NEOPROP: a NEO Propagator for Space Situational Awareness

IAASS Conference 2013

valentino.zuccarelli@astos.de

sven.weikert@astos.de

Authors

ESA:

- Celia Yabar Valles
- Detlef Koschny

IMCCE:

- David Bancelin
- William Thuillot
- Daniel Hestroffer

Astos Solutions:

- Valentino Zuccarelli
- Sven Weikert

Outline

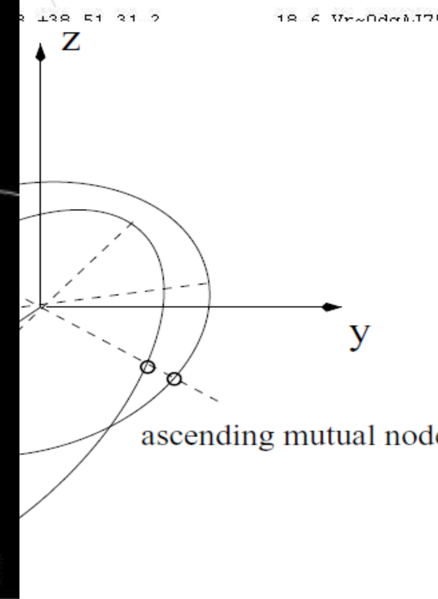
- Overview & Project Objective
- Software Architecture
- Analytical Module
- Numerical Module
- Test Cases
- Conclusions

ESA's Space Situational Awareness Programme

- Objective of the programme:
  "The objective of the SSA programme is to support Europe's independent utilisation of, and access to, space through the provision of timely and accurate information and data regarding the space environment, and particularly regarding hazards to infrastructure in orbit and on the ground."
- Formally launched on 1 January 2009
- The mandate was extended at the 2012 Ministerial Council until 2019
- The SSA programme is active in three main areas:
  - Survey and tracking of objects in Earth orbit (SST)
  - Monitoring space weather (SW)
  - Watching for NEOs (NEO)

NEOPROP Project Objective

“The key objective of this activity is to design, develop, test, verify, and validate trajectory prediction algorithm of NEOs. The final objective of these new prediction algorithms shall be to compute minimum orbital intersection distances (MOIDs) accurately.” [SoW]



Software Requirements

Functional Requirements

The tool shall allow:

- Orbit determination
- Estimation of the uncertainties
- Numerical orbit propagation
- MOID computation

Operational Requirement

The tool shall allow integration into the existing ESA NEO data centre infrastructure (ESA-SSA-NEO SBDC).

Design Requirement and Implementation Constraint

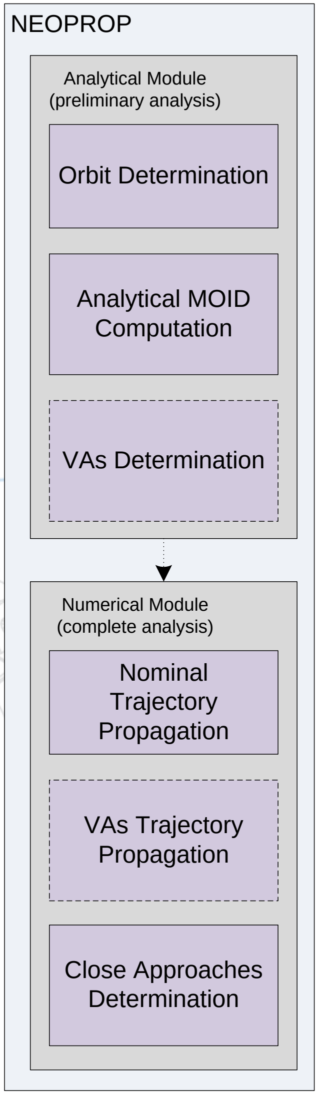
The tool shall implement, whenever possible, different algorithms from those used in NEODyS (Near Earth Object Dynamic Site, based on the OrbFit tool, sponsored by ESA, http://newton.dm.unipi.it/neodys/).

NEOPROP Architecture

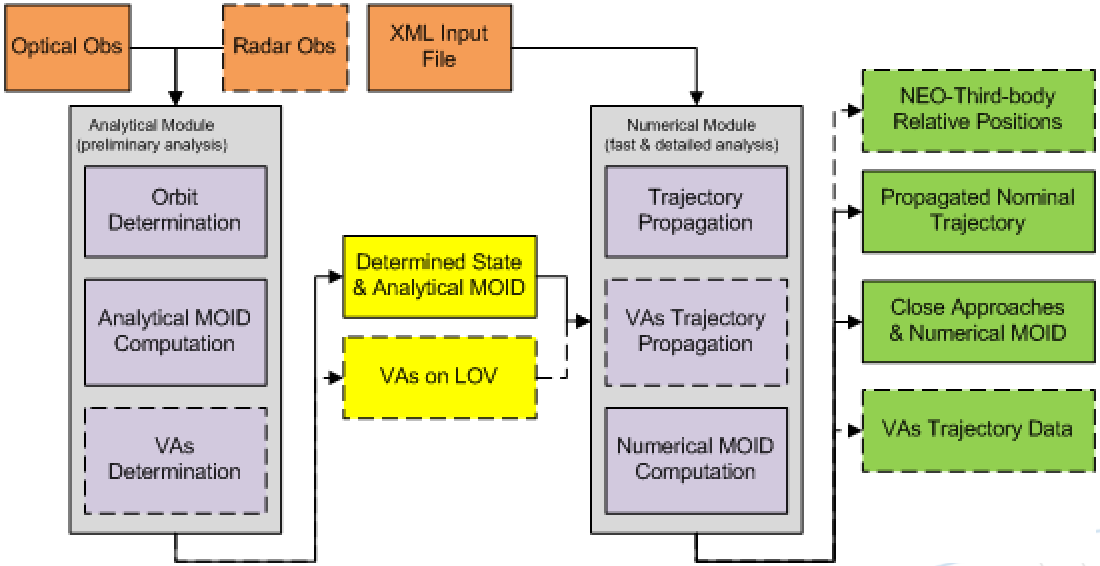
Two separate modules/tools:

1. The **Analytical Module** rapidly assesses the impact risk of a NEO. An Orbit Determination (OD) algorithm will determine the initial state of the NEO, which is used to compute the MOID.
   A set of VAs can be computed along the LOV.
2. The **Numerical Module** refines the risk assessment (if required). The initial state provided by the OD process will be numerically propagated. The numerical propagation can be run in two modes:
   - fast propagation (simplified models)
   - more precise propagation (complete models)

   Also the close approaches will be computed.
   A set of VAs can be propagated.



NEOPROP Interfaces



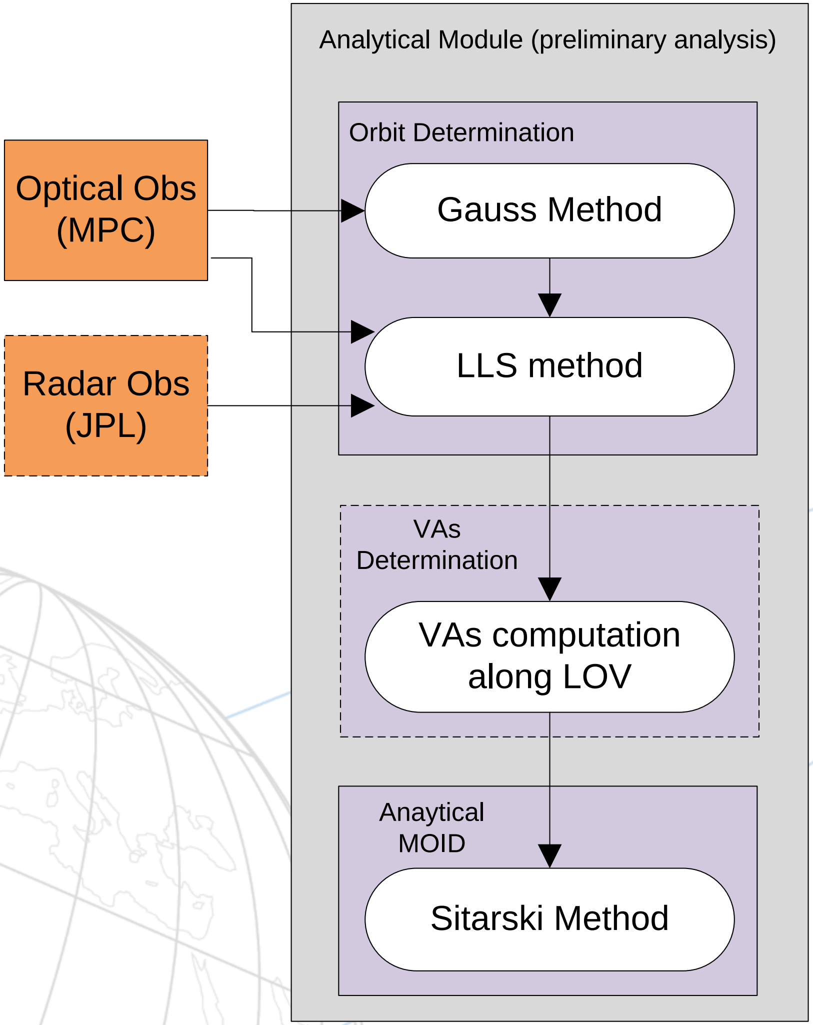
The Analytical Module needs as input:

- all the related optical and/or radar data

The Numerical Module needs as input:

- Initial state of the NEO (created by the Analytical Module)
- Initial states of the VAs (optional)
- Propagator settings (e.g. integrator, perturbations, etc) in XML file

Analytical Module

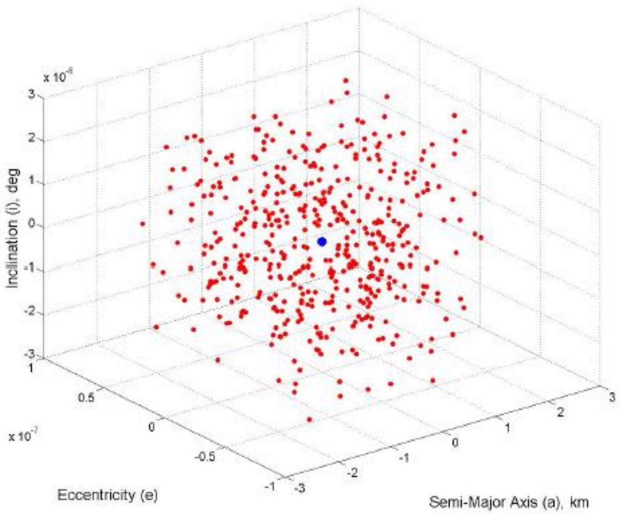


Analytical Module: VAs Generation

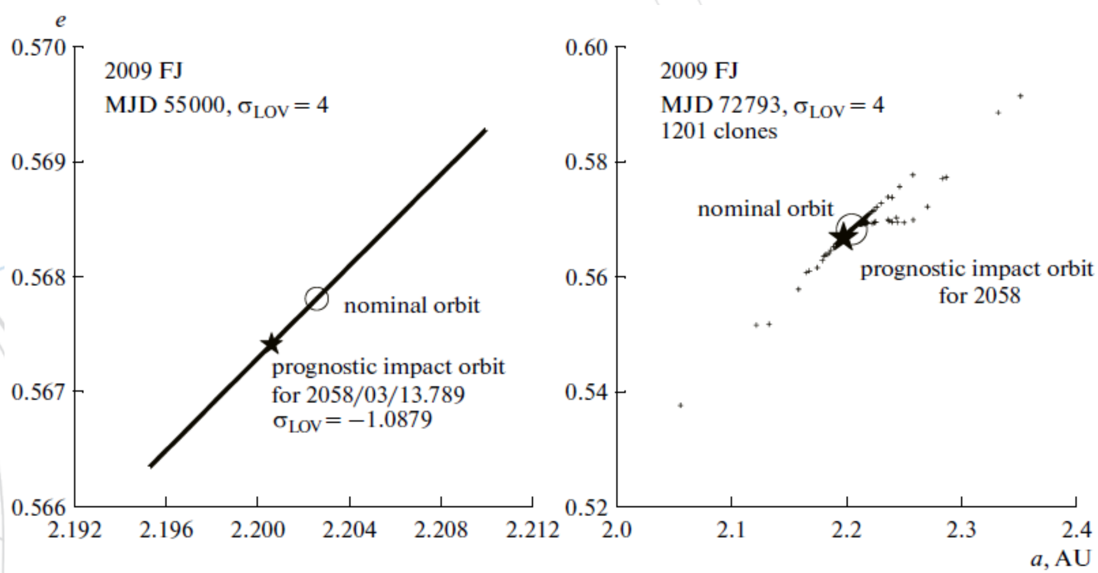
VAs are used to discretize the confidence region. They need to have initial states very close to the nominal solution.

Two different approaches can be used to compute them:

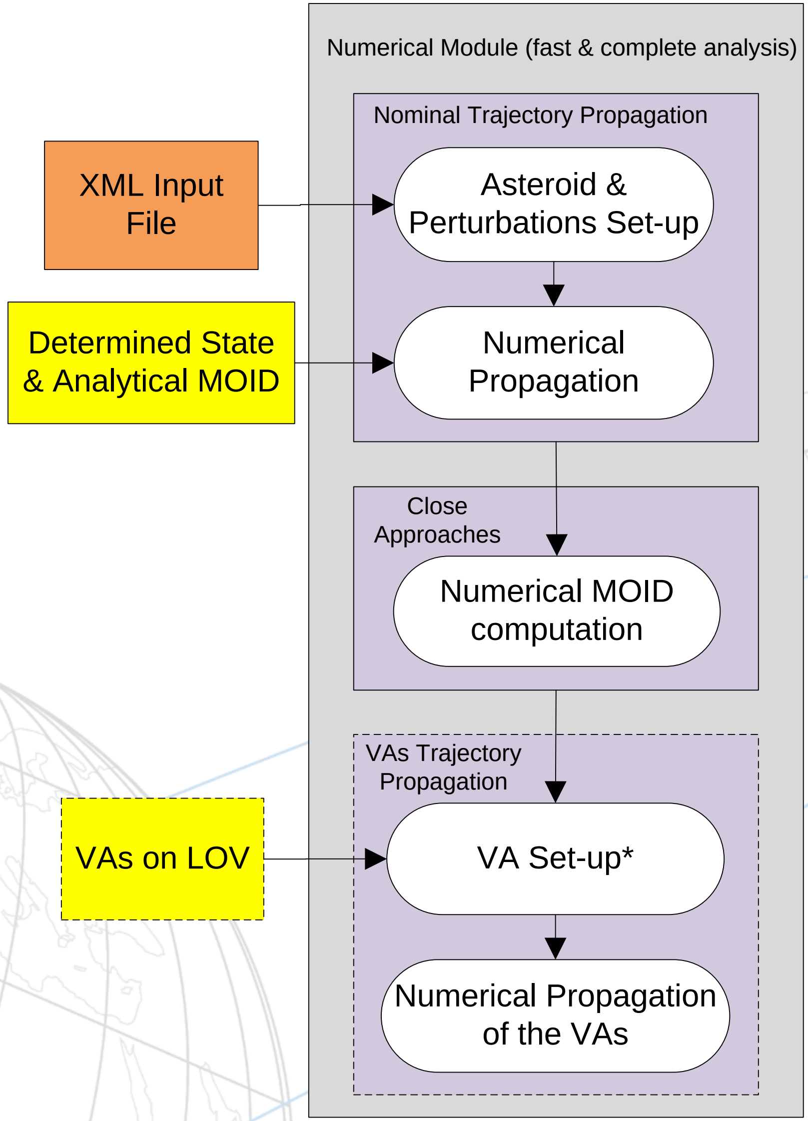
Monte Carlo



Line Of Variation



Numerical Module



*VAs can be imported from an external file or computed with a Monte Carlo technique.

Numerical Module Models

Integrators:

Integrator	Single/Multi-Step	Step-Size
Runge-Kutta 45	single	variable
Dormand Prince 8	single	variable
Runge-Kutta 853	single	variable
Runge-Kutta 4	single	fixed
Runge-Kutta 4 *Adapted*	single	fixed*
Gauss-Jackson 8	multi	fixed
Gauss-Jackson 8 *Adapted*	multi	fixed*
Gauss-Jackson 8 *Self-Adapted*	multi	fixed*

*The integration follows a fixed step-size scheme, but for some trajectory arcs (e.g. close to a celestial body) the step-size might be reduced by a factor of 10.

Perturbations:

"Fast" Analysis	"Complete" Analysis
Third-Body (planets)	Third-Body (planets + 4 main asteroids)
-	Relativistic Effects
Solar Radiation Pressure	Solar Radiation Pressure
-	Yarkovsky
Earth Spherical Harmonics	Earth Spherical Harmonics

Test Case: Analytical Module

The orbital elements and the MOID of 6 NEOs have been computed. As input the available observations (optical and radar) before the reference epoch has been used. As reference NEODyS was used:

	Apophis	2009FJ	2011AG5	2012DA14	2007VK184	2004DC
Epoch [JD]	2456400.5	2456200.5	2456400.5	2456275.0	2456400.5	2456400.5
Δ-a [AU]	0.0000000	0.0003387	0.0000001	-0.0000003	-0.0000100	0.0000000
%-a	0.000%	0.015%	0.000%	0.000%	-0.001%	0.000%
Δ-e [-]	0.0000000	0.0000676	0.0000001	-0.0000079	-0.0000031	0.0000000
%-e	0.000%	0.012%	0.000%	-0.007%	-0.001%	0.000%
Δ-i [°]	0.0015784	-0.0016318	0.0012234	0.0000266	0.0004886	-0.0004472
%-i	0.047%	-0.184%	0.033%	0.000%	0.040%	-0.002%
Δ-Ω [°]	-0.0121976	-0.0114062	0.0188884	0.0050332	-0.0784726	0.0047278
%-Ω	-0.006%	-0.003%	0.014%	0.003%	-0.031%	0.006%
Δ-ω [°]	0.0122278	0.0116644	-0.0189304	-0.0042552	0.0785228	-0.0049840
%-ω	0.010%	0.008%	-0.035%	-0.002%	0.107%	-0.003%
Δ-M [°]	-0.0000262	-0.0912437	-0.0000397	0.0003334	0.0076807	-0.0000278
%-M	0.000%	-0.250%	0.000%	0.003%	0.005%	0.000%
Δ-MOID [AU]	-0.00000002	0.0000008	-0.0000037	-0.0000342	0.0000012	-0.0000043
%-MOID	**-0.001%**	**0.064%**	**-1.040%**	**0.601%***	**0.184%**	**-0.047%**

*computed with the Numerical Module due to Earth close approach on 15-02-2013

Test Case: Numerical Module

Apophis has been used for a long-term propagation. Its orbital elements (previously determined) have been propagated until 14-04-2029 to cover its next Earth approach (on the 13-04-2029). As reference JPL-Horizons and JPL-SBDB were used:

Final state	Δ-Value	%-Value
x [km]	-2.139E+03	**0.00%**
y [km]	-4.366E+01	**0.00%**
z [km]	5.573E+03	**-0.02%**

Time (TDB)	Body	Distance (AU)	Δ-Distance (AU)	%-Distance
2006-Apr-10,23:49	Earth	0.202820223	3.794E-07	**0.000%**
2013-Jan-09,11:44	Earth	0.096665441	4.328E-06	**0.004%**
2016-Apr-24,02:50	Venus	0.078240242	-1.656E-06	**-0.002%**
2020-Oct-12,08:36	Earth	0.21627714	1.078E-06	**0.000%**
2021-Mar-06,01:16	Earth	0.112651436	-2.238E-07	**0.000%**
2024-Mar-07,15:45	Venus	0.124438646	6.291E-06	**0.005%**
2029-Apr-13,21:46	Earth	0.000254828	1.366E-06	**0.533%**
2029-Apr-14,14:33	Moon	0.000636175	8.743E-08	**0.014%**

Test Case: Analytical+Numerical Module

The 2007VK184 NEO has a possible Earth impactor in 2048 [NEODyS]:

Time (TDB)	σ (LOV)	Distance (Earth Radius)
2048-Jun-03 02:08	1.29	0.92

The Analytical Module has been run to generate VAs along the LOV. The VAs have been passed to the Numerical module and propagated till 2048-Jun-04. NEOPROP detected an Earth impactor at exactly the same epoch:

Time (TDB)	σ (LOV)	Distance (Earth Radius)
2048-Jun-03 02:08	1.40	0.98

Conclusions

NEOPROP is able to successfully:

- determine the initial state of an asteroid from optical and radar obs
- compute its MOID
- compute VAs (along LOV and MC)
- numerically propagate its trajectory and VAs
- compute close approaches

All the test cases demonstrated high accuracy of the tool:

All results **within 1%** of reference (NEODyS, JPL-Horizons, JPL-SBDB)

Thank you!