From Hyperspectral Data Processing to Pulsar Navigation

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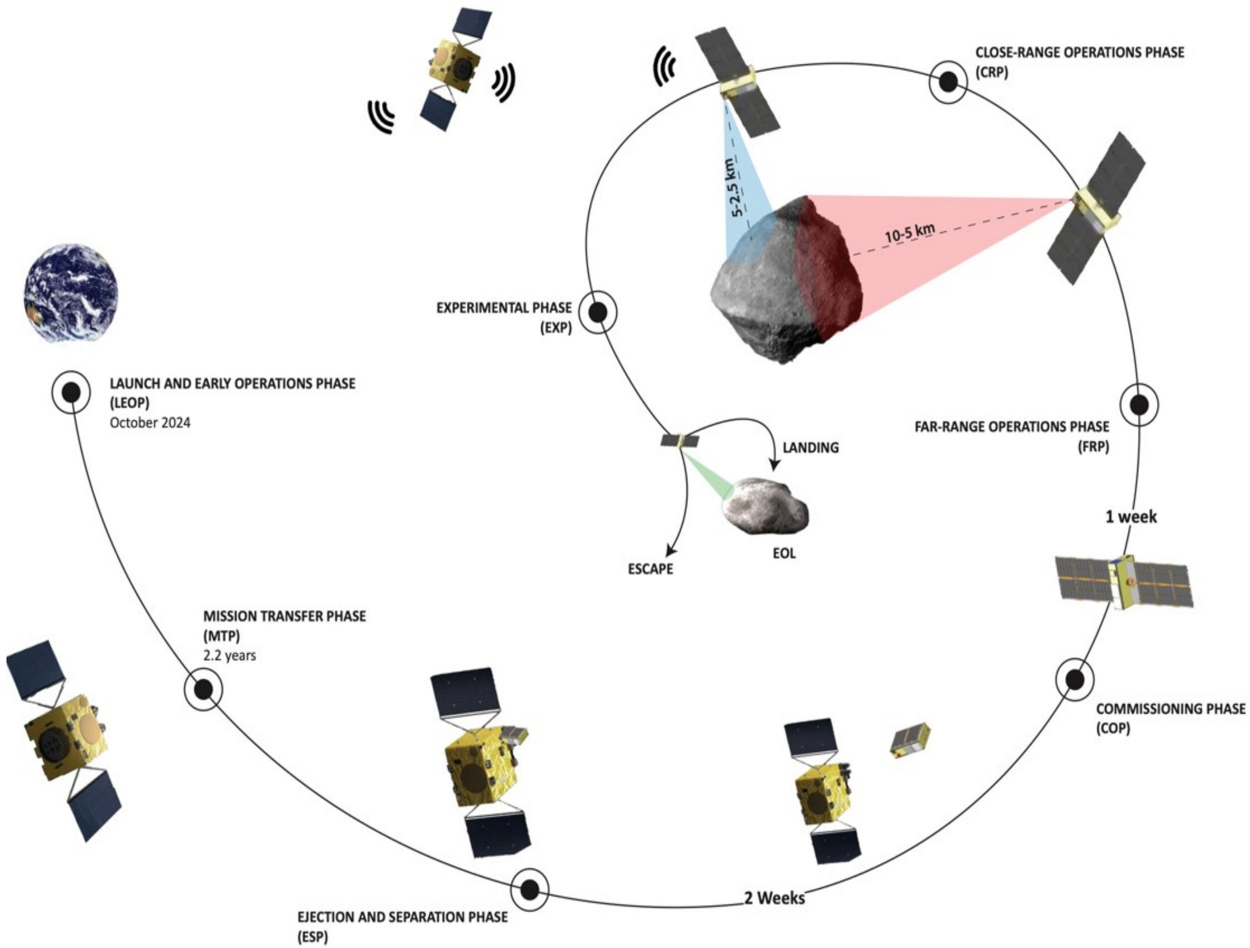
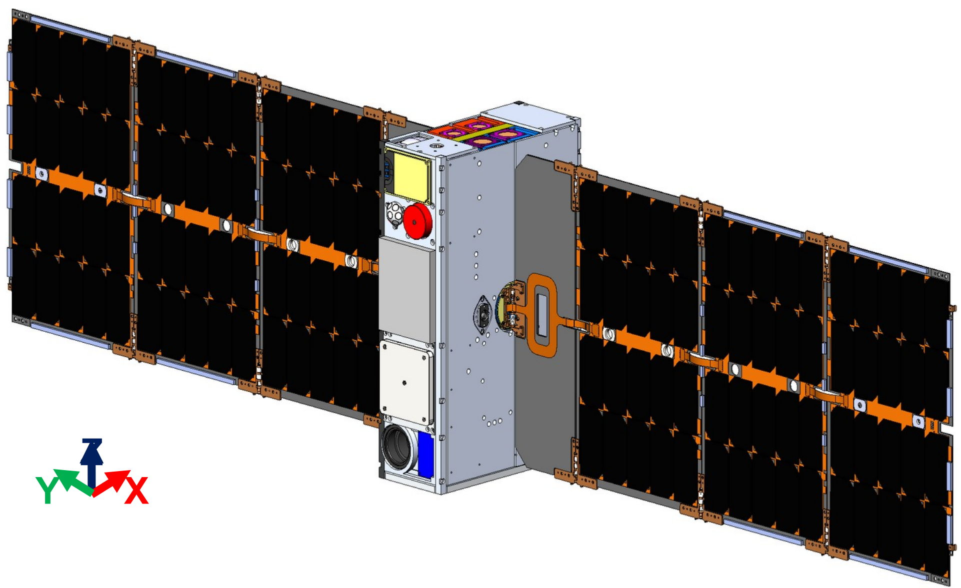
ESA Projects: Hera/Milani Mission



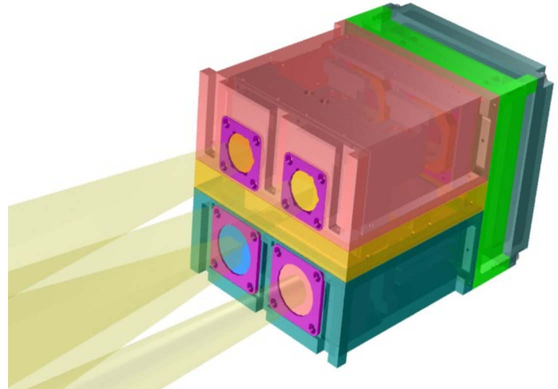
ESA Projects: Milani – Consortium and Spacecraft

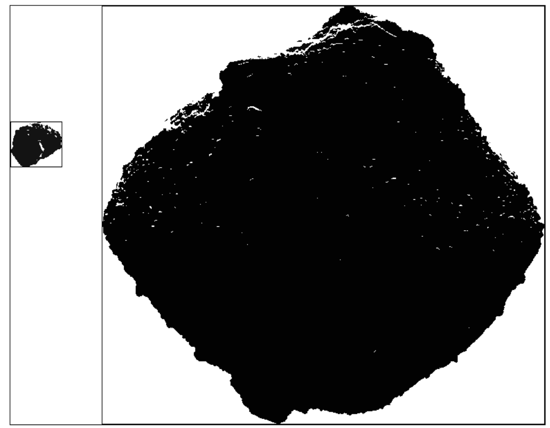
- Based on Trestles 6U bus
- Payloads: **ASPECT** + VISTA
- Navigation Camera
- Propulsion System
- Inter-Satellite Link (ISL) Radio



ESA Projects: Milani – The Spectral Imager

- ASPECT Spectral imager (500 – 2500 nm)
- 4 channels, one datacube ~ 480MB
- Increase chance for good quality data – image sequence (5-20datacubes) for one target area
- Decode RAW data stream, select one image for evaluation (green wavelength, green pixels only)
- Evaluate image processing building blocks:
  Overall image quality (<u>sharpness</u>)(Laplacian histogram)
  Image content quality (<u>coverage</u>)(Image/Area, Borders)
- Construct single <u>image quality score</u>, datacube with best score → OBC → Earth. All data to archive memory.



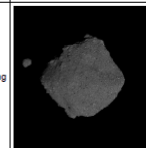
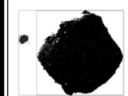
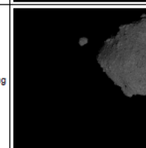
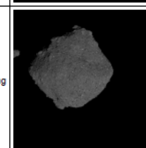
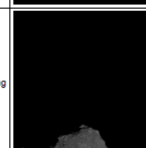
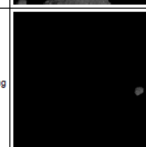
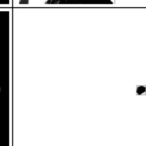
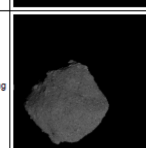
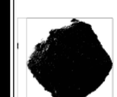


ESA Projects: Milani – Coverage Tests, Object Identification

Input

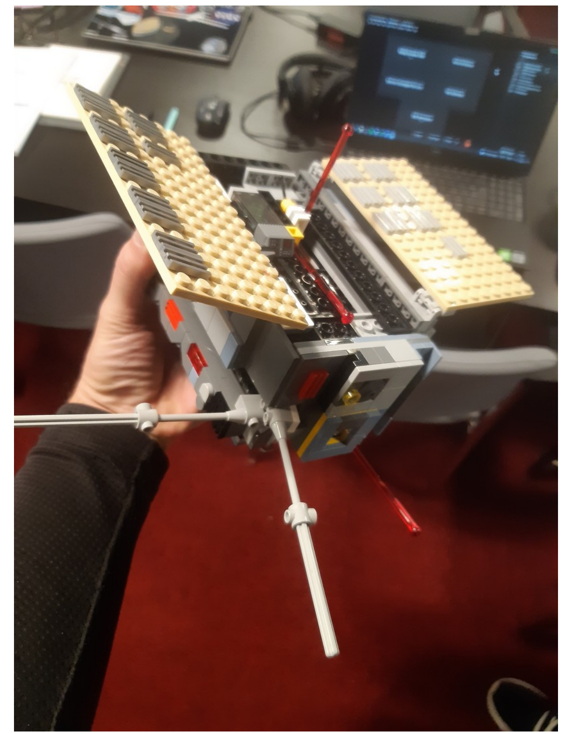
Required coverage (% of asteroid):	60
Expected D1 pixels:	240519
Expected D2 pixels:	3139
Minimal D2 pixels:	500
D1,D2 size margin (%):	30
BWStat weight:	0.5
Otsu weight:	0.5
Fixed weight:	0
Fixed threshold:	1000

Output

File	Original	Area coverage	All(px)	A1 (px)	A2 (px)	All coord	A1 coord	A2 coord	D1 exp (px)	D2 exp (px)	A1 border (%)	A2 border (%)	coverage ratios (%)	assignment	D1 only	D2 only	D1+D2
b8f1169e_frame-3-boulder-v_0.png			467665	240519	3139	58 - 831, 203 - 808	192 - 830, 204 - 807	59 - 129, 371 - 436	240583	3191	0.00	0.00	D1/A1 -0.03 D1/A2 -98.70 D2/A1 7437.42 D2/A2 -1.63	A1 = D1 A2 = D2	D1(99.97%)	D2(98.37%)	D1(99.97%) D2(98.37%)
b8f1169e_frame-3-boulder-v_1.png			328515	162947	3149	480 - 1023, 32 - 637	614 - 1022, 33 - 636	481 - 551, 200 - 265	240583	3191	43.36	0.00	D1/A1 -32.27 D1/A2 -98.69 D2/A1 5006.46 D2/A2 -1.32	A2 = D2 A1 = D1 (cut)	D1(67.73%)	D2(98.68%)	D1(67.73%) D2(98.68%)
b8f1169e_frame-3-boulder-v_2.png			450120	240583	1940	0 - 744, 110 - 715	105 - 743, 111 - 714	1 - 42, 278 - 341	240583	3191	0.00	5.64	D1/A1 0.00 D1/A2 -99.19 D2/A1 7439.42 D2/A2 -39.20	A1 = D1 A2 = D2 (cut)	D1(100.00%)	D2(60.80%)	D1(100.00%) D2(60.80%)
b8f1169e_frame-3-boulder-v_3.png			154998	62482	2700	23 - 734, 805 - 1023	217 - 733, 806 - 1022	24 - 94, 973 - 1022	240583	3191	38.77	4.28	D1/A1 -74.03 D1/A2 -98.88 D2/A1 1858.07 D2/A2 -15.39	A2 = D2 A1 = D1 (cut)	D1(25.97%)	D2(84.61%)	D1(25.97%) D2(84.61%)
b8f1169e_frame-3-boulder-v_4.png			4824	3165	0	898 - 970, 531 - 598	899 - 969, 532 - 597	0 - 0, 0 - 0	240583	3191	0.00	0.00	D1/A1 -98.68 D1/A2 -100.00 D2/A1 -0.81 D2/A2 -100.00	A1 = D2		D2(99.19%)	D2(99.19%)
b8f1169e_frame-3-boulder-v_5.png			430155	240583	254	0 - 711, 325 - 930	72 - 710, 326 - 929	1 - 9, 503 - 539	240583	3191	0.00	3.28	D1/A1 0.00 D1/A2 -99.89 D2/A1 7439.42 D2/A2 -92.04	A1 = D1	D1(100.00%)		D1(100.00%)

ESA Projects: Slavia

- Tandem flight of two 12 or 16U CubeSats
- Payloads: **VESNA** + HANKA + ŘÍP2
- Navigation: Star tracker, Sun sensor, GPS
- Propulsion System (formation, attitude)
- UHF, S-band, X-band communication



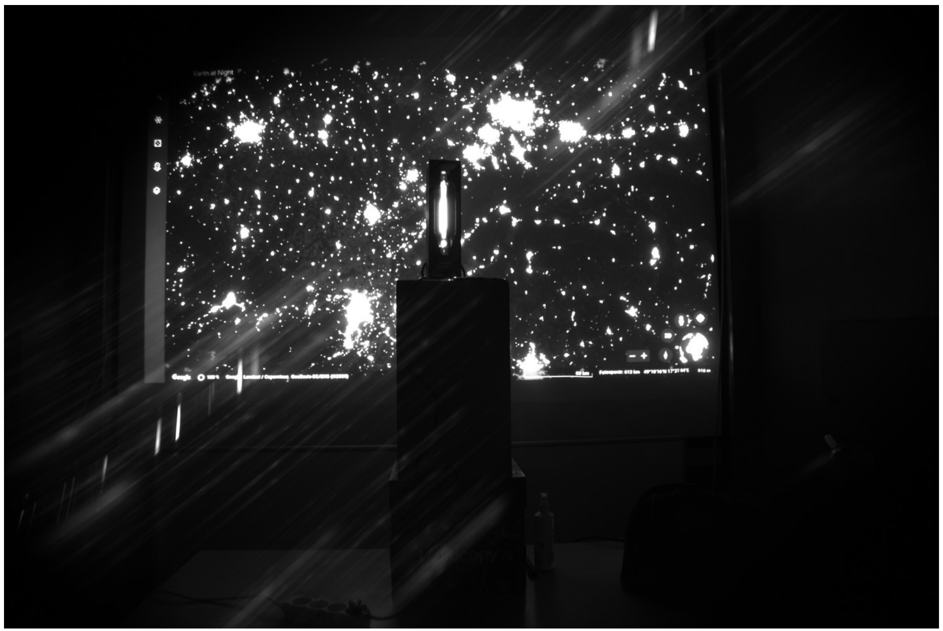
ESA Projects: Slavia – VESNA Hyperspectral Camera

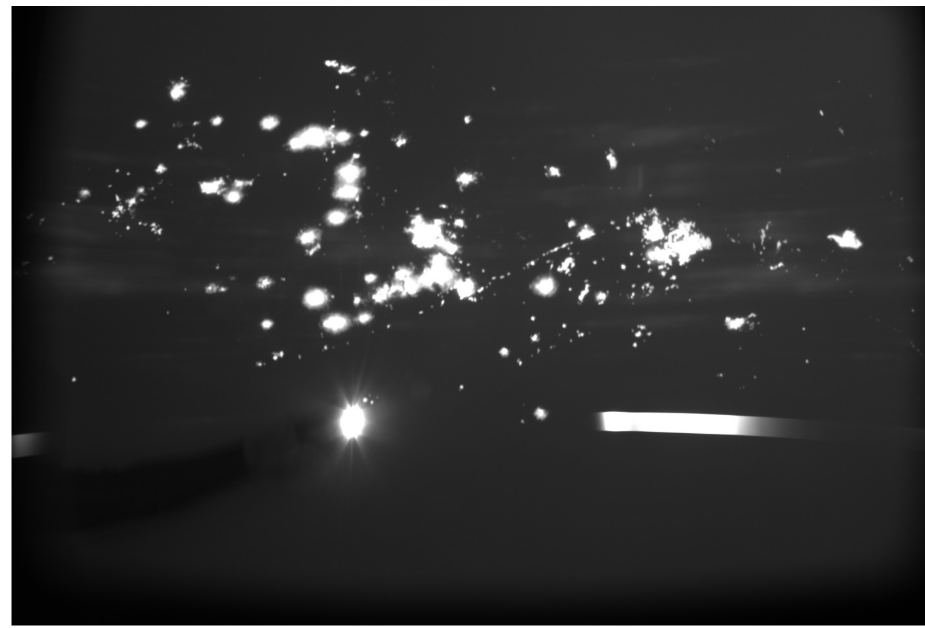
- 2k – 4k 12bpp, 4fps camera with grating
- ~95min orbit, 35min night side
- 4k * 4k * 2Bpp = 32MB raw image
- (35*60)*4fps*32MB = 262GB per orbit
- comm. window each 12hours, ~500MB
- 1 event/day expected (meteor showers)

→ Filter valuable data to fit data budget

ESA projects: Slavia – VESNA Hyperspectral Camera

- Test end evaluation dataset, confirm correct expected in orbit scientific data
- Sources of night images, disturbances (clouds), categories (sea, city, land)
- Meteor light source, setup geometry



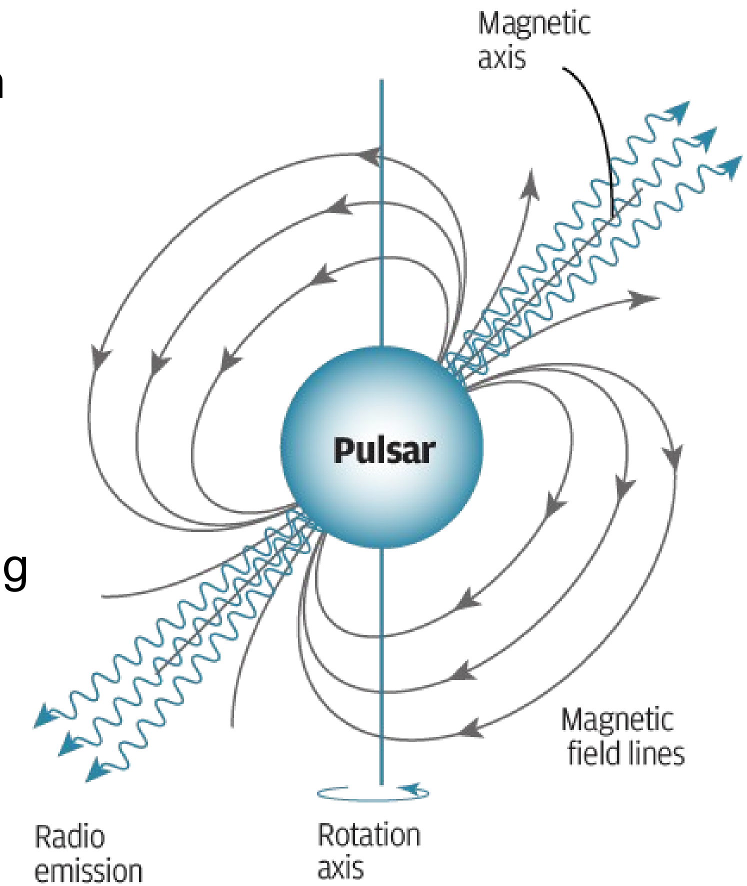


Autonomous Space Navigation for Interstellar Missions

- Autonomous – self contained, real-time, no Earth GS support
- Interstellar – being able to work even out of Solar system (missions to other stars)
- Motivation: Interstellar missions, DSN capacity, uninterruptible sources
- Clock (PPS source) from pulsar radio signal
- Cooperation with AI CAS Ondřejov, 7m and 10m antennas
- Radio observations in 1-2Ghz band

Autonomous Space Navigation - Pulsars

- Celestial periodic signal source, whole EM spectrum but mainly X-ray and radio used. Neutron star, rotation based, binary systems
- Period 1ms to 15s (0.3-3s normal, 1-10ms MSPs)
- Mass of 1 - 2M_s , radius ~ 10km, dist 300 - 200 000ly
- Weak sources – Crab, Vela, J0437-4715, B1937+21
- Interstellar medium – dispersion, scintillation, scattering



Autonomous Space Navigation - Pulsar X-ray and Radio Signals

- Signal de-dispersion, filtering
- Epoch folding - empirical rate function

$$\tilde{\lambda}(T_i) = \frac{1}{N_p T_b} \sum_{j=1}^{N_p} c_j(T_i)$$

- Cross correlation to compare with template - phase
- Pulse TOA barycentric correction

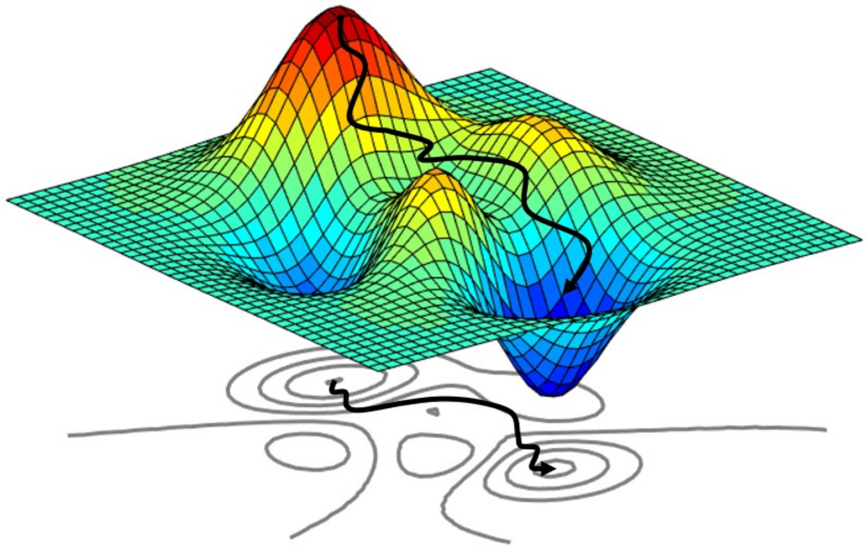
$$t_{SSB} - t_{SC} = \frac{1}{c}|D - b| - \frac{1}{c}|D - p| + \sum_{k=1}^{N} \frac{2\mu_k}{c^3} \ln |n_{sc} \cdot p_k + \|p_k\| \,|$$

- Measurement precision > 1us → time-keeping ~ 0.1us

Requirements specification using nonlinear programming

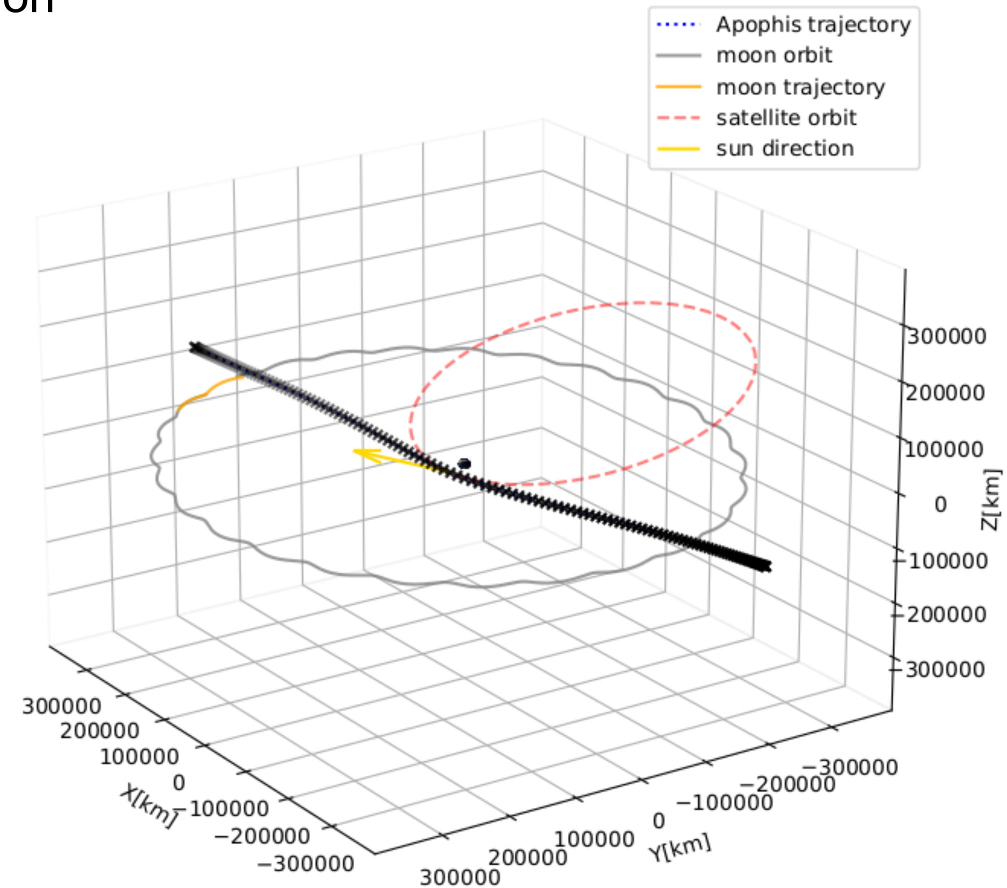
- Mission Requirements - typically originate from mission objectives: requirements on vehicle mass, fuel or power capacity
- Nonlinear programming minimizes given objective function while finding respective functional parameters
- IPOPT - nonlinear programming solver for large and sparse problems
- Nonlinear programming problem formulation:

$$
\begin{aligned}
\min_{\mathbf{z}\in\mathbb{R}^w} \quad & J(\mathbf{z}) \\
\text{subj.to} \quad & \mathbf{c}_L \leq \mathbf{c}(\mathbf{z}) \leq \mathbf{c}_U \\
& \mathbf{z}_L \leq \mathbf{z} \leq \mathbf{z}_U
\end{aligned}
$$



Requirements specification using nonlinear programming

- Application - orbit parameter optimization
- Near-Earth asteroid Apophis rendezvous mission
- Find orbital elements
  $O = (a, e, i, \omega, \Omega, v)$
- Minimize $v(t_f) - v_A(t_f)$



Requirements specification using nonlinear programming

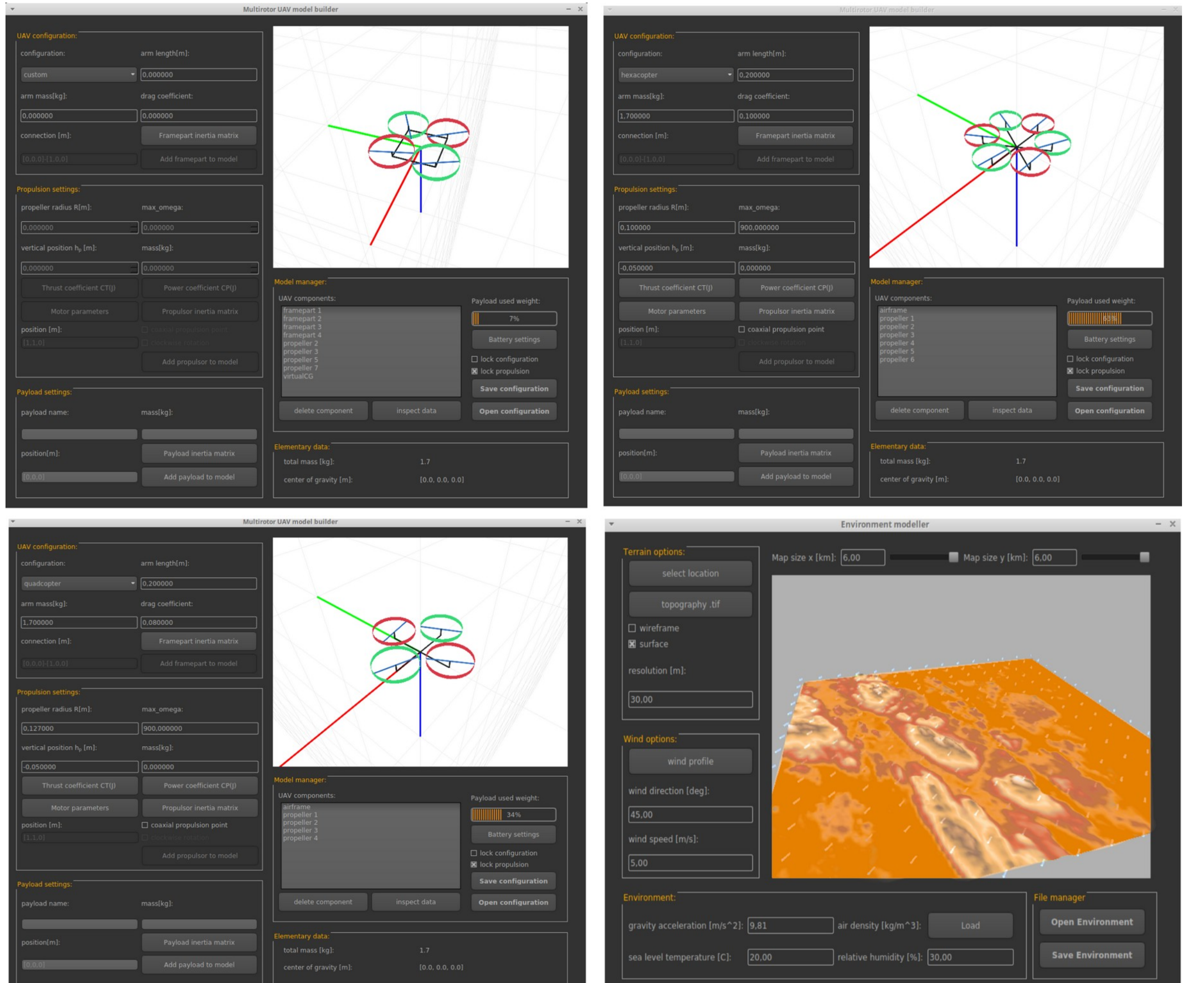
- Optimization - extraterrestrial drone missions
- Automatic trajectory generation respecting operational bounds of the vehicle and environmental constraints while minimizing the objective

$$J = \Phi(\mathbf{x}(t_0), t_0, \mathbf{x}(t_f), t_f) + \int_{t_0}^{t_f} g(\mathbf{x}(t), \mathbf{u}(t), t)\mathrm{d}t$$

- Direct transcription – Gauss pseudospectral methods
- Vehicle mathematical model utilization
- Extraterrestrial propeller vehicle missions: Ingenuity helicopter, Dragonfly mission

Credit: NASA/Johns Hopkins APL

Requirements specification using nonlinear programming



Requirements specification using nonlinear programming

- Minimum energy multicopter mission - minimum energy problem using multicopter dynamics concerning external conditions with minimum state of charge constraints boundary condition. SoC = $100(1 - E_c(t_f)/E_{bat})$ [%], SoC > SoC req. Battery mass is found to respect the constraints.

$$E_C = \int_{t_0}^{t_f} \sum_{i=1}^{N} \left(J_m^i \dot{\omega}_i + \frac{4}{\pi^3} \rho \left[R_{pr}^i \right]^5 \omega_i^2 C_P^i(J_i) + b_m^i \omega_i \right) \omega_i \;\; dt$$