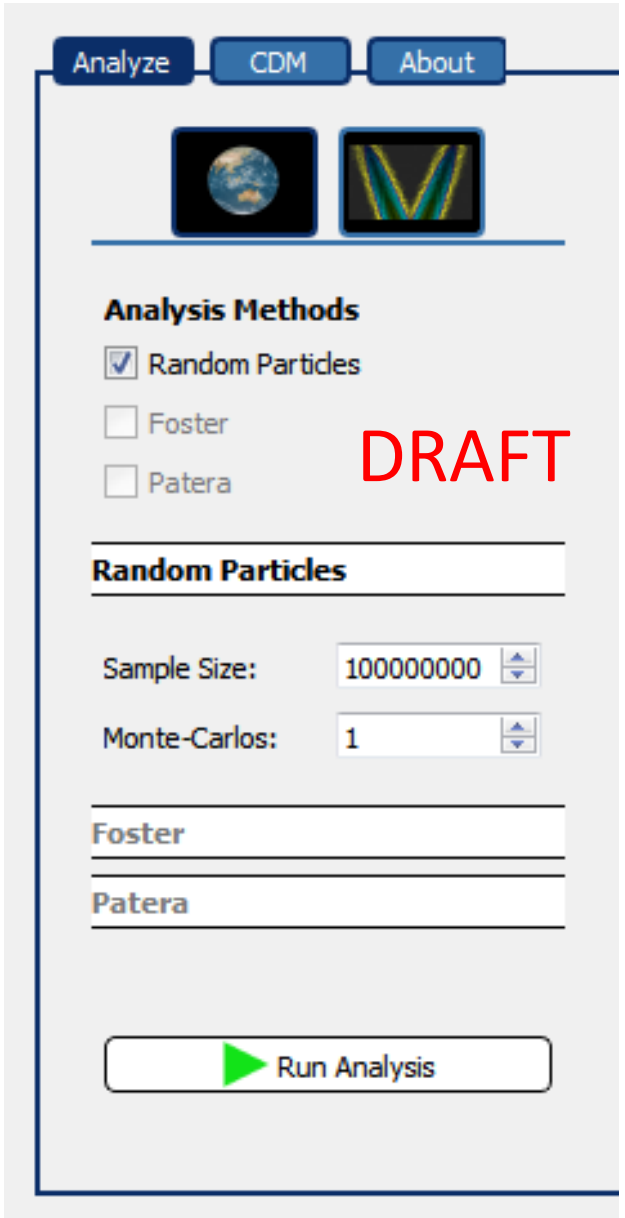
Position Uncertainties

Back-Bone of
collision likelihood
estimations





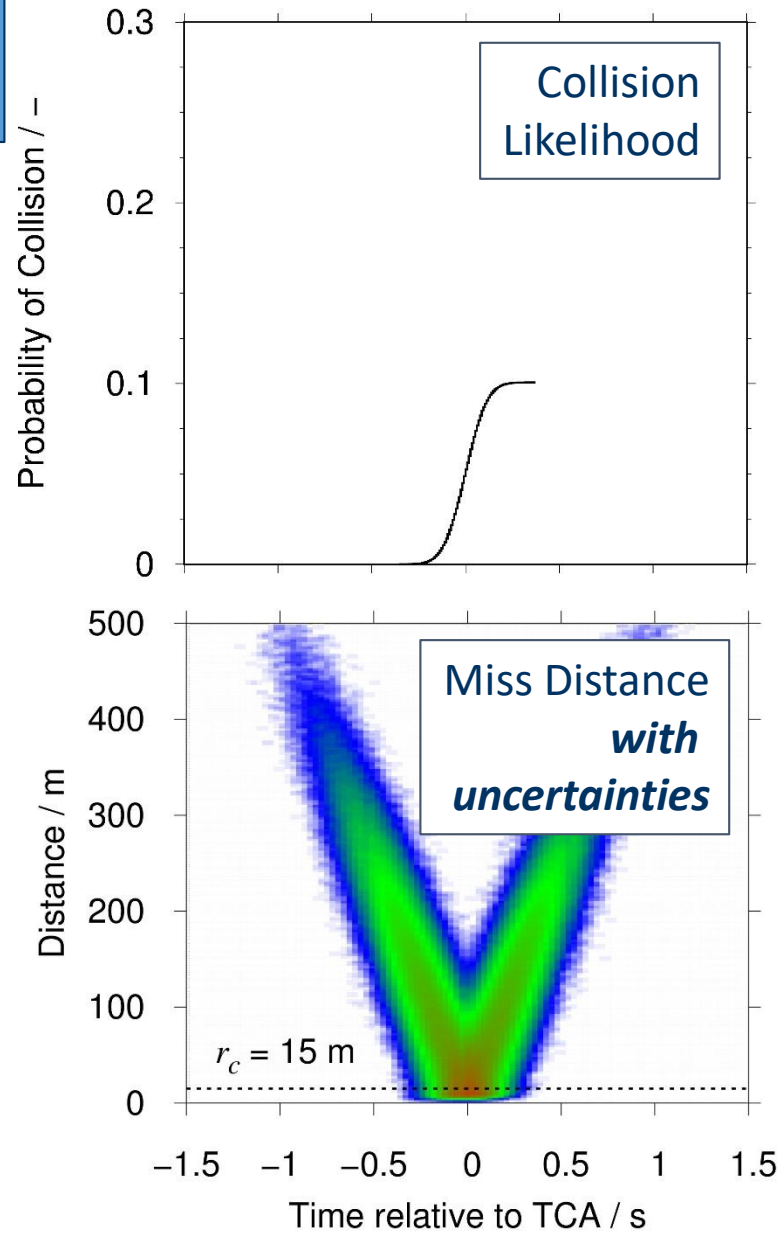
Analysing a Scenario Next Up …



Visual support e.g.

Additional Data & Features:

- Collision likelihood
- Time of highest collision likelihood
- Particle method allows non-Gaussian state errors
- Efficient testing for state error Gaussianity
- Recommendation of applicable methods
- Manual sensitivity analysis
- Compare different methods



Summary & Outlook

New SERC tool provides …

- Easy viewing of **legacy Conjunction Data Messages**
- **Visual** of close approach
- State uncertainty **with confidence**
- Various visual cues and help functions (e.g. play / reset..)

New features coming soon …

- Collision likelihood assessment using different methods
- More close approach meta-data
- Graphs
- Test for Gaussianity of Error around TCA

SERC SPACE ENVIRONMENT RESEARCH CENTRE

serc.org.au

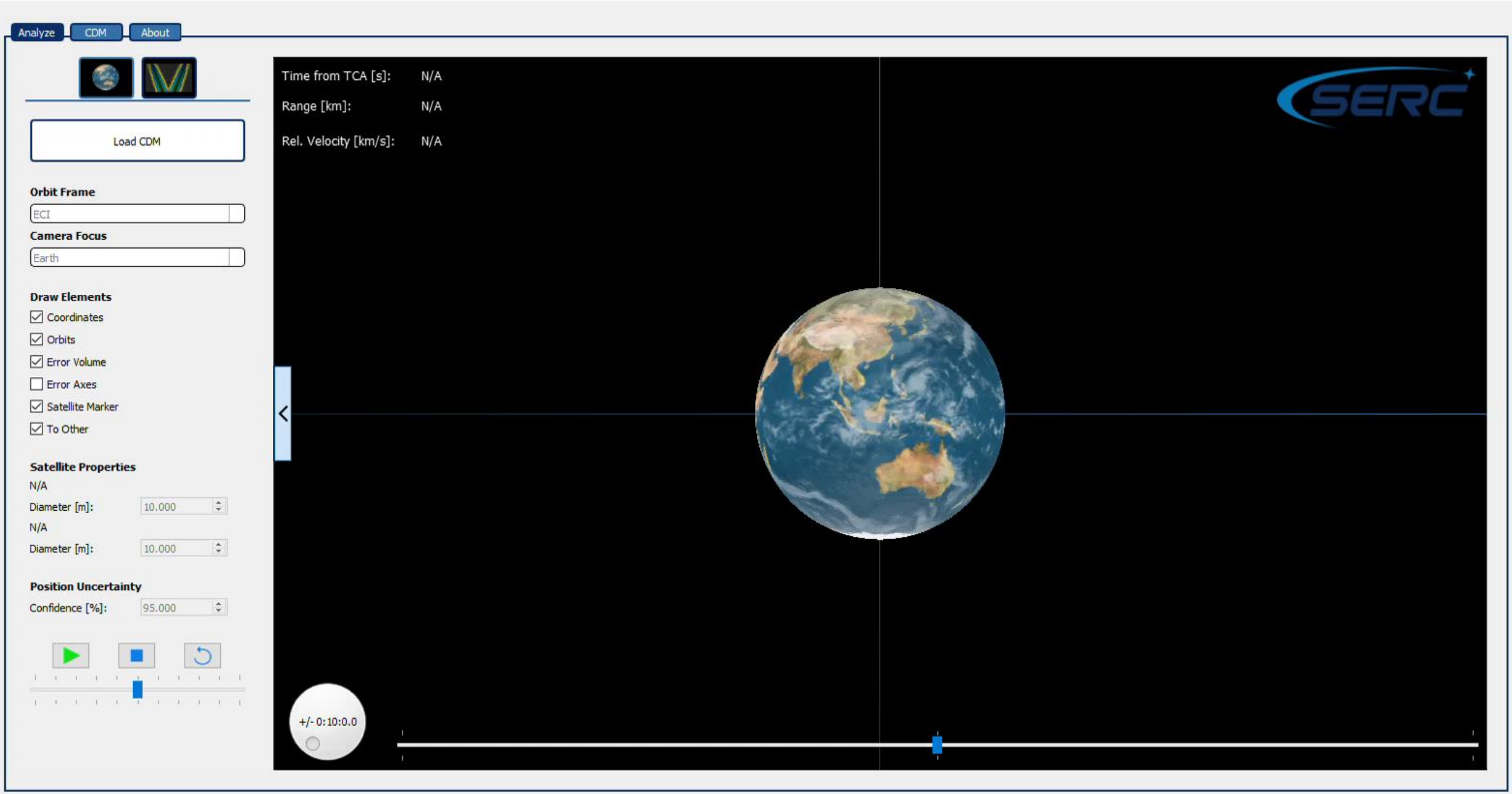
info@serc.org.au

facebook.com/serc.aus

@serc_aus

Australian Government
Department of Industry, Innovation and Science

Business Cooperative Research Centres Programme

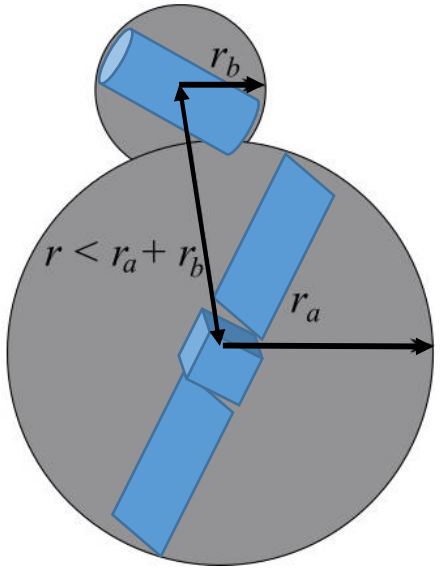

Analyze
CDM
About
Load CDM
Orbit Frame
ECI
Camera Focus
Earth
Draw Elements
Coordinates
Orbits
Error Volume
Error Axes
Satellite Marker
To Other
Satellite Properties
N/A
Diameter [m]:
10.000
N/A
Diameter [m]:
10.000
Position Uncertainty
Confidence [%]:
95.000
Time from TCA [s]: N/A
Range [km]: N/A
Rel. Velocity [km/s]: N/A
SERC
+/- 0:10:0.0

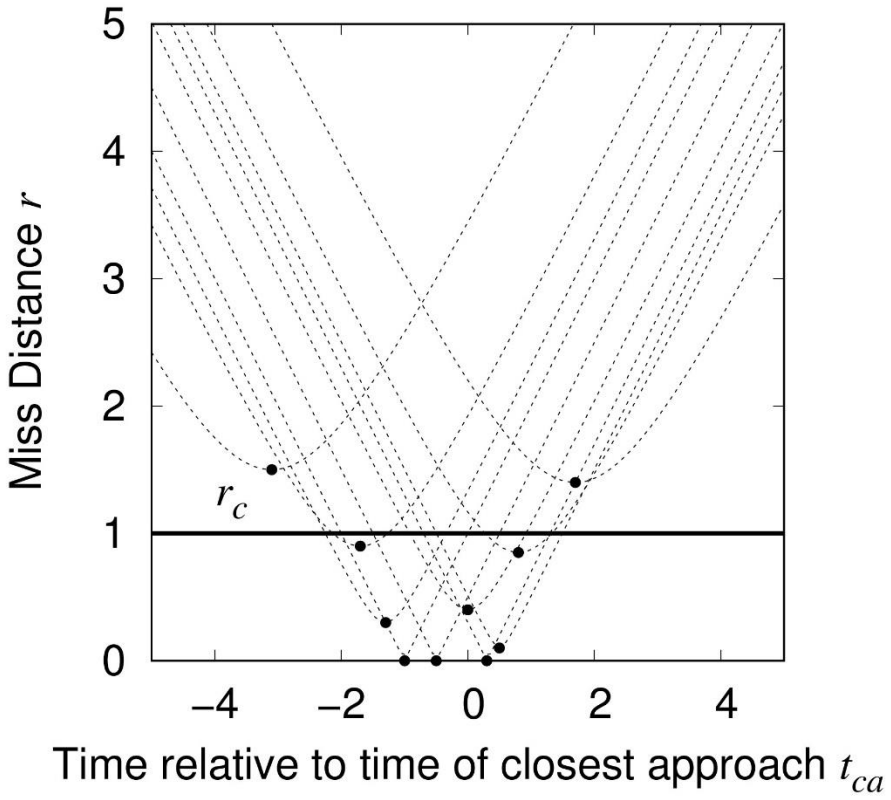
Particle Method Fundamentals

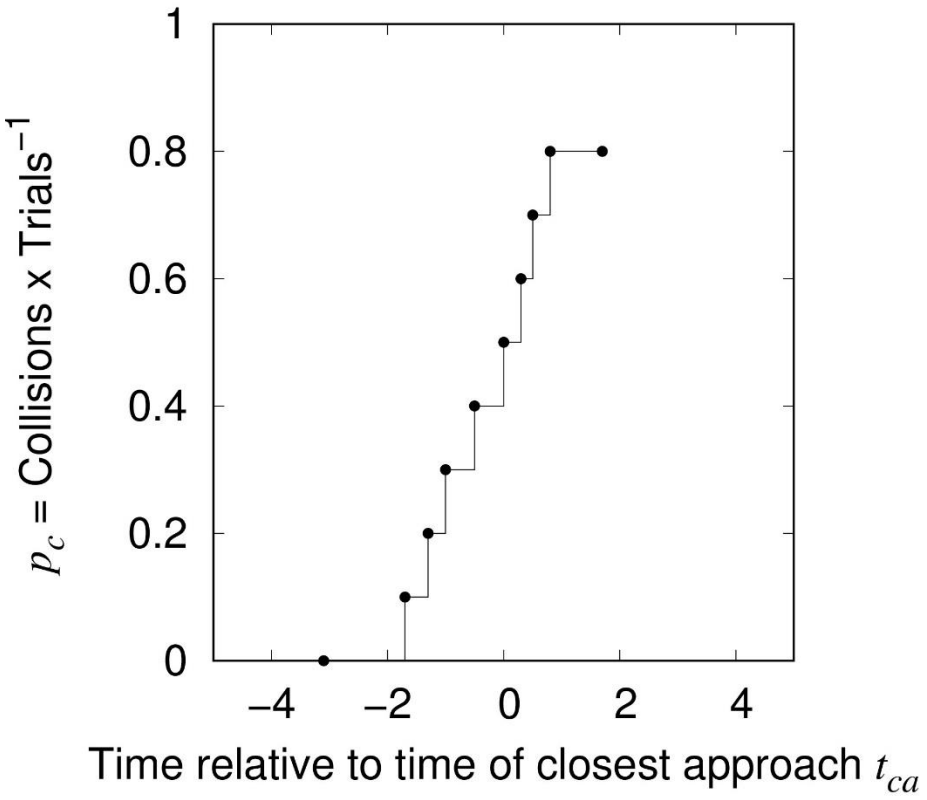
Condition for Collision:

$r < r_c$

(r_c = combined hardbody radius)

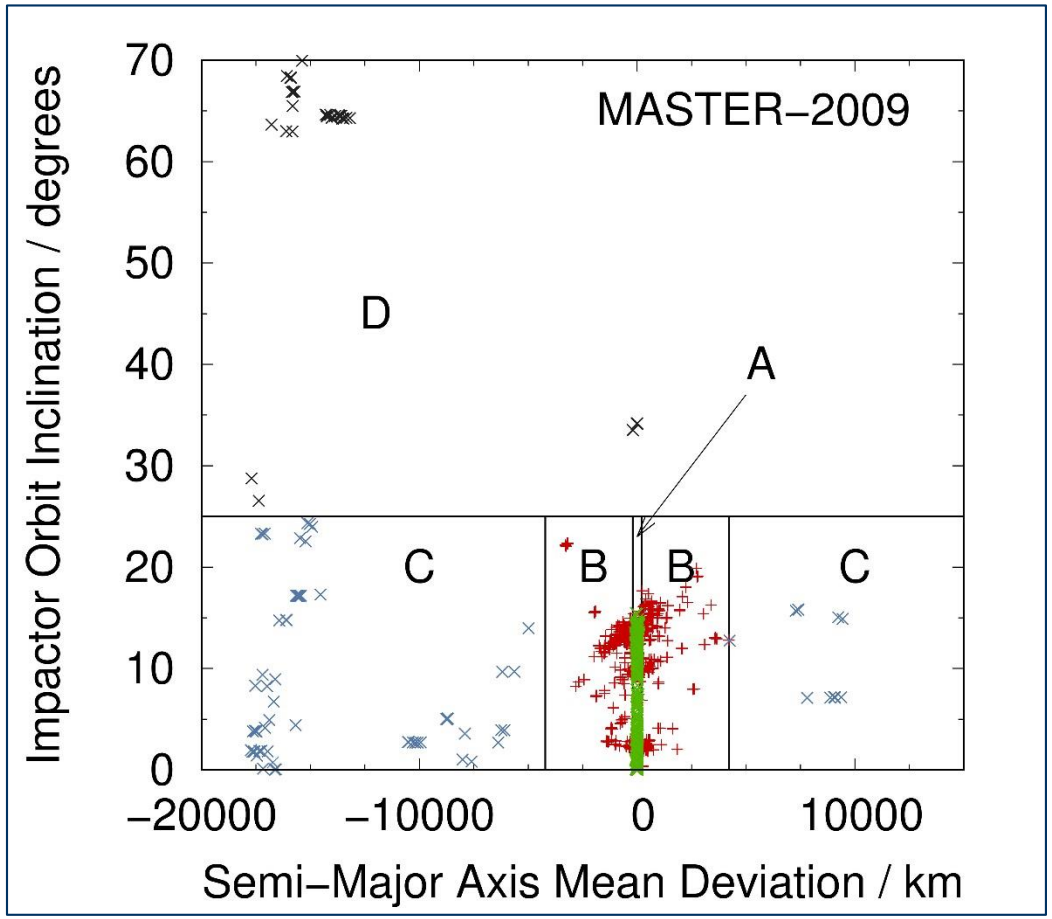






- Both objects considered spheres
- Collision Probability determined from number of particle pairs with $r < r_c$
- Results vary between samples
- Result only informative in combination with valuation of its variability (Central Limit Theorem, Chernoff-Hoeffding bound / Dagum bound)

GEO Encounters Characteristics



GEO Libration

61 %

GEO Drift

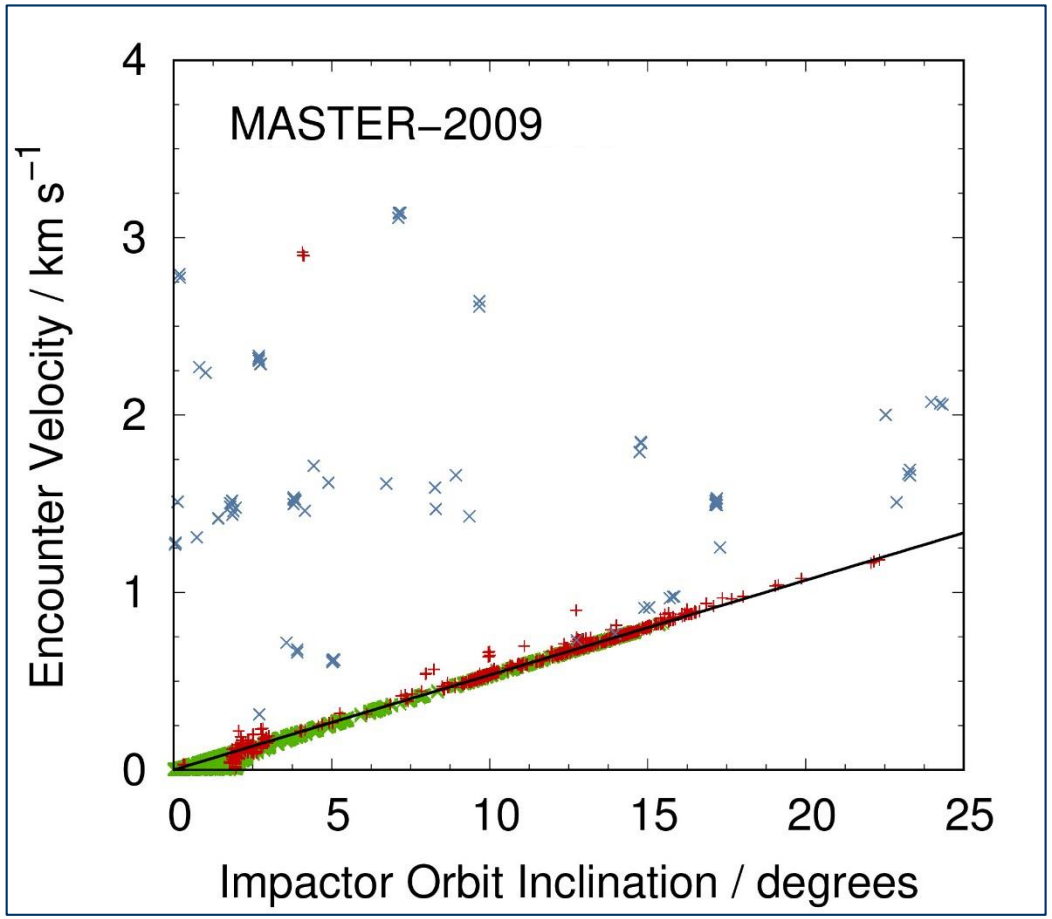
36 %

GEO Transient

2 %

Inclined

1 %



Encounter Velocities

- GEO Libration: generally < 1 km/s; as low as < 1 m/s
- GEO Drift: generally < 1 km/s
- GEO Transient & Inclined: generally > 1 km/s