Asteroid selection database for space mining mission analysis

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Imagine space concepts for tomorrow and beyond
SAC LAB
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Introduction

ECOCEL

Exploitation des Ressources des Corps Célestes

First French interdisciplinary study on the space mining

Law and regulations

Engineering and Planetology

Economics

Geography

Political sciences

ECOCEL Objectives

Space mining → Recommendations / Overview → **for the French Government**

Engineering and Planetology

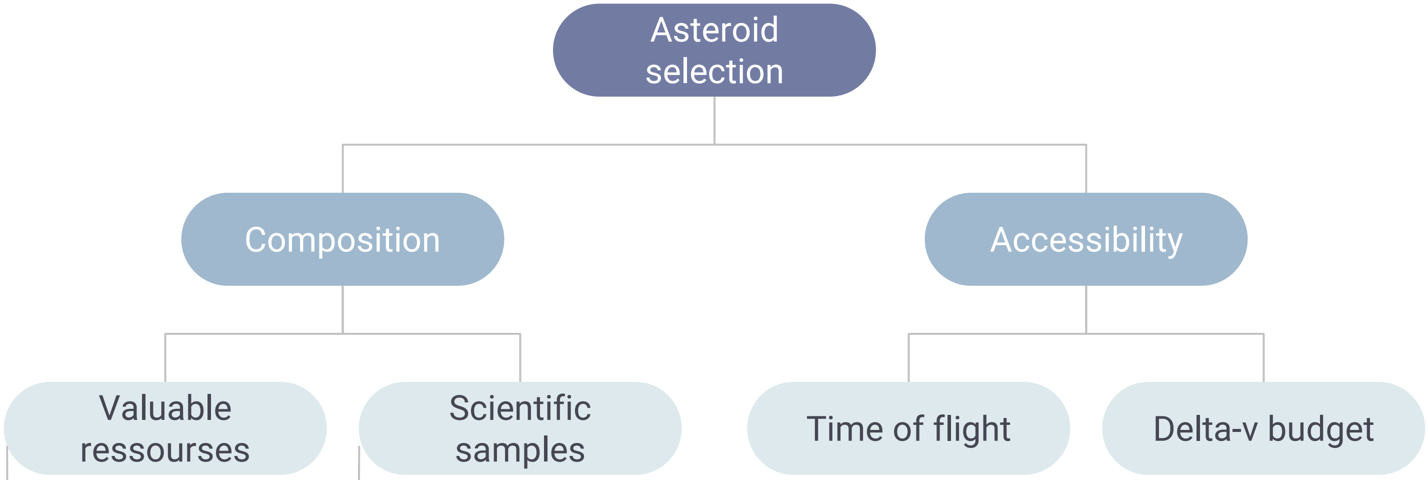
Space Advanced Concepts Laboratory

SaCLaB study:

- *Ressources*
- *Accessible objects*
- *Technology*
- *Timeframe*

Asteroid selection database

Database content



Valuable metals (platinum, cobalt)

Raw material for space construction and propellant

Carbon-rich (mineral and organic components of Solar System)

Mission analysis

Departure / Arrival options:
Earth, cis-lunar space, Sun-Earth Lagrange point orbits

Database creation

Step 1

Step 2

Step 3

Collect available data

Basic orbital and physical parameters of near-Earth asteroids (NEAs) are collected from JPL Small-Body Database [1]

Complete by composition data

The composition is inferred from asteroid-meteorite samples link from literature.

Compute mission opportunities

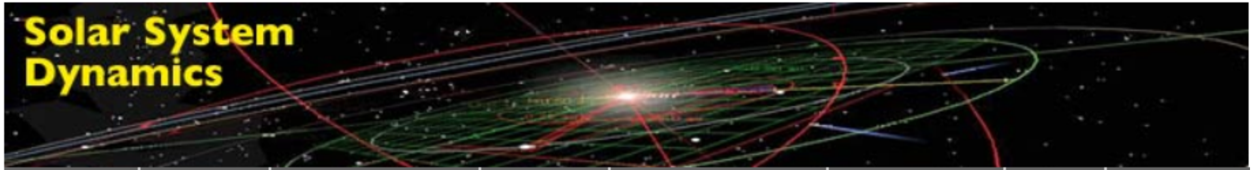
For each object in database we computed mission opportunities for one-way and round trip missions from Earth.

[1] https://ssd.jpl.nasa.gov/sbdb.cgi

Step 1: data from JPL Small-Body Database

Selection constraints

1. NEAs
   → **23340 objects**
1. Defined Spectral class Tholen [2] or SMASSII [3]
   → **326 objects**



BODIES | ORBITS | EPHEMERIDES | TOOLS | PHYSICAL DATA | DISCOVERY | FAQ | SITE MAP

JPL Small-Body Database Search Engine

[Refine Search] **Results:** 326 matching objects

Constraints: asteroids **and** NEOs **and** [spec. type (SMASSII) is defined **or** spec. type (Tholen) is defined]

SPK-ID ?	object fullname ?	a (au) ?	e ?	i (deg) ?	node (deg) ?	peri (deg) ?	q (au) ?	Q (au) ?
2000433	433 Eros (A898 PA)	1.458	0.2230	10.83	304.30	178.88	1.133	1.78
2000719	719 Albert (A911 TB)	2.639	0.5466	11.57	183.87	156.18	1.196	4.08
2000887	887 Alinda (A918 AA)	2.474	0.5703	9.39	110.43	350.50	1.063	3.88
2001036	1036 Ganymed (A924 UB)	2.665	0.5330	26.68	215.55	132.36	1.244	4.09
2001580	1580 Betulia (1950 KA)	2.197	0.4874	52.09	62.30	159.52	1.126	3.27
2001620	1620 Geographos (1951 RA)	1.246	0.3355	13.34	337.19	276.96	0.828	1.66
2001627	1627 Ivar (1929 SH)	1.863	0.3968	8.45	133.12	167.79	1.124	2.60
2001685	1685 Toro (1948 OA)	1.368	0.4358	9.38	274.25	127.21	0.772	1.96
2001862	1862 Apollo (1932 HA)	1.47	0.5599	6.35	35.63	285.98	0.647	2.29
2001863	1863 Antinous (1948 EA)	2.258	0.6065	18.40	346.44	268.07	0.889	3.63
2001864	1864 Daedalus (1971 FA)	1.461	0.6145	22.21	6.62	325.63	0.563	2.36

[1] https://ssd.jpl.nasa.gov/sbdb.cgi
[2] Tholen, D. J. (1989)
[3] Bus, S. J., & Binzel, R. P. (2002)

Step 2: Composition data

Meteorite samples → Asteroid's spectral type → Asteroid's composition

- Spectroscopy technique for asteroid observations

→ Classifications:
Tholen [2] or SMASSII [3]

- Established asteroid–meteorite links [4]

Chemical composition from [5]:

- Fe
- Ni
- Au
- Pb
- Is
- Rh
- Re
- Ge
- Si
- Al
- H20
- P
- Ga
- Ge
- Cd
- Cu
- As
- Sc
- In
- Sb
- Te

→ Estimated surface composition
→ Internal structure and composition are undefined

[4] Cloutis, E. A., Binzel, R. P., & Gaffey, M. J. (2014).
[5] McSween Jr, H. Y., & Huss, G. R. (2010). *Cosmochemistry*.

Step 2: Composition data

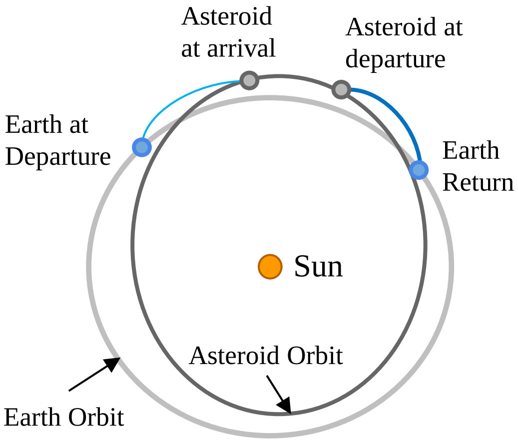
	spkid	name	chondrite_type	spec_b	spec_t	fe	ni	au	pt	si	al	ga	cd	cu	h2o
0	2000433	Eros	O	S	S	21.8	1.24	0.000016	0.000109	18.60	1.160	0.00054	0.000003	0.0090	0.00
1	2000719	Albert	O	S	NaN	21.8	1.24	0.000016	0.000109	18.60	1.160	0.00054	0.000003	0.0090	0.00
2	2000887	Alinda	O	NaN	S	21.8	1.24	0.000016	0.000109	18.60	1.160	0.00054	0.000003	0.0090	0.00
3	2001036	Ganymed	O	S	S	21.8	1.24	0.000016	0.000109	18.60	1.160	0.00054	0.000003	0.0090	0.00
4	2001580	Betulia	CM, CI	NaN	C	18.2	1.10	0.000014	0.000100	10.64	0.865	0.00098	0.000069	0.0125	18.18
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
321	3114075		M	X:	NaN	88.0	10.00	0.000000	0.000000	0.00	0.000	0.00000	0.000000	0.0000	0.00
322	3114077		O	Sq	NaN	21.8	1.24	0.000016	0.000109	18.60	1.160	0.00054	0.000003	0.0090	0.00
323	3114105		NaN	L	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
324	3114106		M	X:	NaN	88.0	10.00	0.000000	0.000000	0.00	0.000	0.00000	0.000000	0.0000	0.00
325	3448992		O	S	NaN	21.8	1.24	0.000016	0.000109	18.60	1.160	0.00054	0.000003	0.0090	0.00

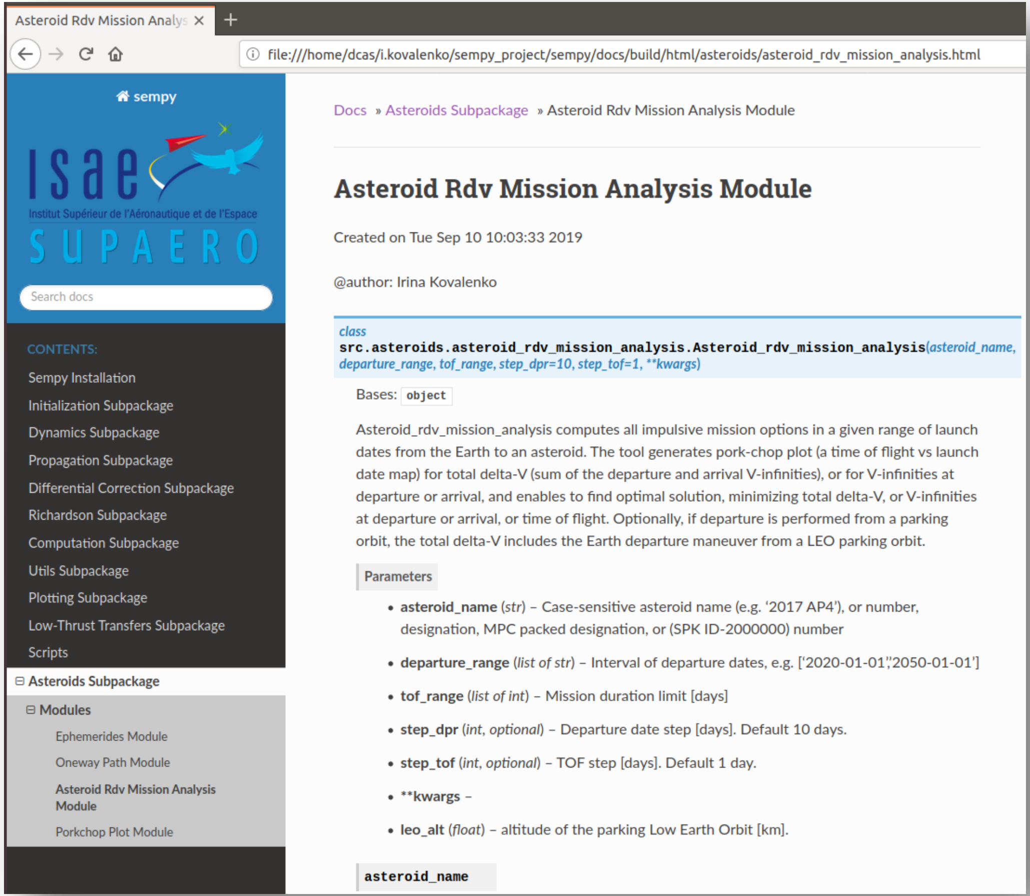
Step 3: Mission opportunities

Tools ○ SEMPy

Sun Earth Moon dynamics python package

Mission analysis ○ One-way mission
○ Round-trip mission




Asteroid Rdv Mission Analys ×

file:///home/dcas/i.kovalenko/sempy_project/sempy/docs/build/html/asteroids/asteroid_rdv_mission_analysis.html

sempy

Search docs

CONTENTS:

- Sempy Installation
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- Differential Correction Subpackage
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- Scripts
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    - Oneway Path Module
    - Asteroid Rdv Mission Analysis Module
    - Porkchop Plot Module

Docs » Asteroids Subpackage » Asteroid Rdv Mission Analysis Module

Asteroid Rdv Mission Analysis Module

Created on Tue Sep 10 10:03:33 2019

@author: Irina Kovalenko

class **src.asteroids.asteroid_rdv_mission_analysis.Asteroid_rdv_mission_analysis**(*asteroid_name, departure_range, tof_range, step_dpr=10, step_tof=1, **kwargs*)

Bases: `object`

Asteroid_rdv_mission_analysis computes all impulsive mission options in a given range of launch dates from the Earth to an asteroid. The tool generates pork-chop plot (a time of flight vs launch date map) for total delta-V (sum of the departure and arrival V-infinities), or for V-infinities at departure or arrival, and enables to find optimal solution, minimizing total delta-V, or V-infinities at departure or arrival, or time of flight. Optionally, if departure is performed from a parking orbit, the total delta-V includes the Earth departure maneuver from a LEO parking orbit.

Parameters

- **asteroid_name** (*str*) – Case-sensitive asteroid name (e.g. '2017 AP4'), or number, designation, MPC packed designation, or (SPK ID-2000000) number
- **departure_range** (*list of str*) – Interval of departure dates, e.g. ['2020-01-01','2050-01-01']
- **tof_range** (*list of int*) – Mission duration limit [days]
- **step_dpr** (*int, optional*) – Departure date step [days]. Default 10 days.
- **step_tof** (*int, optional*) – TOF step [days]. Default 1 day.
- ****kwargs** –
- **leo_alt** (*float*) – altitude of the parking Low Earth Orbit [km].

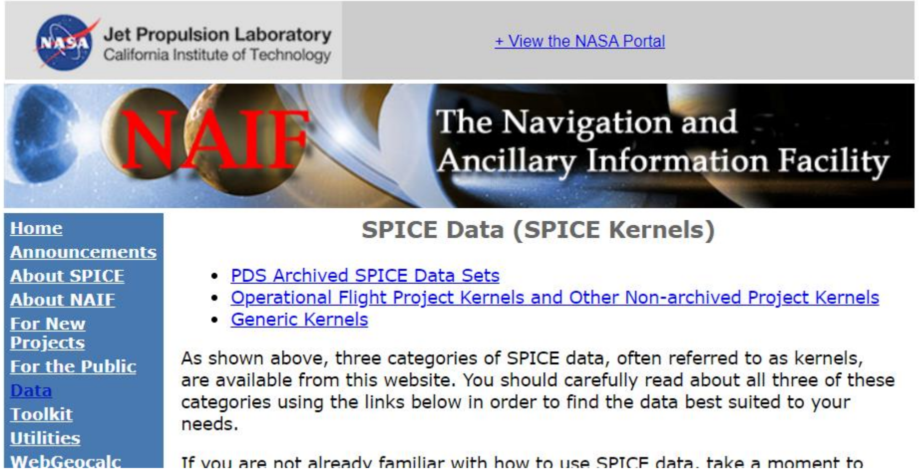
`asteroid_name`

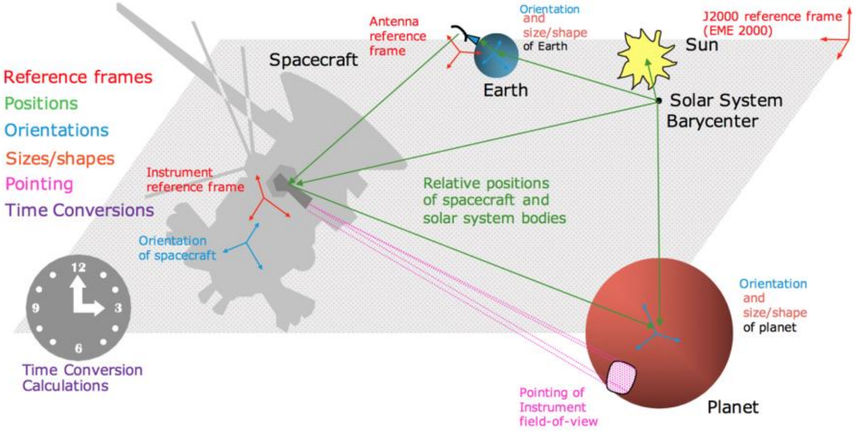
SEMPy mission analysis tools

SEMPy: mission analysis methods

Ephemerides Earth's and asteroids ephemerides from JPL Horizons system [9]

SPICE Kernels





Source: https://www.cosmos.esa.int/web/spice (c)

SEMPy: mission analysis methods

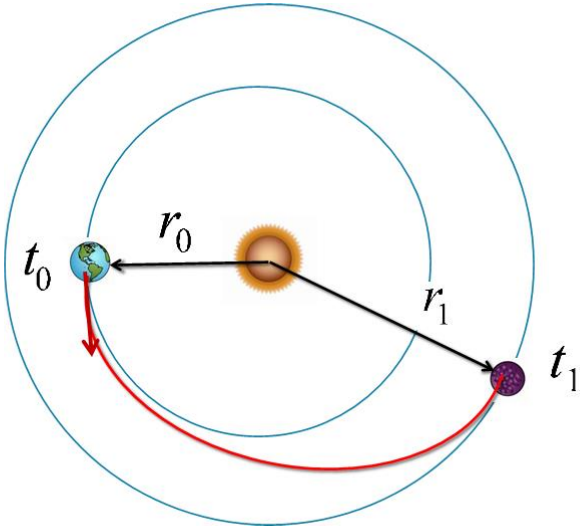
Ephemerides	Earth's and asteroids ephemerides from JPL Horizons system [9]
Lambert's problem	Lambert's problem solutions for Earth→ Asteroid and Asteroid→ Earth (if round trip).

Lambert's problem

Given:

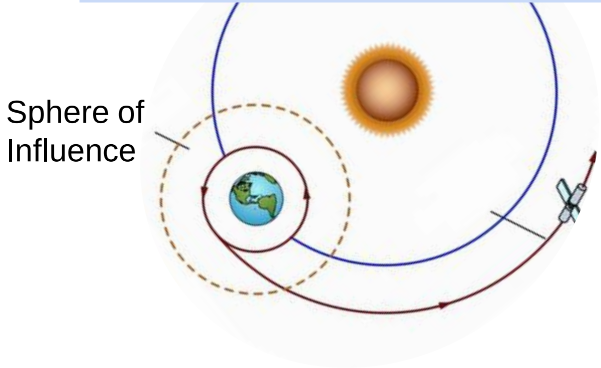
- $\mathbf{r_0}$ position at time $\mathbf{t_0}$
- $\mathbf{r_1}$ position at time $\mathbf{t_1}$

Find:
a conic trajectory between two positions



SEMPy: mission analysis methods

Ephemerides	Earth’s and asteroids ephemerides from JPL Horizons system [9]
Lambert’s problem	Lambert’s problem solutions for Earth→ Asteroid and Asteroid→ Earth (if round trip).
Patched conic approximation	Two body approximation for departure from a low-Earth orbit (LEO). **Delta-v**: - the Earth departure maneuver from a circular parking orbit - the maneuver to match the NEA's velocity at arrival - the maneuver to depart the NEA (if round trip mission)



SEMPy: mission analysis methods

Ephemerides	Earth's and asteroids ephemerides from JPL Horizons system [9]
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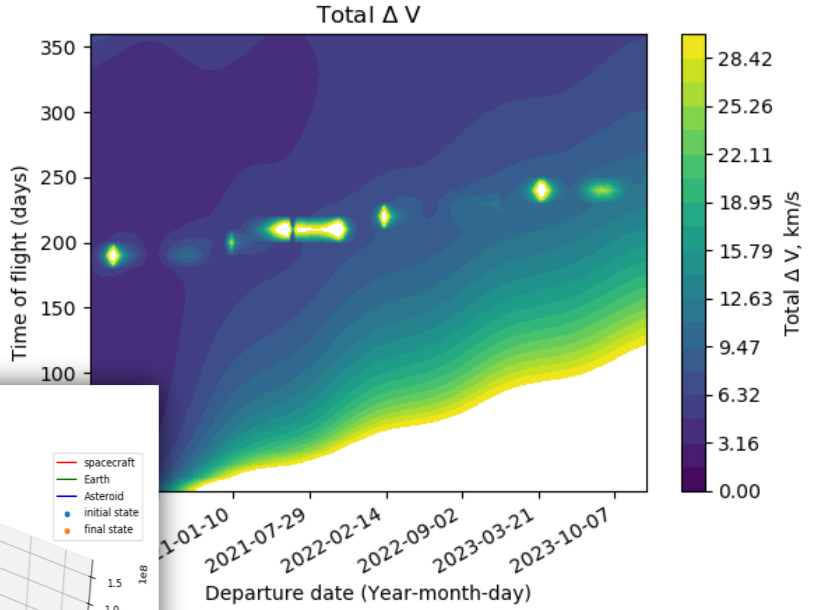
SEMPy Tools: Constraints	Precomputed trajectories - **launch interval** 2020-2050 - **mission duration** 450 days - **stay at asteroid** at least 10 days (if round trip mission)
Output	Optimal **delta-v** and **TOF** solutions + associated all the maneuvers and Lambert's solution values

SEMPy: mission analysis methods

Input: Constraints

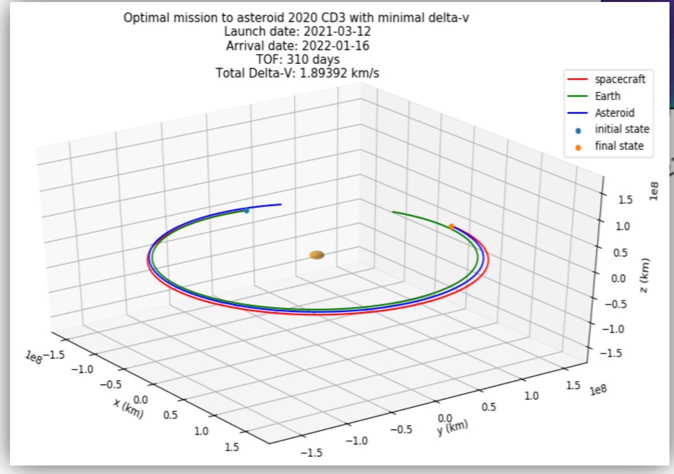
- **Launch interval** 2020-2050
- **Mission duration** 450 days
- **Stay at asteroid** at least 10 days (if round trip mission)
- **Departure LEO** (optional)



Output

Optimisation parameters choice:

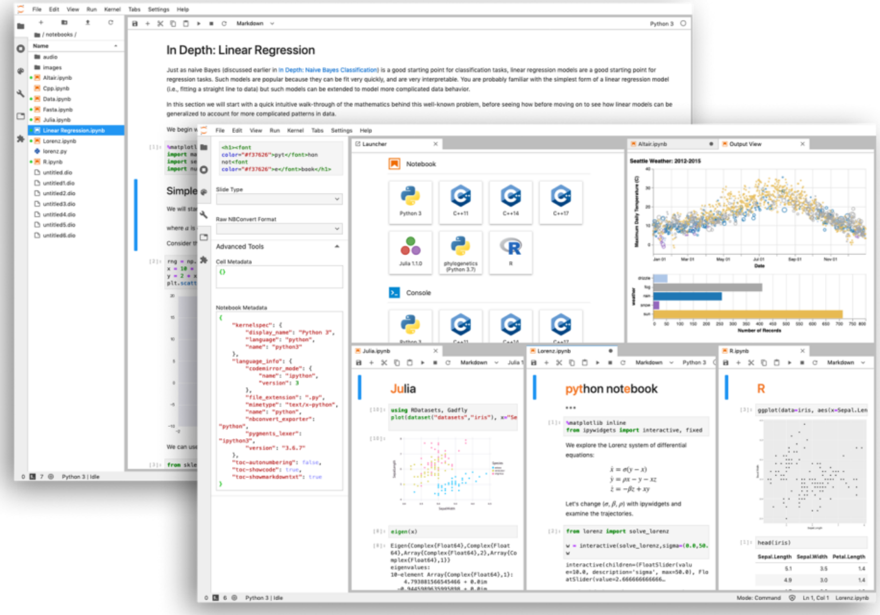
- **Time of flight (TOF)**
- **Total delta-v**
- **Departure/arrival delta-v**
- **Hyperbolic excess velocity**



SEMPy database tools

SEMPy database tools

User interface

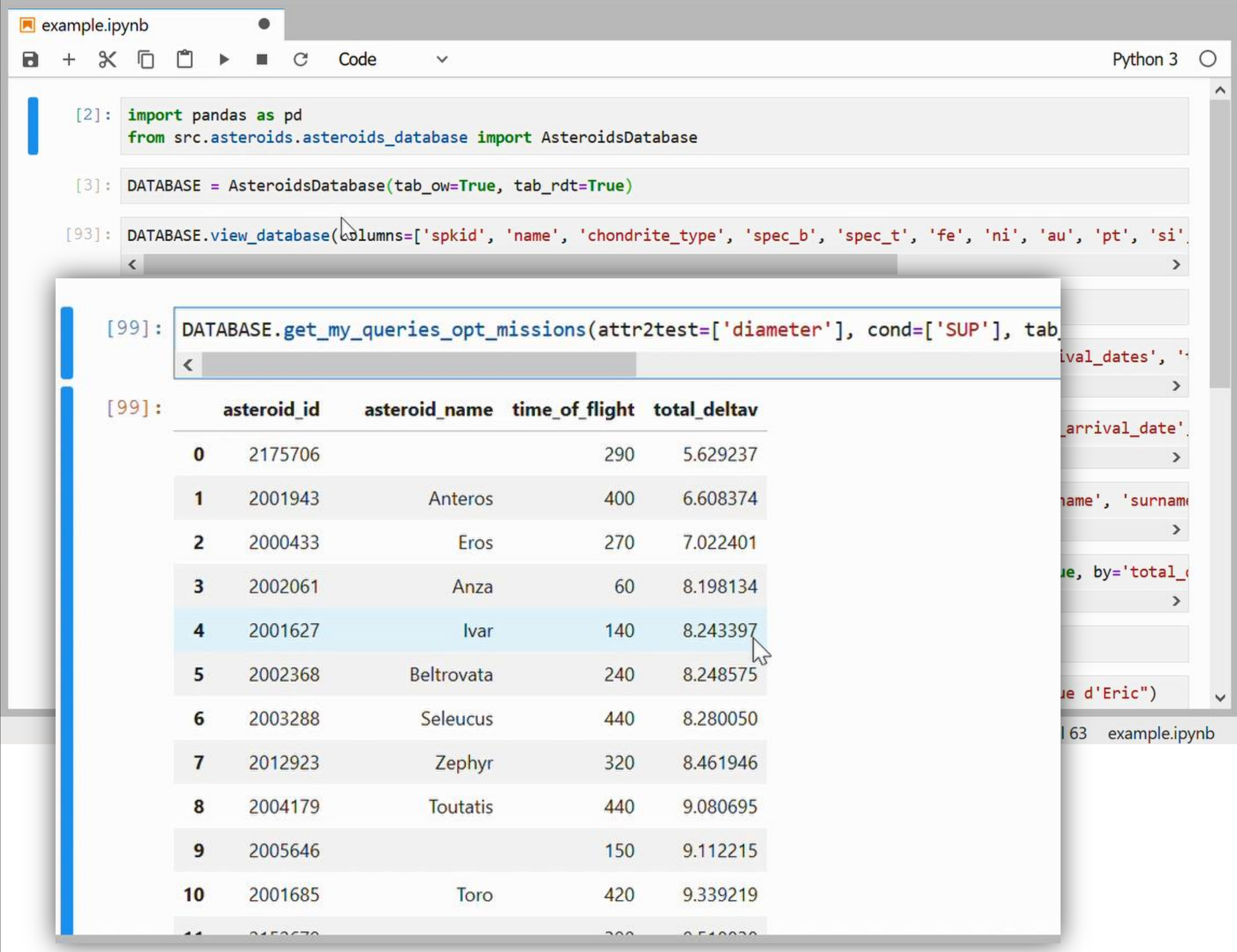


- Environment for **code** and **data**
- Consistent with Python methods in SEMPy
- Flexible for new functions, new data
- Open source

SEMPy database tools

Functionalities:

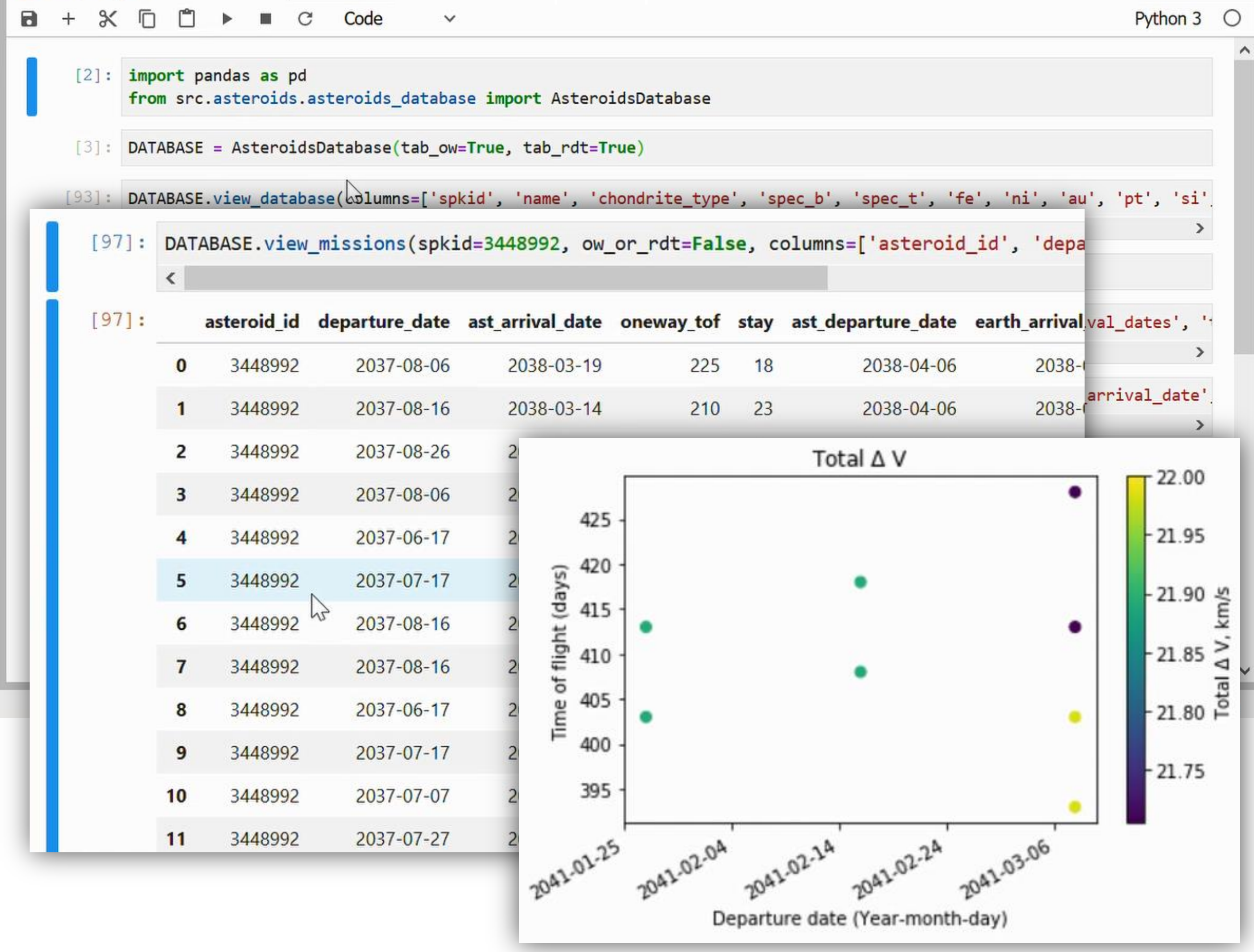
- **Multicriteria target selection:**
    - mission parameters (TOF, delta-v, …)
    - composition
    - diameter
    - ...



SEMPy database tools

Functionalities:

- Multicriteria target selection:
  - mission parameters (TOF, delta-v, …)
  - composition
  - diameter
  - …
- **Mission opportunities for each object**
  - precomputed one-way
  - and round-trip

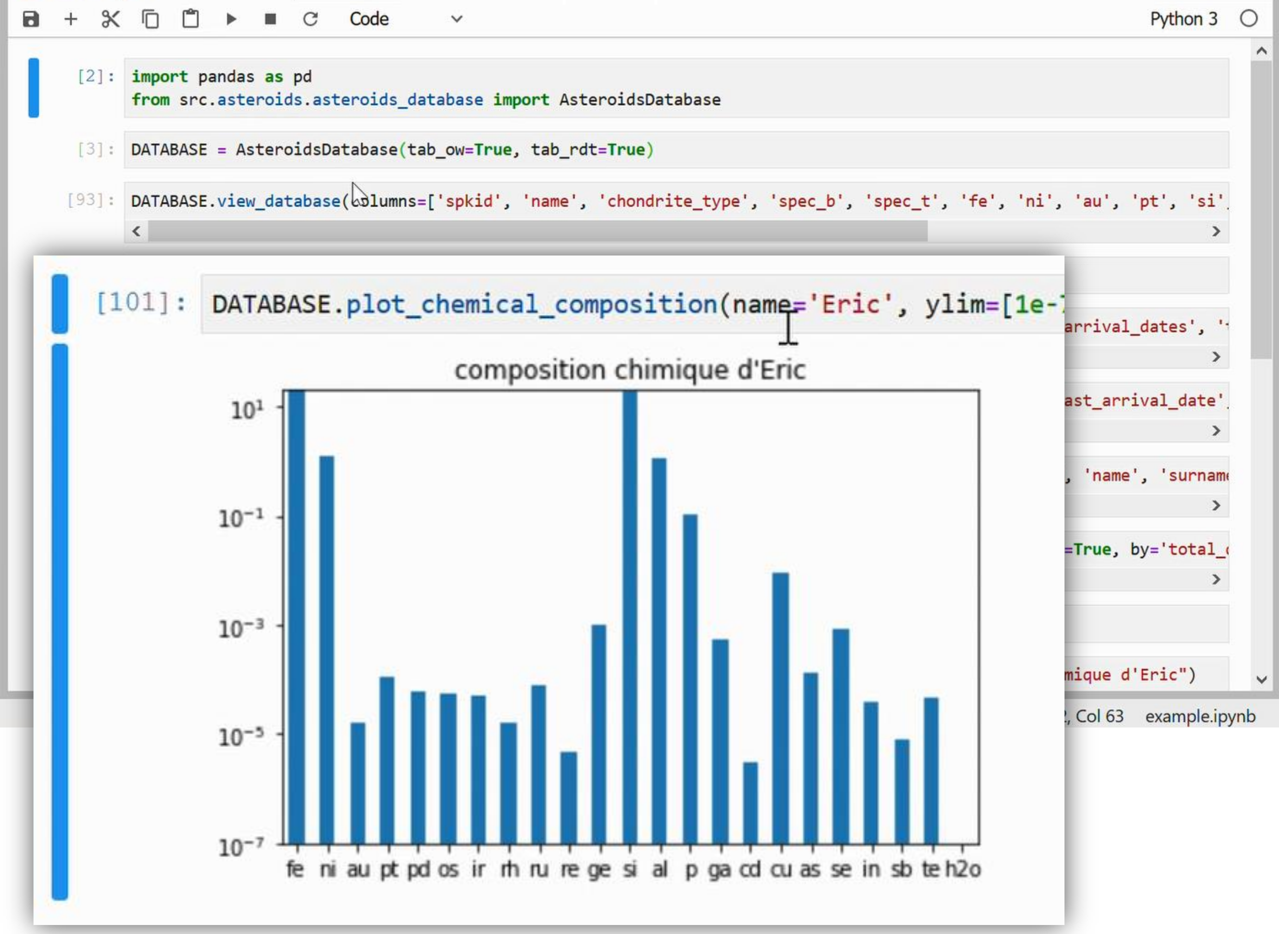


SEMPy database tools

Functionalities:

- Multicriteria target selection:
  - mission parameters (TOF, delta-v, …)
  - composition
  - diameter
  - ...
- Mission opportunities for each object
  - precomputed one-way
  - and round-trip

- **Data visualisation**

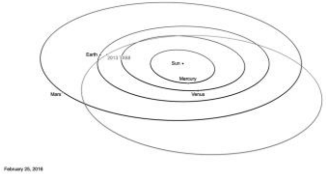


Conclusion and future work

Comparison with other databases

	NASA Ames [6]	JPL MDT [7]	CNEOS [8]	ECOCEL
Asteroids type	NEAs	All	NHATS [12]	NEAs with Tholen/SMASSII class
Launch interval	2020-2045	2020-2040	2020-2040	2020-2050
Mission duration	10 years	2000 days	450 days	450/900 days
Delta-v limit	10 km/s		12 km/s	(optional)
Flyby authorized	✓	✗	✗	✗
One-way flight	✓	✓	✗	✓
Roundtrip flight	✓	✗	✓	✓
Parking orbit	200 km	✗	400 km	✓ (optional)
Composition	✗	✗	✗	✓

Future work



Nov 2019 — **Mission analysis tools**

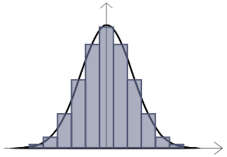
SEMpy preliminary mission analysis: Earth-Asteroid mission

June 2020 — **Database creation**

Composition: chemical elements, water
Precomputed trajectories

Oct 2020 — **Database extension**

Lunar flyby opportunities
Multiple targets mission



… 2020 — **Data analysis**

Data interpretation and visualisation
Statistical analysis

2021 — **ECOCEL Final report**

Overview and recommendations for the French Government

Thank you for your attention!

Any questions?

Corresponding author

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References

[1] JPL Nasa. Jpl small-body database search engine.

[2] THOLEN, David J. Asteroid taxonomic classifications. In : Asteroids II. 1989. p. 1139-1150.

[3] Bus, S. J., & Binzel, R. P. (2002). Phase II of the small main-belt asteroid spectroscopic survey: A feature-based taxonomy. Icarus, 158(1), 146-177.

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[6] Nasa Ames Research Center. Trajectory browser.

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[9] SPICE Kernels https://naif.jpl.nasa.gov/naif/spiceconcept.html