Apophis T–9 Years: Knowledge Opportunities for the Science of Planetary Defense – Session 5

This is what a MASCOT can do for you – at Apophis

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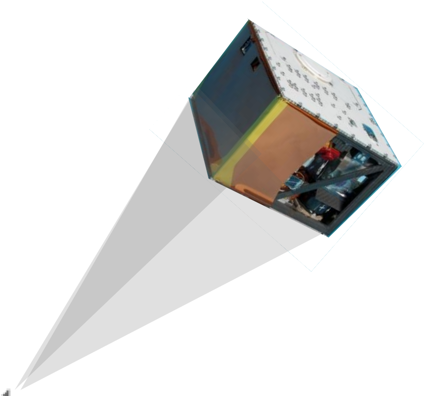
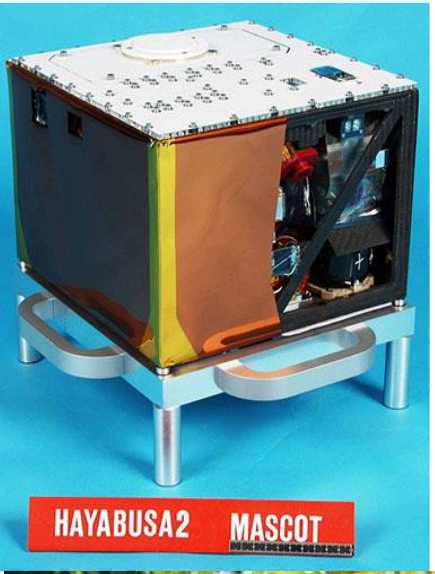
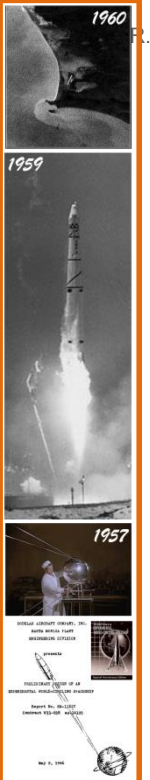


MASCOT – Mobile Asteroid Surface Scout



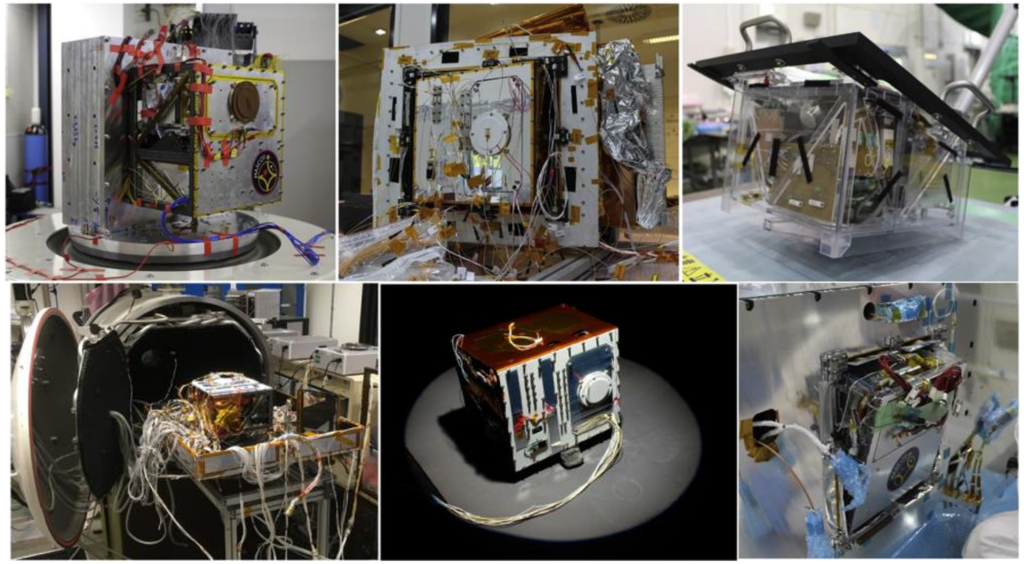
- MASCOT was launched to (162173) Ryugu aboard JAXA's sample-return mission Hayabusa2 in 2014
- landed successfully on October 3rd, 2018 (*during IAC 2018*)
- operated for >17 hours, at "4½" locations (4 w/stereo & 1 tilt)

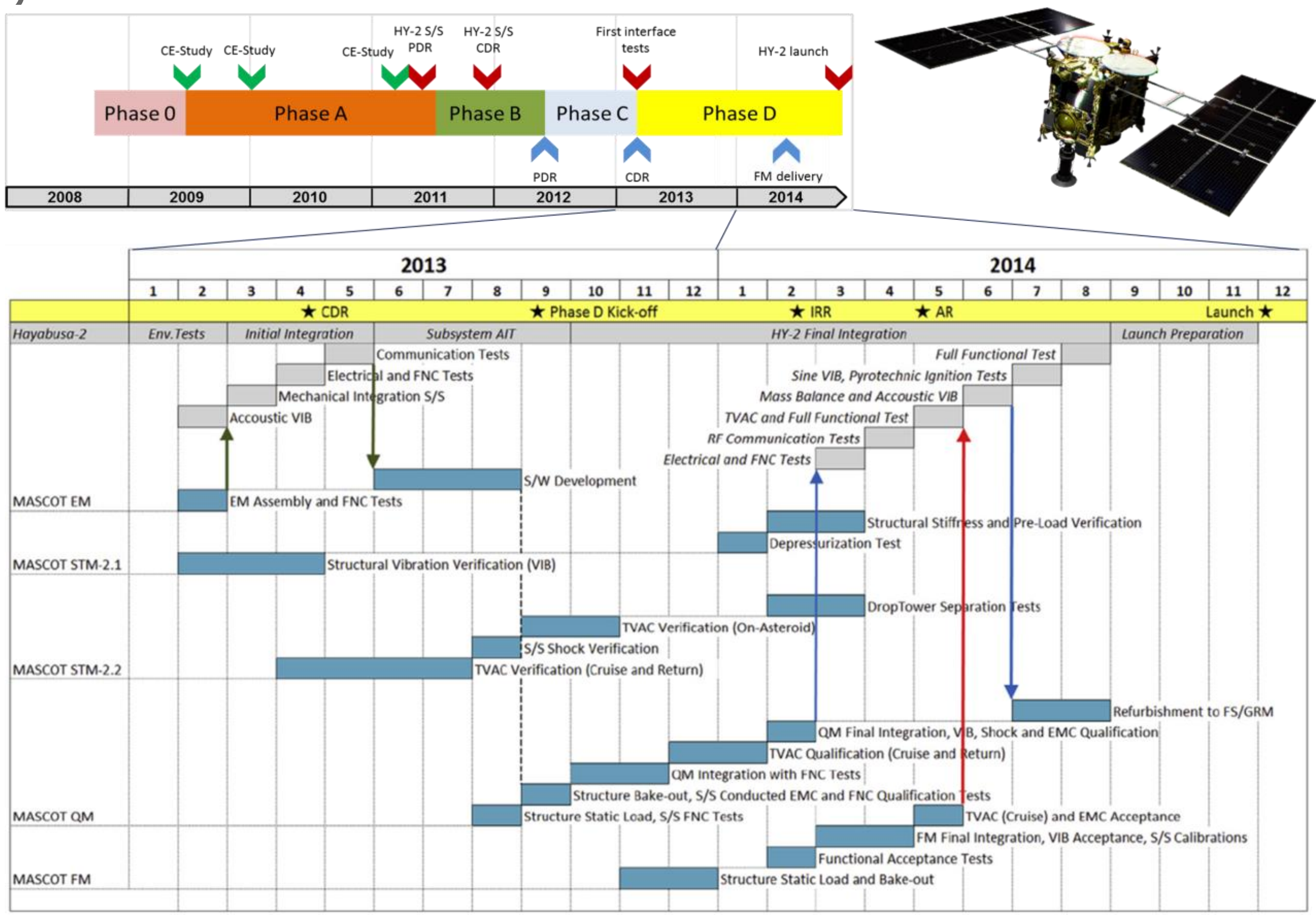
- lander at the instrument level of a mainstream mission
- high degree of design re-use
- high-density design
- serves 4 full planetary science quality instruments



60 years of responsive space
1959 – 2019

MASCOT – fast-paced, responsive, concurrent





- 4 years of precursor studies
- 2 years from funding release to FM delivery
- 11 models of MASCOT built
- concurrent AIV with focus on earliest possible testing

DLR cnes CENTRE NATIONAL D'ÉTUDES SPATIALES IAS Orsay Technische Universität Braunschweig JAXA 宇宙航空研究開発機構 Japan Aerospace Exploration Agency

the MASCOT-Team

Berlin: DLR Inst. of Planetary Research
- MasCAM
- MARA

Bremen: DLR Inst. of Space Systems
- Project Management
- Systems Engineering
- AIV/AIT
- subsystems such as OBC, Thermal, etc.

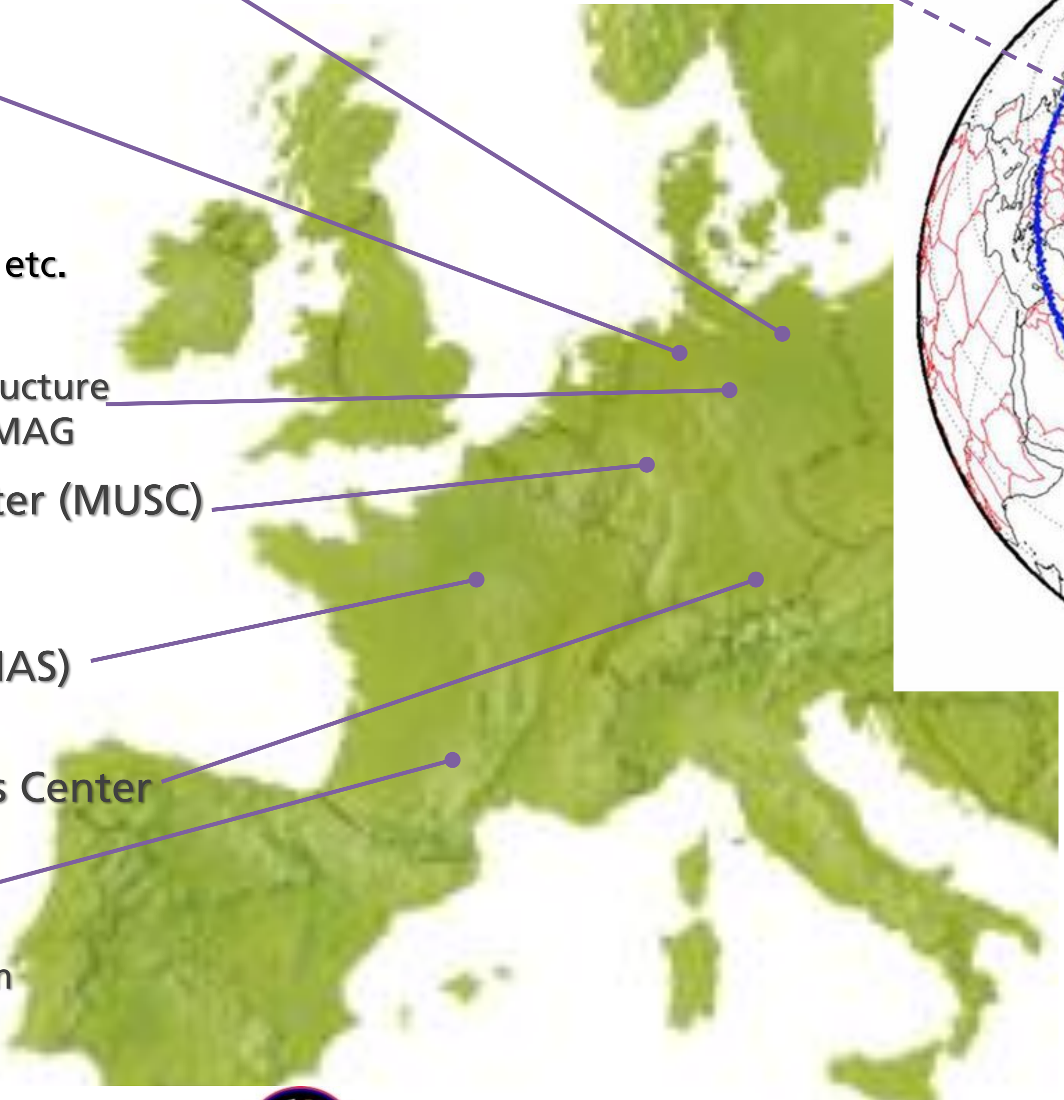
Braunschweig:
1. DLR Inst. of Composite Structures – Structure
2. Technical Univ. of Braunschweig – MasMAG

Köln: DLR Microgravity User Support Center (MUSC)
- Science Payload Management
- Ground Segment

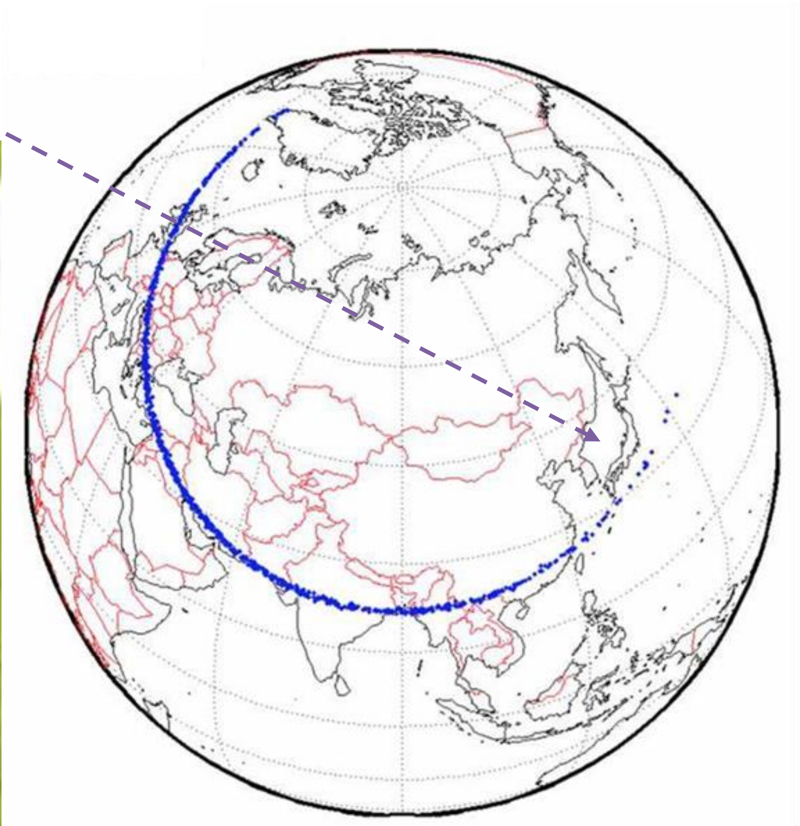
Paris: Institut d'Astrophysique Spatiale (IAS)
- MicrOmega

München: DLR Robotics & Mechatronics Center
- Mobility
- Motion Analysis

Toulouse: CNES
- Power Subsystem
- Mission Analysis
- Antenna

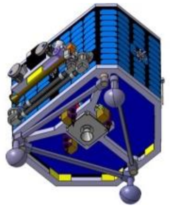


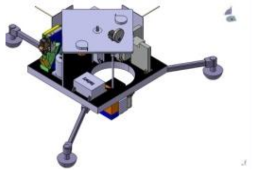
Sagamihara: JAXA
- HAYABUSA2
- MASCOT CCOM

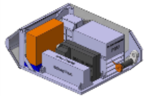


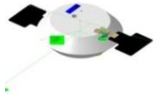
*subcontractors and their production sites not shown

10-year history behind the 17 hours on Ryugu

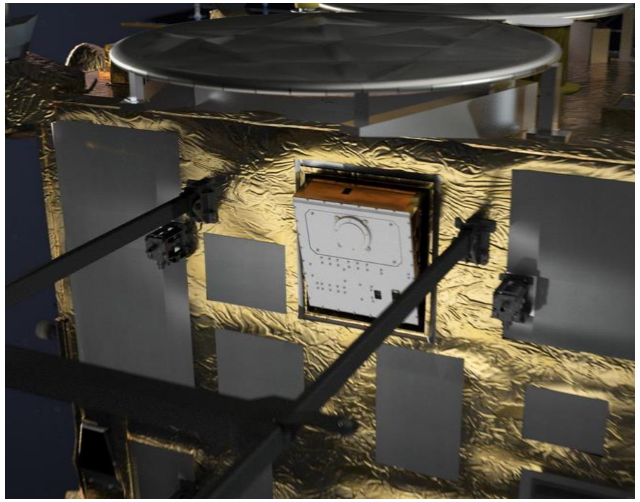


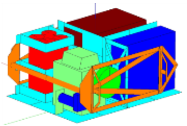




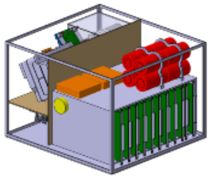


- the development was done within a very short time but due to programmatic changes and growing knowledge on NEAs many configurations were studied in detail

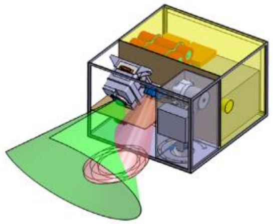


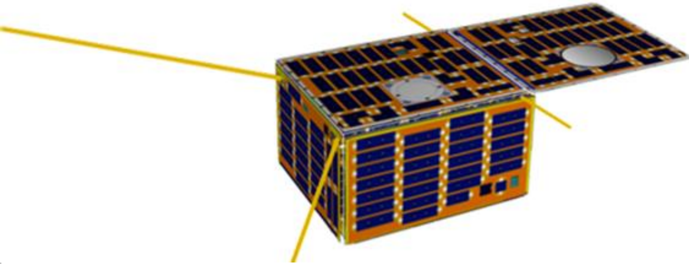


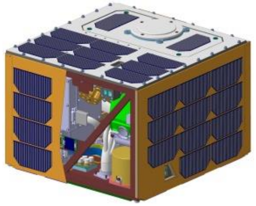
- the MASCOT concept is agile, lightweight and flexible ⇒ It can be applied on most future exploration missions of low gravity bodies, ≈80 m ≤ Ø ≤ ≈10… km

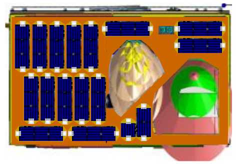


- MASCOT landers are considered in many mission studies e.g. AIM (ESA), MMX (JAXA), ARRM (NASA),…

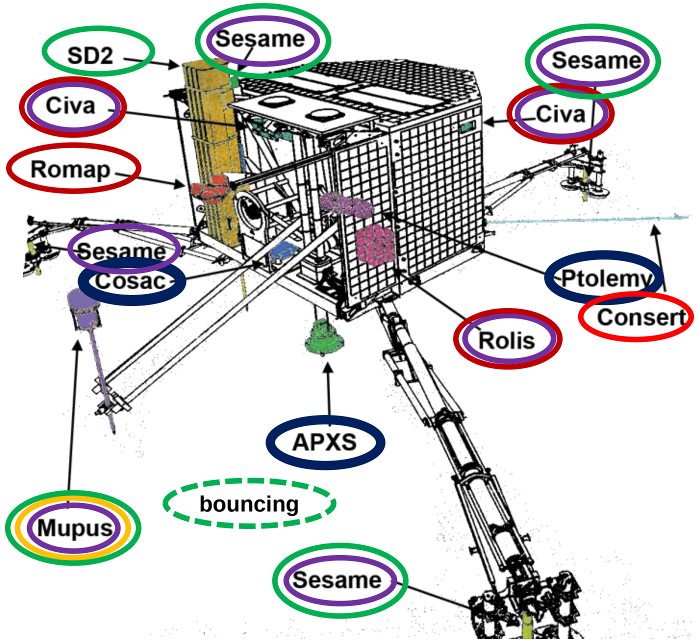








"okay, so… compared to a real spacecraft… – can a 10 kg shoe-box address all topics?"



target body properties addressed…

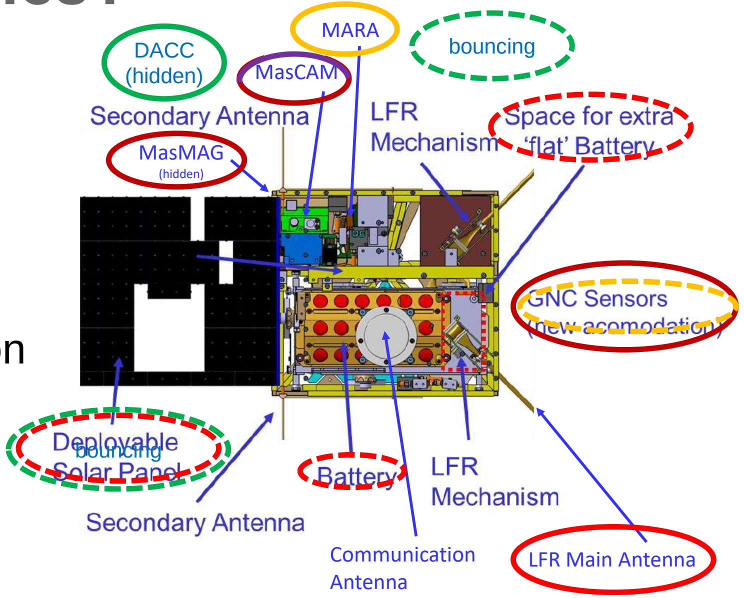
- surface structure
- composition
- mechanical properties
- thermal properties
- interior structure
- spacecraft orientation

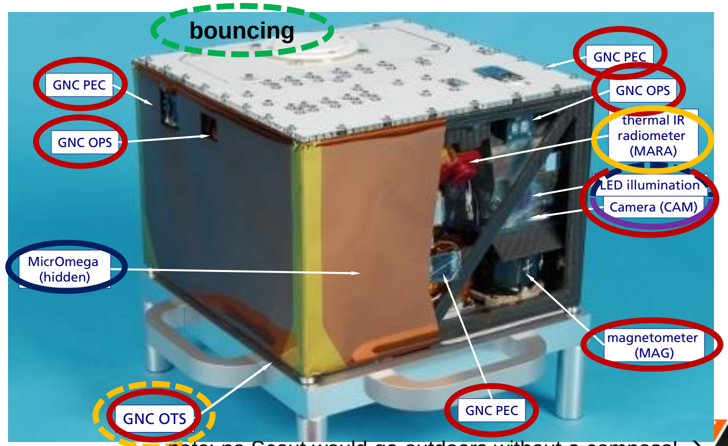
heritage landers:

- cover all fields
- medium-integrated design concept
- separate instrument interfaces 'as usual'
- requirements-driven design, drives mission

MASCOTs:

- focus on key topics
- organically integrated design
- across unit border optimized interfaces
- constraints-driven design



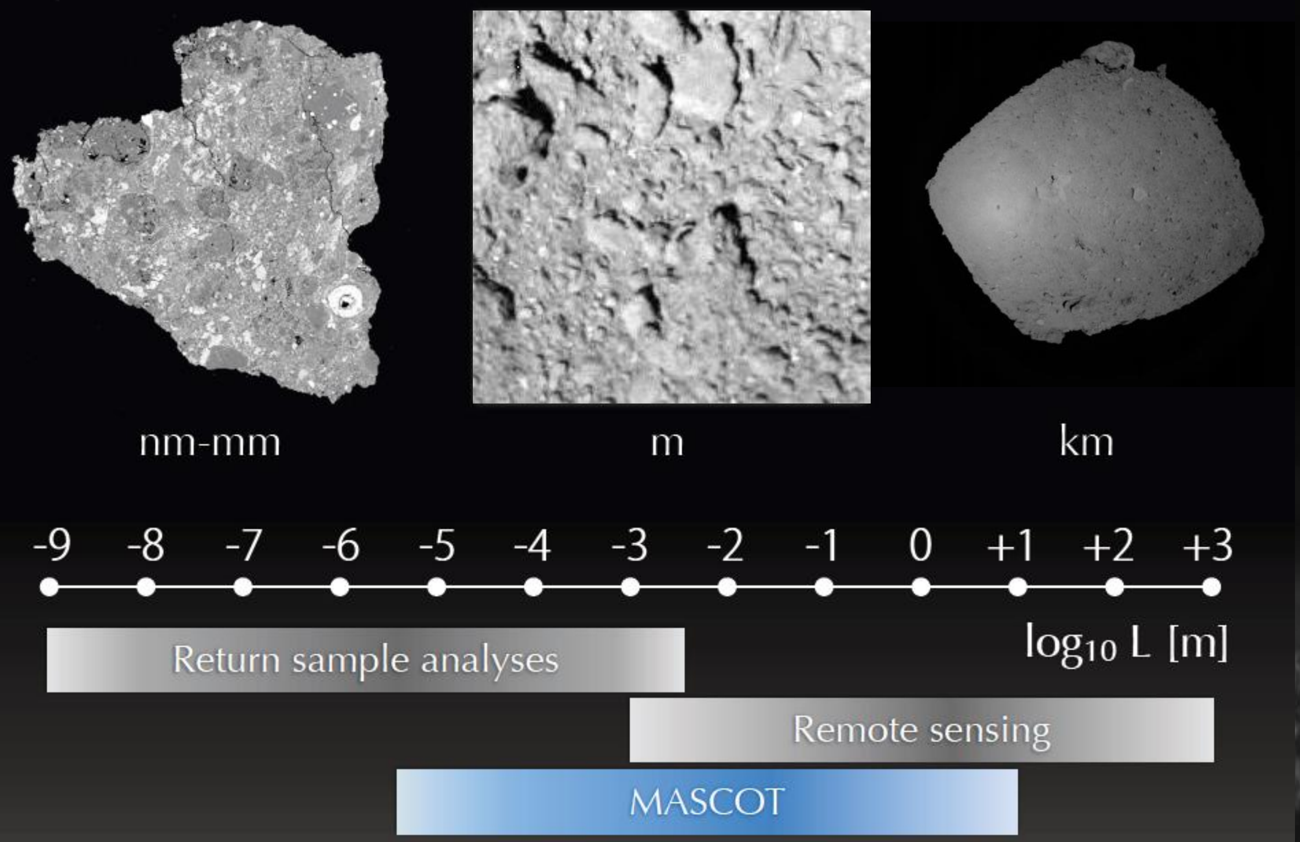


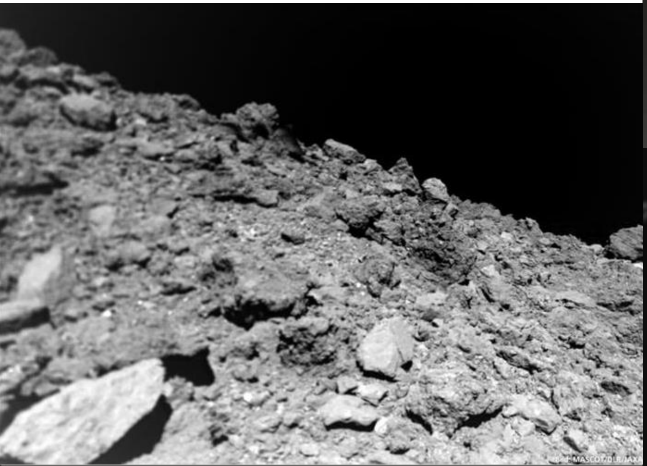
note: no Scout would go outdoors without a compass! →

MASCOT – bridging orders of magnitude

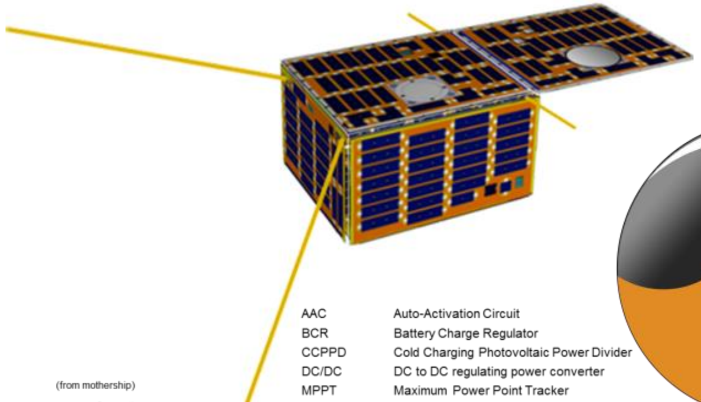
- provides ground truth
- multiscale science

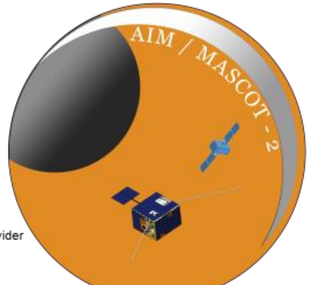
- returned samples
  ($10^{-9}…10^{-3}$ m)
- remote sensing
  ($10^{-3}…10^{3}$ m)



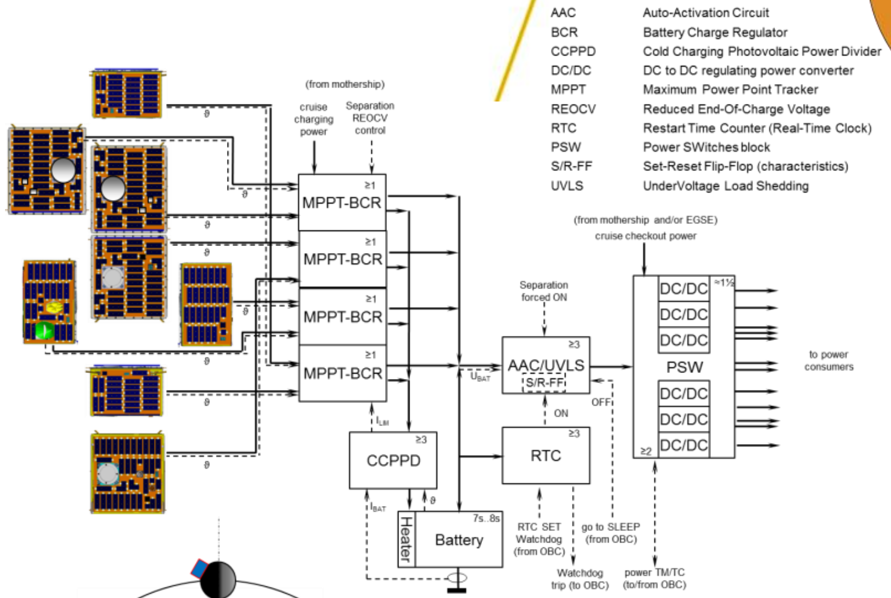


the next MASCOT? – uh, sorry, no..t, yet…

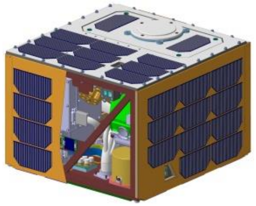


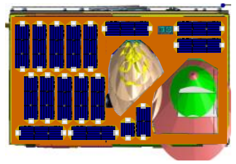


- long-life lander – **MASCOT2** @ AIM study: ≥100 days
  - target: Didymoon – secondary of (65803) Didymos
  - mission risk taker: <85 m (!) from DART impact
  - subsurface science Low Frequency Radar
  - high efficiency high density design
  - photovoltaic supply
  - more autonomy

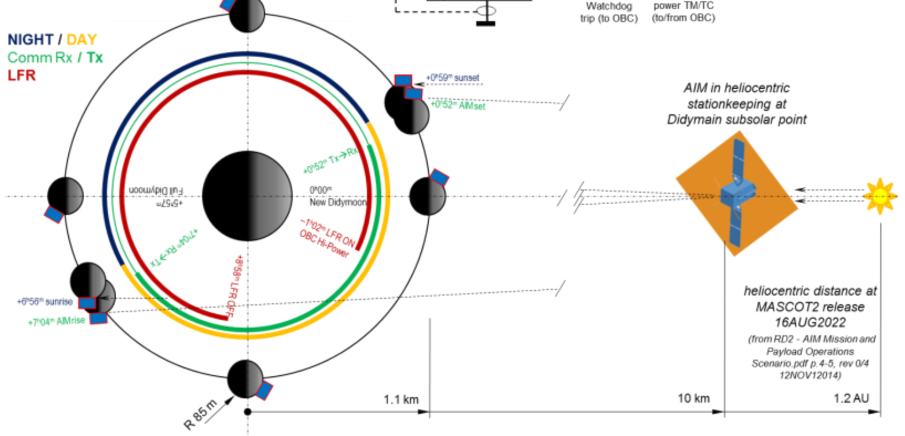


- direct derivatives of MASCOT for NEAs

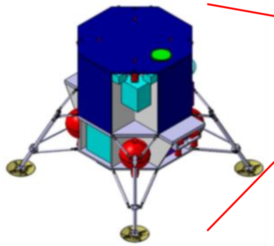


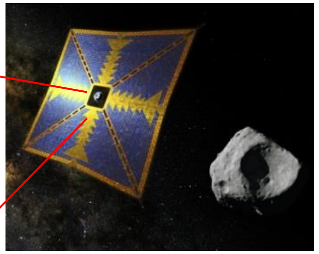


every small solar system body mission – study or ongoing – asked about having a MASCOT

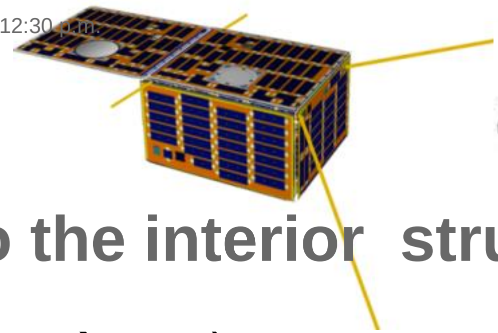


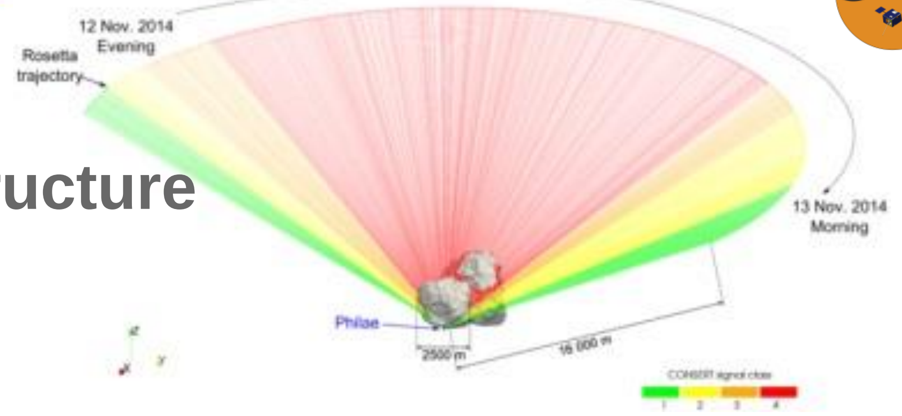
- larger landers – same principle: **OKEANOS**





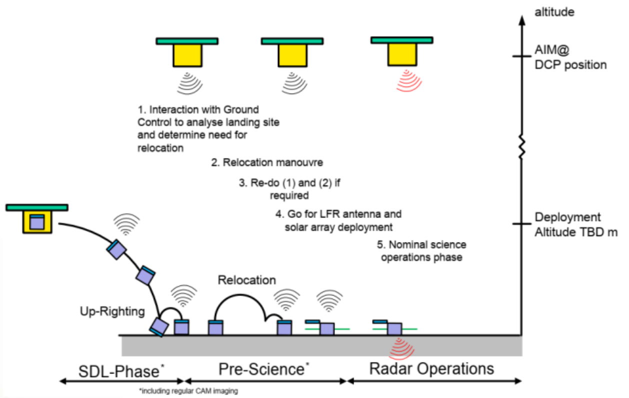
JAXA „Solar Power Sail“ – 35-year Jupiter Trojan sample-return mission (55 m)² membrane

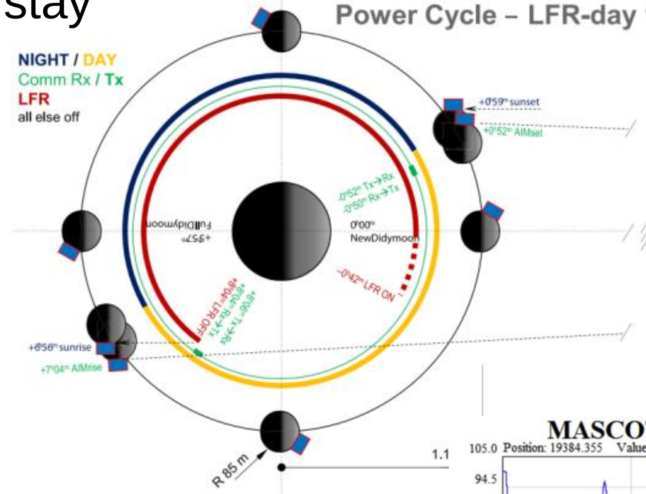


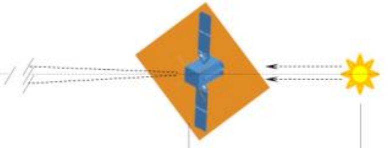


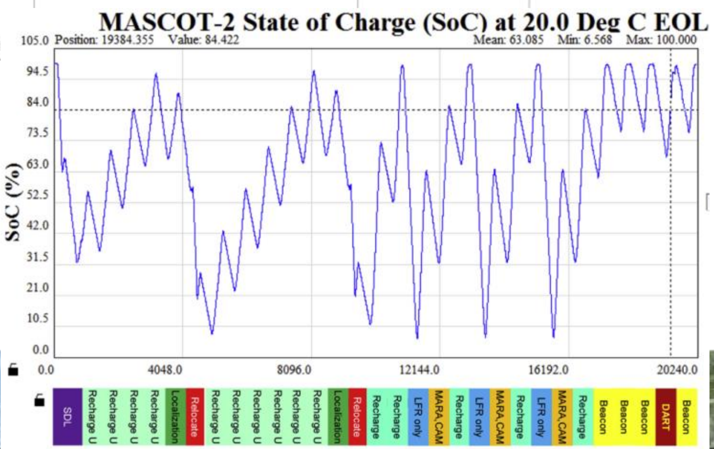
MASCOT2 for AIM
Low Frequency Radar – the key to the interior structure

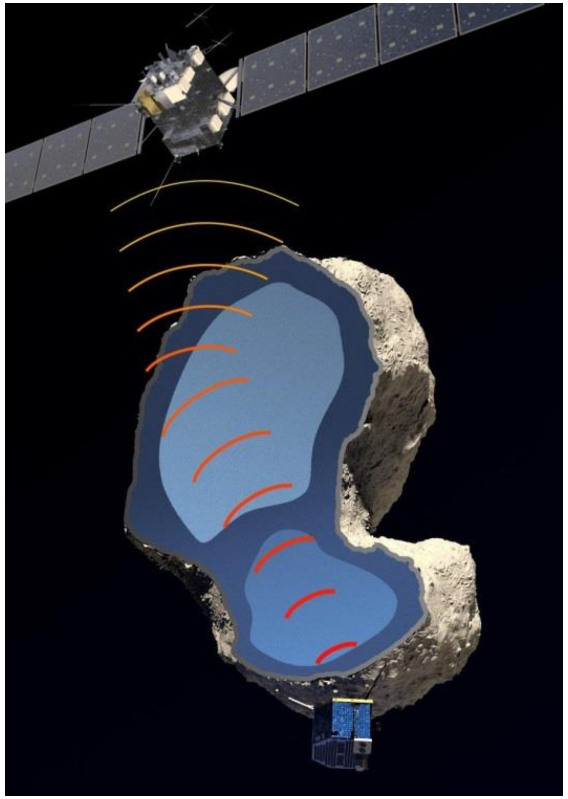
- change of the largest instrument (MicrOmega → LFR)
- change from brief scouting to long-term observations
- additional 'small' instrument, DACC accelerometer
- MasCAM, MARA, MasMAG stay

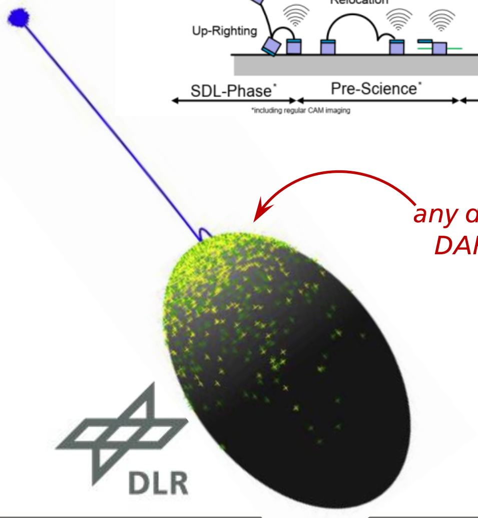












any dot within 85 m of DART Ground Zero

reuse from MASCOT to MASCOT2

- doing a Phase 0/A study with Phase C/D/E detail
- converging from heterogeneous maturity at unit level to a mature system

MASCOT-2	MASCOT
NewConsert	MMEGA
Instrument Front End	Instrument Front End
Instrument Harness	Instrument Harness
Instrument Antenna module 1	
Instrument Antenna module 2	
Instrument landing antenna	
Instrument Backend	Instrument Backend
DACC	MAG frontend
Instrument Backend (only Ebox-Card)	Instrument Backend (only Ebox-Card)
	MAG frontend with harness pigtail
MARA	MARA
MARA_Sensor	MARA_Sensor
MARA_Board	MARA_Board
Camera (visual)	Camera (visual)
CAM_detector	CAM_detector
P/L harness (from Sensor to E-Box)	P/L harness (from Sensor to E-Box)
Mobility	Mobility
Motor_Gear_Excenter_Assy	Motor_Gear_Excenter_Assy
Motor_Gear_Excenter_Assy 2	
Harness (including connectors)	Harness (including connectors)
Sensor	Sensor
Electronic Board MCC	Electronic Board MCC
GNC	GNC
Temperature sensors (GNC)	Temperature sensors (GNC)
Optical Proximity Sensors	Optical Proximity Sensors
Photoelectric Cells	Photoelectric Cells
LED	
Data Handling	Data Handling
OBC-Digital (M/R)	OBC-Digital (M/R)
OBC-Analog (M/R)	OBC-Analog (M/R)
OBC clock module	
Communications	Communications
S-band transceiver nominal	UHF transceiver
antenna	antenna
RF harness	RF harness
RF coupler	RF coupler
Ground plate for bottom antenna	Ground plate for bottom antenna
Power Subsystem	Power Subsystem
Battery (14 cells)	Battery (9 cells)
Battery Case	Battery Case
PCDU	PCDU
MPPT-BCR Module	
Deployable Panel	
Panel deployment system	
Flexcell body panels	
Structure	Structure
Main structure	Main structure
External Walls	External Walls
E-Box	E-Box
Radiator	Radiator
Preload Relief Mech	Preload Relief Mech
NEA	NEA
Thermal	Thermal
Heater -- HY2	Heater -- HY2
Thermometers -- HY2	Thermometers -- HY2
MLI (E-Box)	MLI (E-Box)
Thermometers (MASCOT internal)	Thermometers (MASCOT internal)
Heat Pipes	Heat Pipes
Harness (including connectors)	Harness (including connectors)
Backplane	Backplane
Flexible Harness	Flexible Harness
MESS	MESS
MESS structure	MESS structure
Umbilical Connector	Umbilical Connector
HY-2 to MESS Connector + Harness (MDM)	HY-2 to MESS Connector + Harness (MDM)
HY-2 to MESS Connector + Harness (SMA)	HY-2 to MESS Connector + Harness (SMA)
Push-off Spring	Push-off Spring
Push-off Plate	Push-off Plate
Push-off Bolt	Push-off Bolt
CFRP-reinforced PEEK standoff b/w MASCOT and HY2	CFRP-reinforced PEEK standoff b/w MASCOT and HY2
MESS-MLI	MESS-MLI
RF Antenna on MESS	RF Antenna on MESS
Caltarg	Caltarg

Mobility	Mobility
Motor_Gear_Excenter_Assy	Motor_Gear_Excenter_Assy
Motor_Gear_Excenter_Assy 2	
Harness (including connectors)	Harness (including connectors)
Sensor	Sensor
Electronic Board MCC	Electronic Board MCC
GNC	GNC
Temperature sensors (GNC)	Temperature sensors (GNC)
Optical Proximity Sensors	Optical Proximity Sensors
Photoelectric Cells	Photoelectric Cells
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Data Handling	Data Handling
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Motor_Gear_Excenter_Assy 2	
Harness (including connectors)	Harness (including connectors)

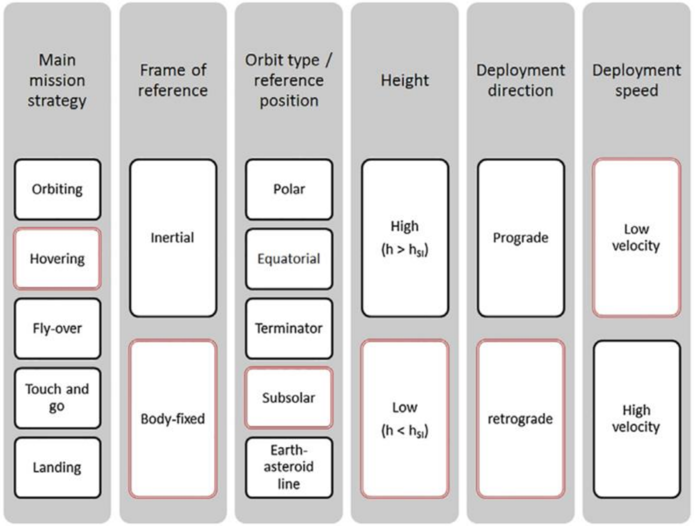
Comparison of the BOM for MASCOT2 and MASCOT system. The colors indicate the commonality levels: green = reuse, red = modify, orange = add, yellow = swap and black = descope oh,… we're only doing fast flybys… ☹

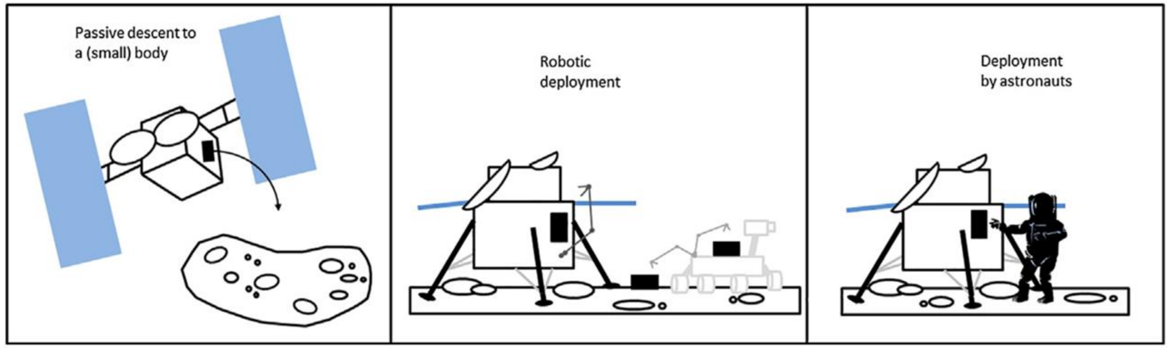
we do have something for you, too ☺

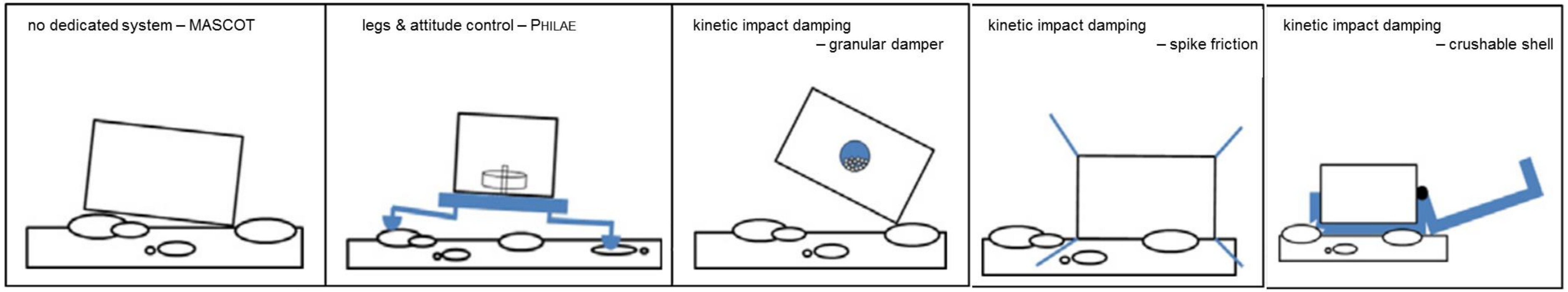
"a MASCOT, please"

…or: towards a wider portfolio

- small instruments packages are useful in many* missions
- mobile or stationary
- network science
- scouting







*) at least, every small solar system body mission we are aware of indicated interest in one way or another…

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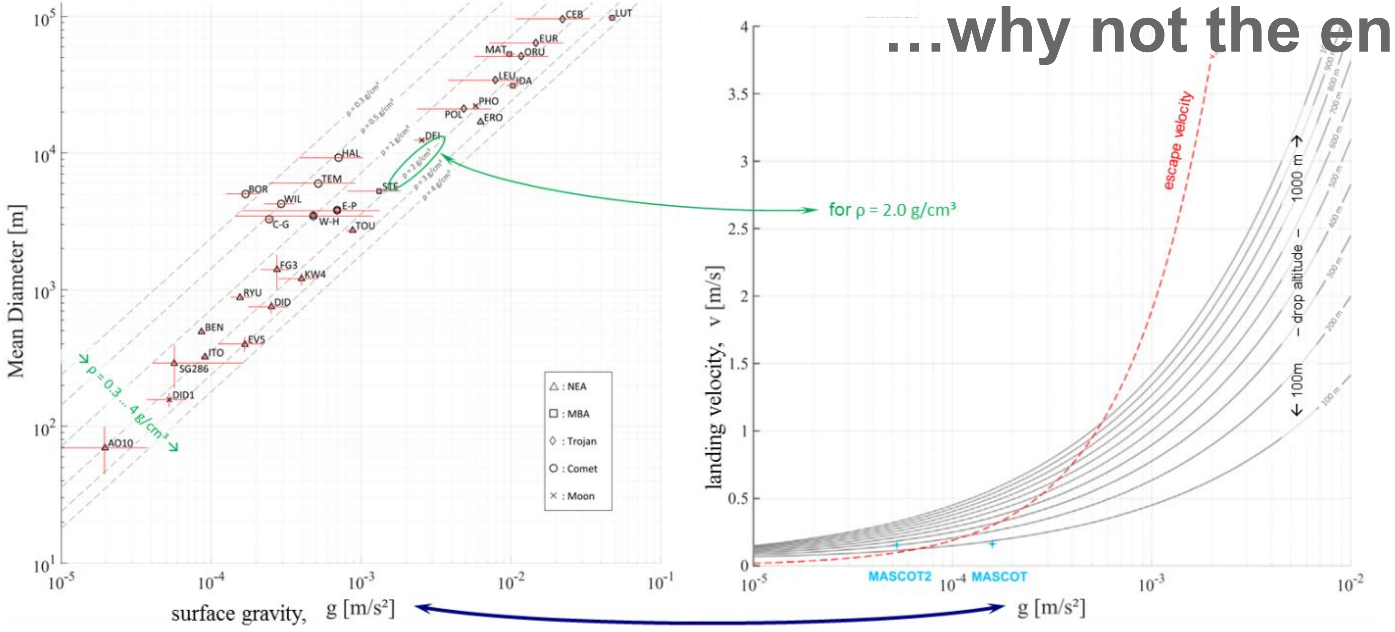
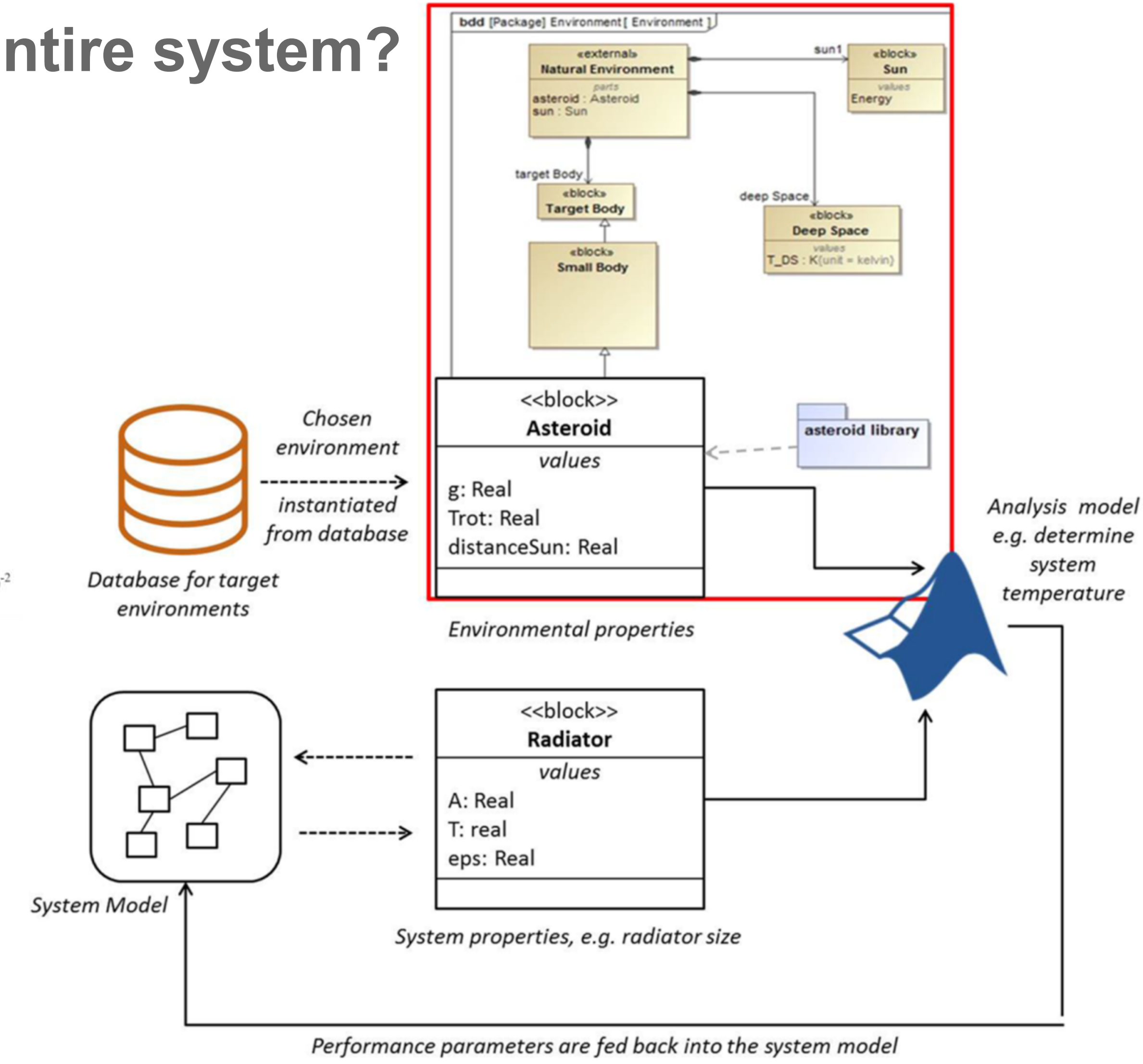
everything is modelled

…why not the entire system?

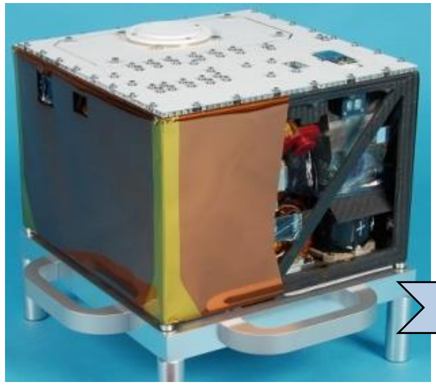


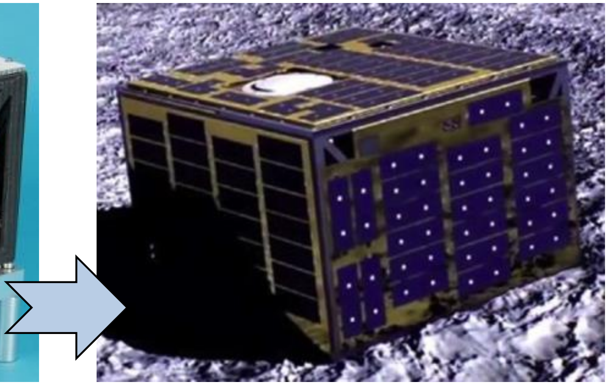


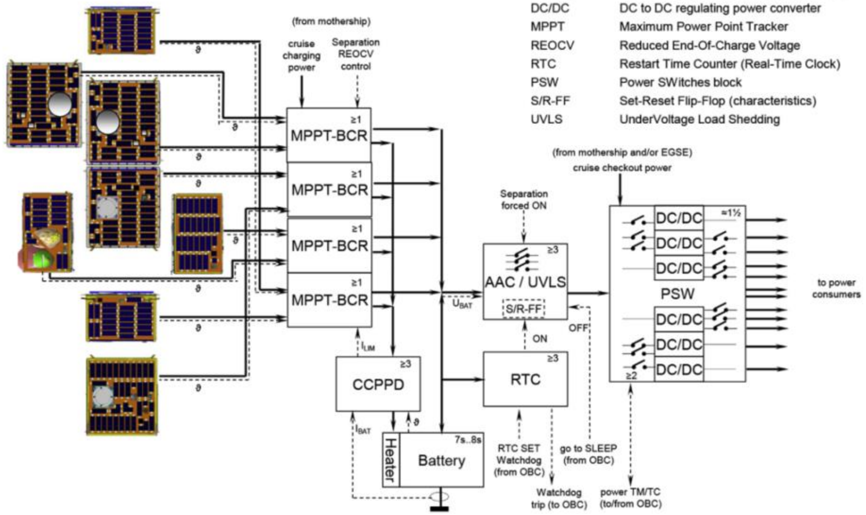
- model building is common in most technical domains of a spacecraft (power, thermal, dynamics,…)
- **Model Based System Engineering** extends this to the system level by connecting domain models at their interfaces – as in the spacecraft

a system is structured by its interfaces: tailored re-use builds on existing connections

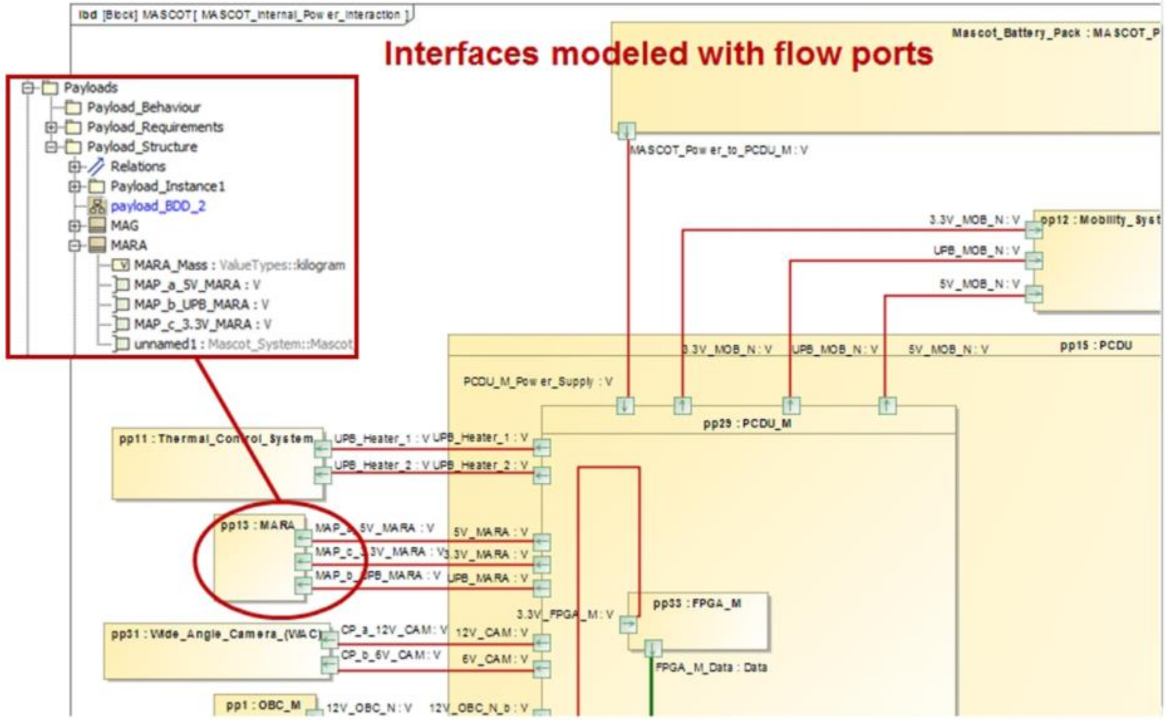
AAC	Auto-Activation Circuit
BCR	Battery Charge Regulator
CCPPD	Cold Charging Photovoltaic Power Divider
DC/DC	DC to DC regulating power converter
MPPT	Maximum Power Point Tracker
REOCV	Reduced End-Of-Charge Voltage
RTC	Restart Time Counter (Real-Time Clock)
PSW	Power SWitches block
S/R-FF	Set-Reset Flip-Flop (characteristics)
UVLS	UnderVoltage Load Shedding



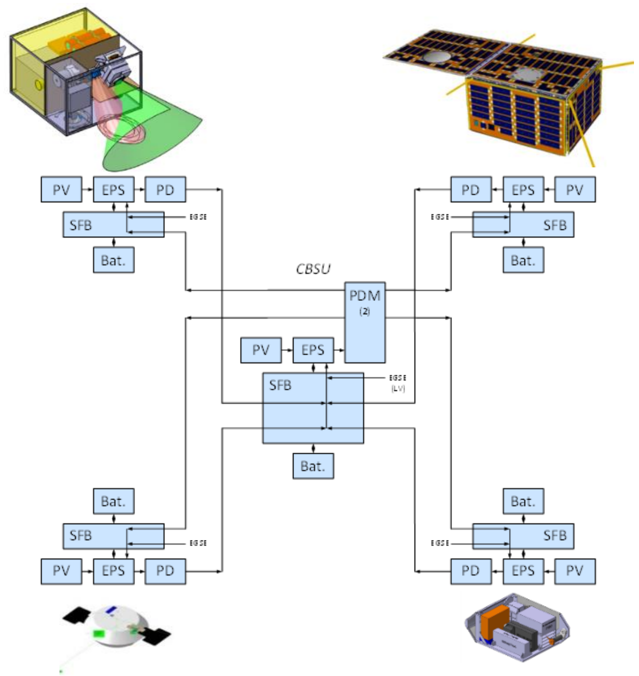




- new *or* different functions require new *and* different units
- re-use saves effort and fosters more responsive implementation
- detailled functional modelling identifies which interfaces are kept, modified, added, or no longer used
- change can be confined to those elements where it happens anyway

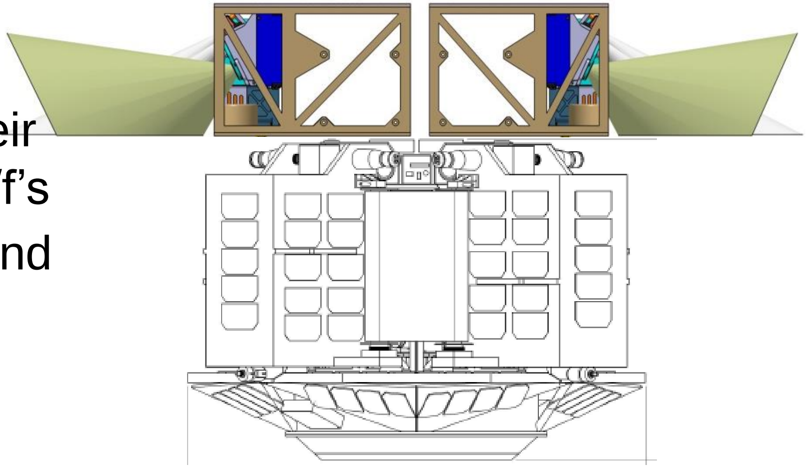


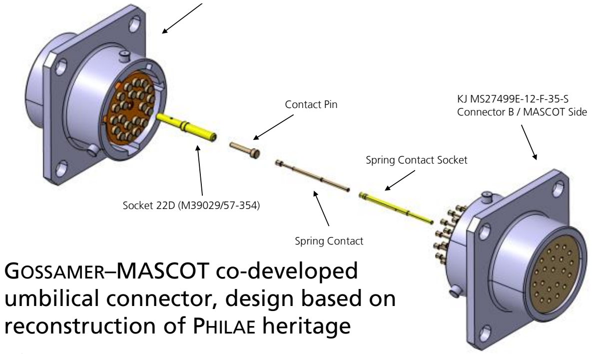
integrating a lander comfortably



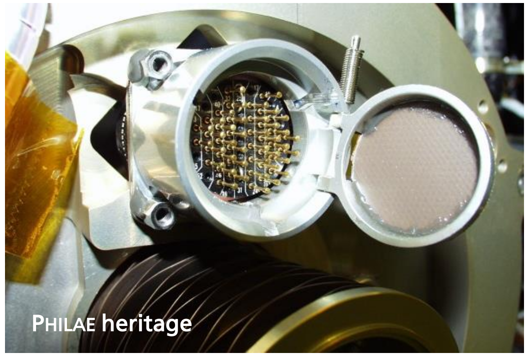
- MASCOTs integrate at the instrument level to their mothership – power, data, mechanical, thermal i/f's
- unlike instruments, they carry all the resources and capabilities of a small spacecraft:
    - battery & photovoltaics
    - GNC sensors & actuators
    - processing power & communication

all these can be shared!

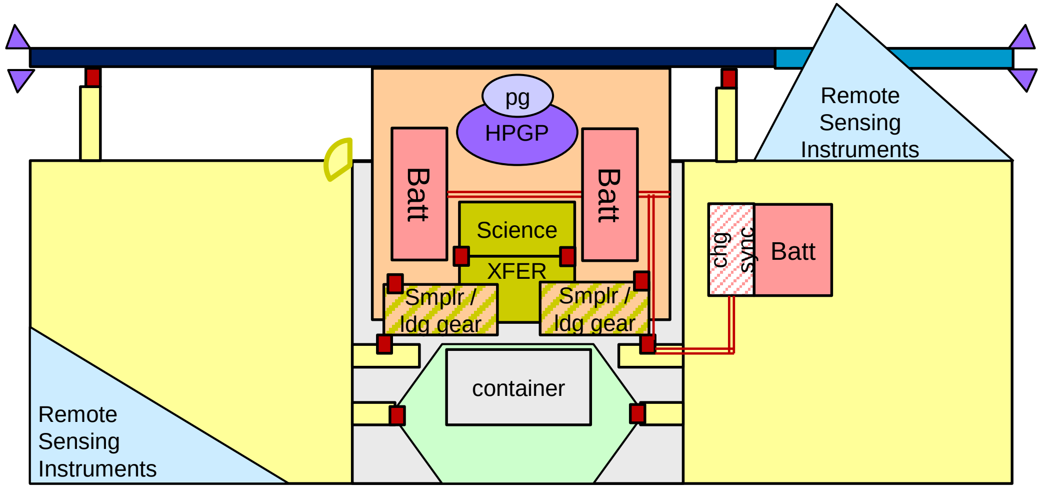




GOSSAMER–MASCOT co-developed umbilical connector, design based on reconstruction of PHILAE heritage

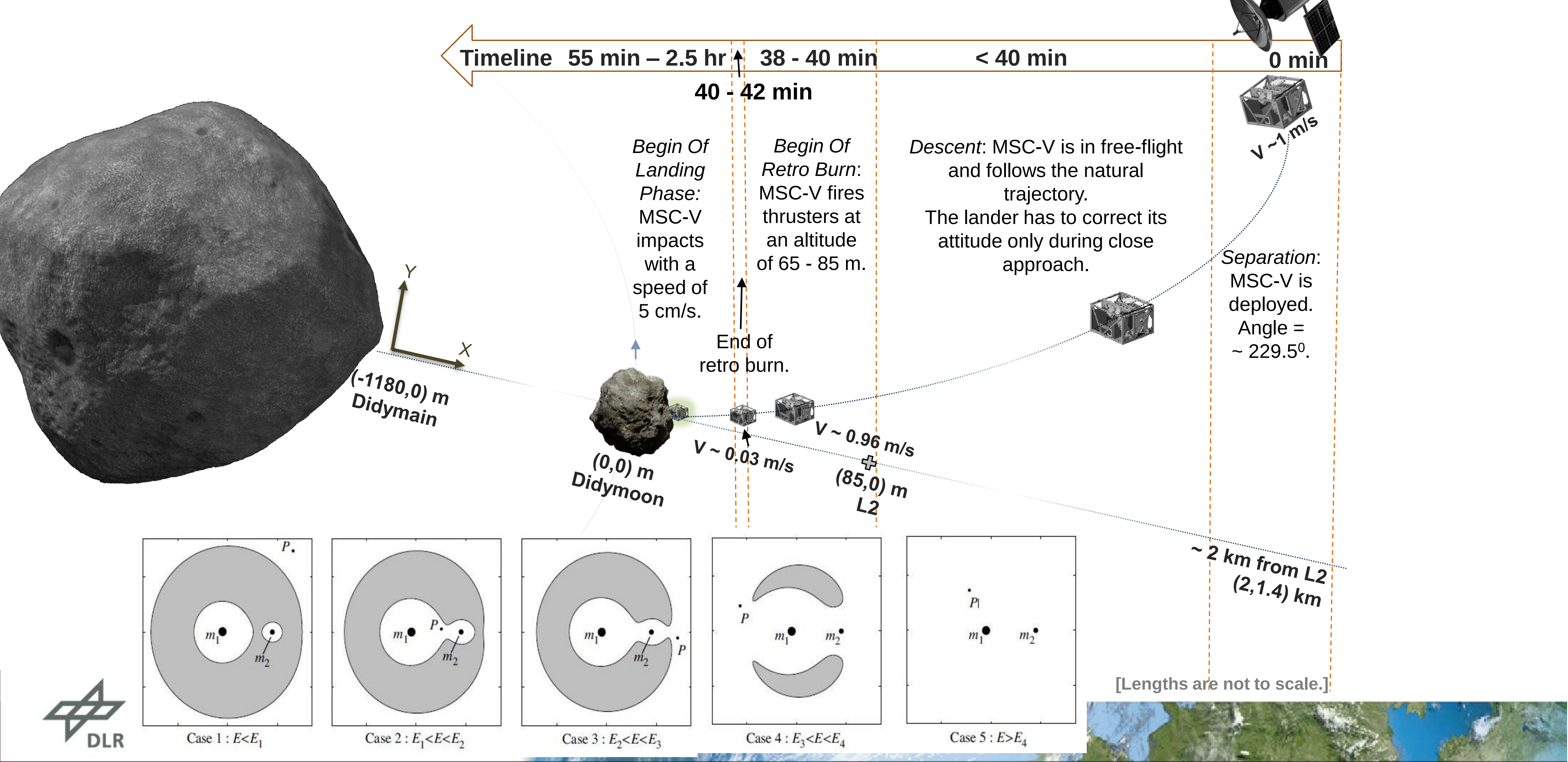


PHILAE heritage

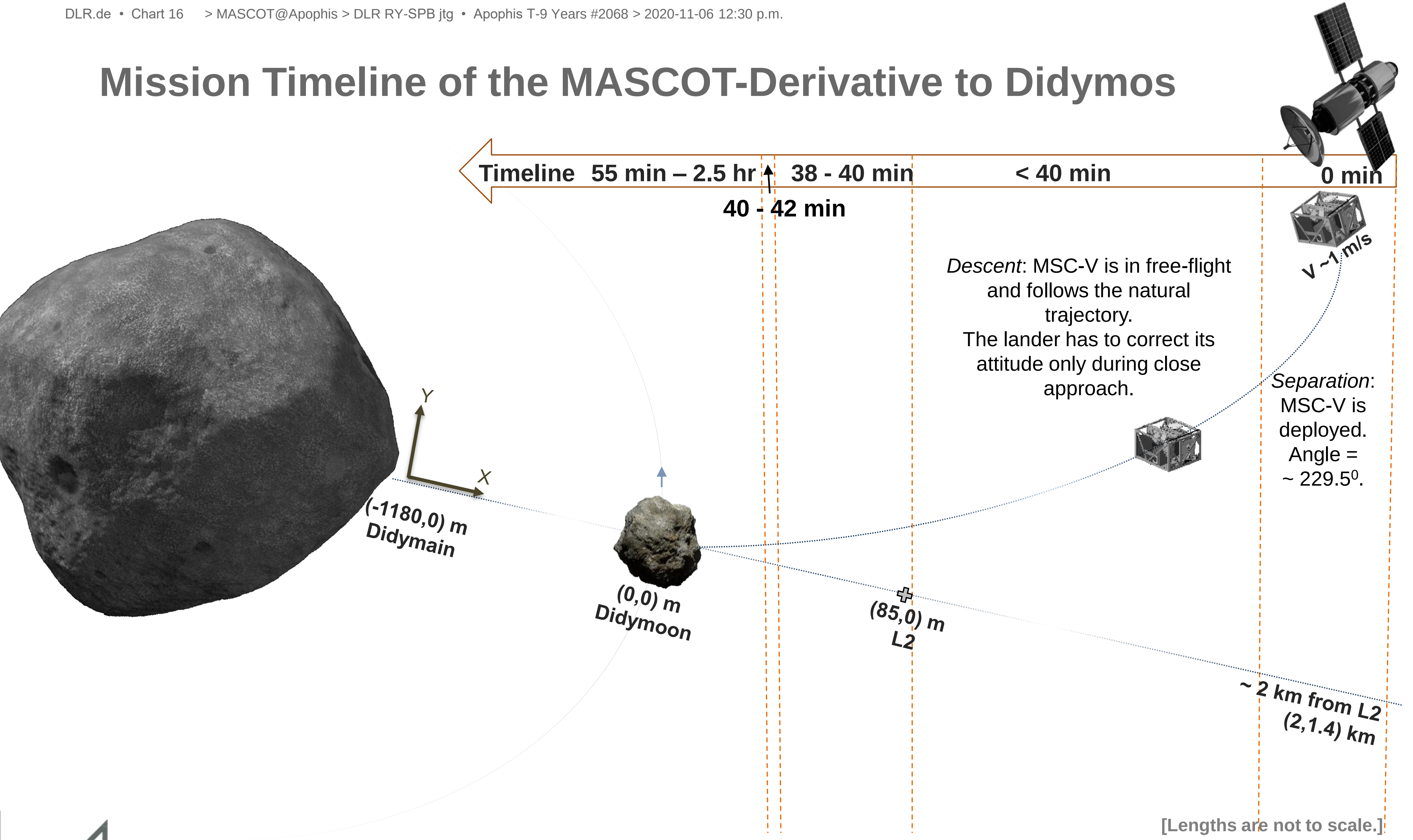


figures adapted from: Seefeldt et al., 2016, Ksenik

Mission Timeline of the MASCOT-Derivative to Didymos

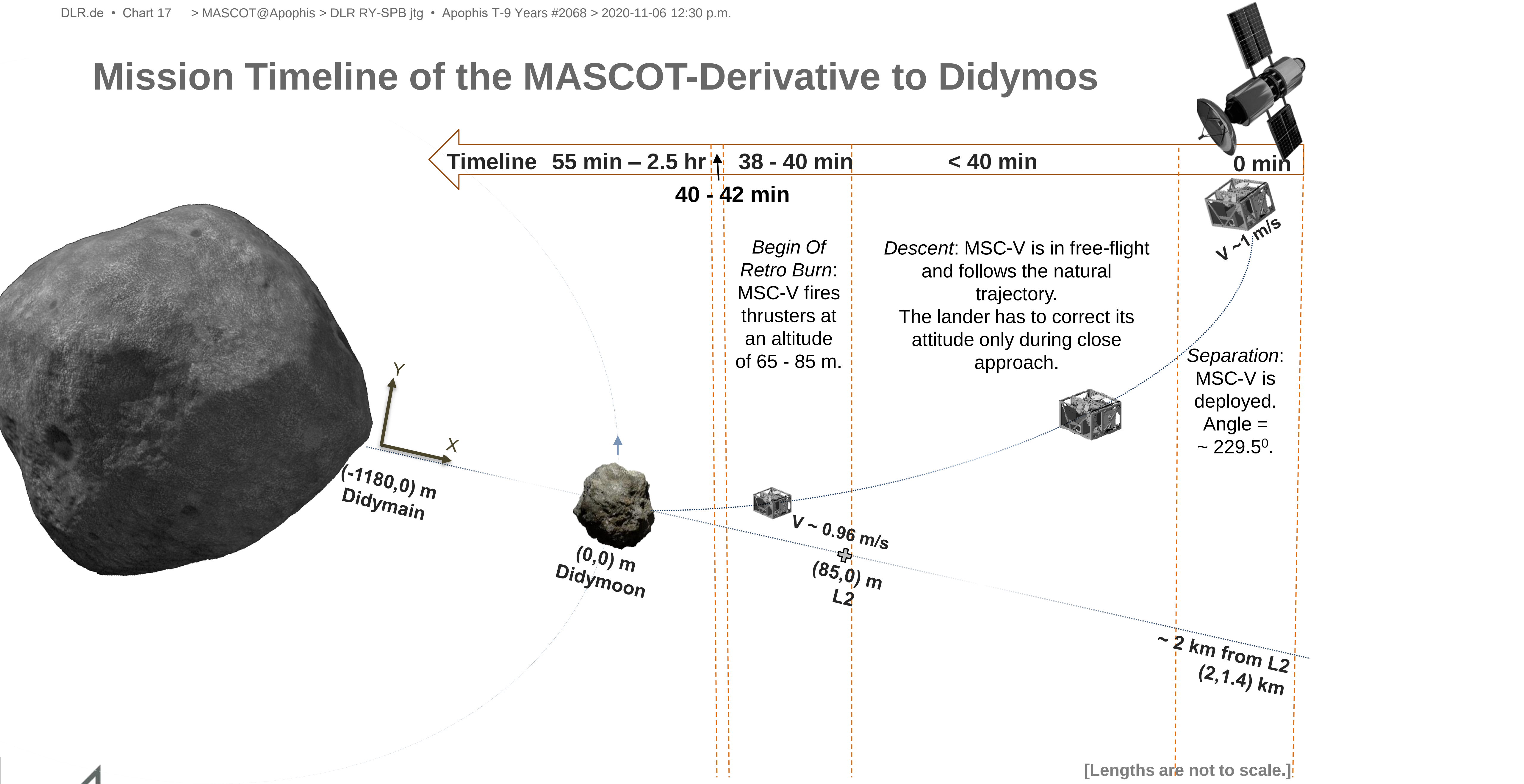


Mission Timeline of the MASCOT-Derivative to Didymos

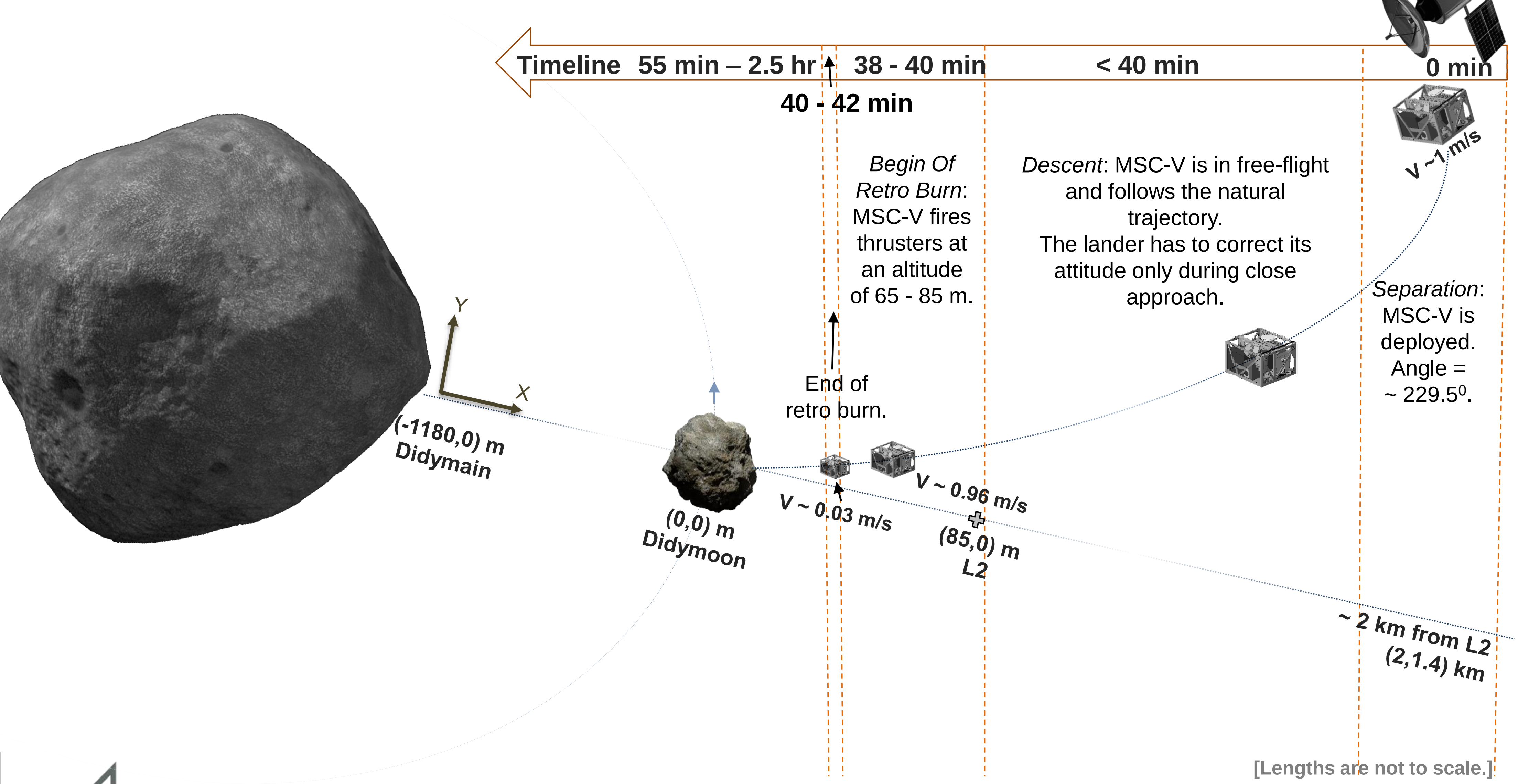


[Lengths are not to scale.]

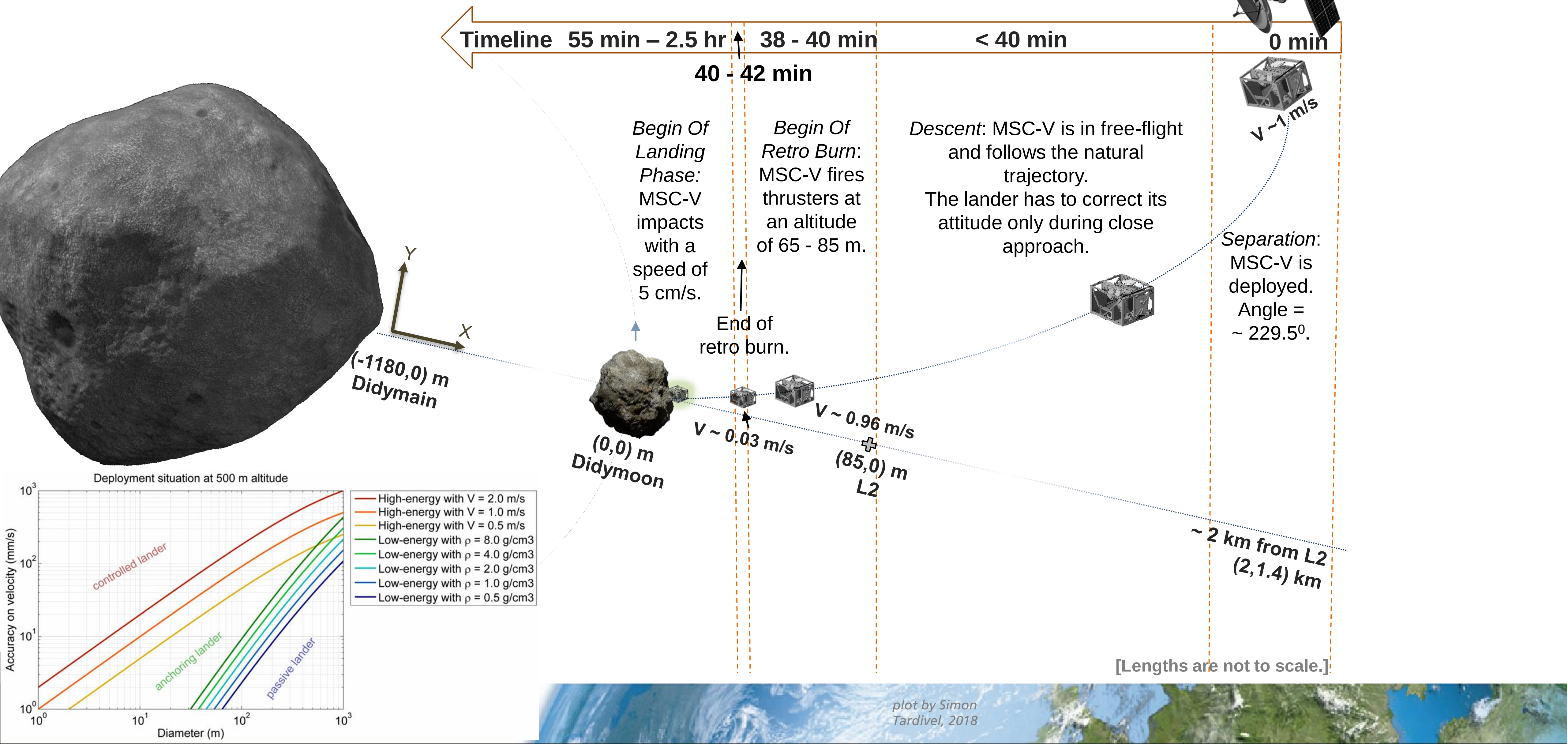
Mission Timeline of the MASCOT-Derivative to Didymos



Mission Timeline of the MASCOT-Derivative to Didymos



Mission Timeline of the MASCOT-Derivative to Didymos



Gravimeter on MASCOT@Apophis

Existing gravimeters are:

- Heavy devices
- Large in size
- Not used for space applications

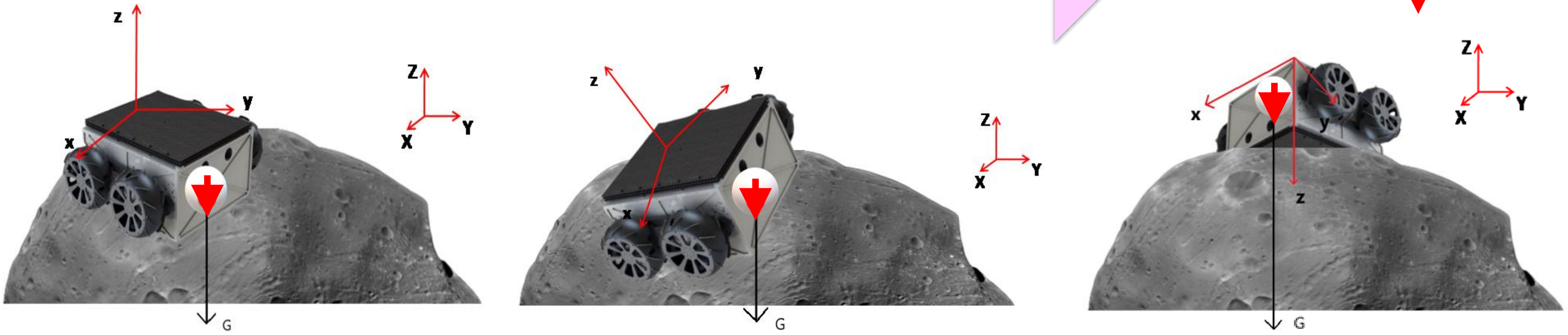
Solution

Measurements of small changes in acceleration based on the local gravity vector

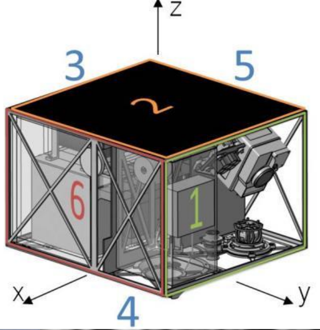
Local gravity vector identification

Small, compact solution which operates under every gravity condition

?



Gravimeter integrated on MMX rover in different attitude configurations as an example



1	+Y
2	+Z
3	-Y
4	-Z
5	-X
6	+X

our next mission?

your next mission!

- just drop us there, we'll place the seismometer

been there, done that – on Mt Etna with ROBEX

- don't worry about the big battery you use only once in LEOP

we'll take it to the surface where it'll see useful days

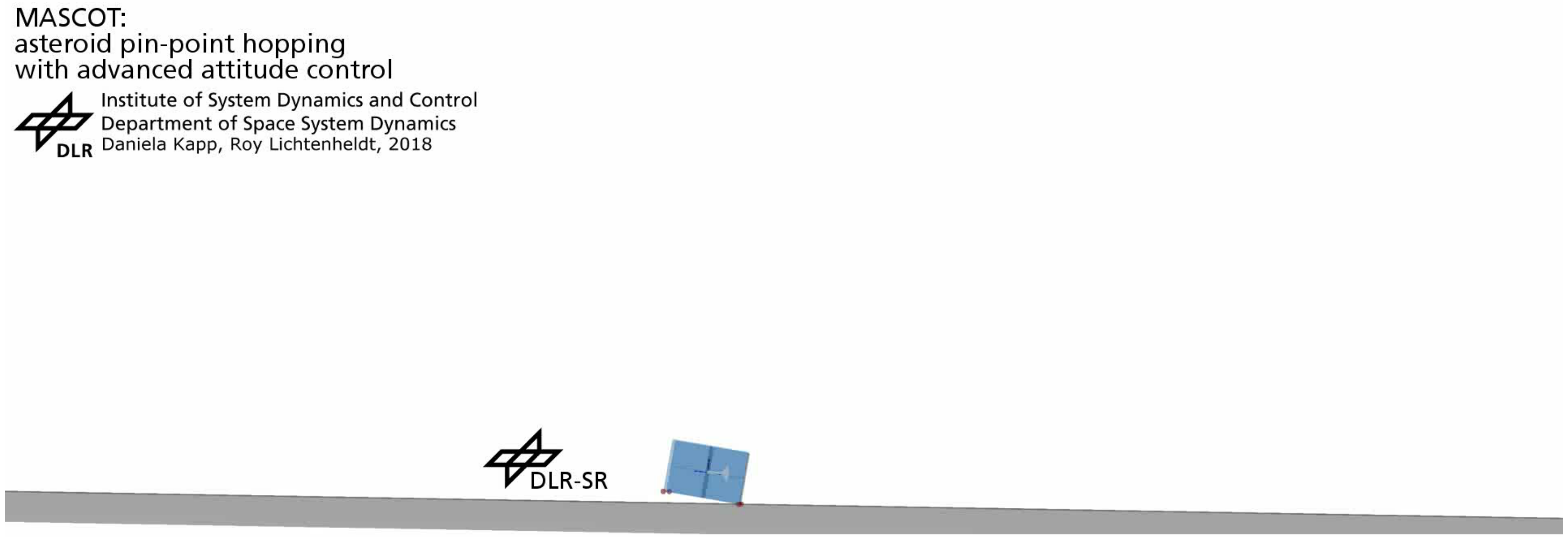
- these can bring a MASCOT, those can use it, too

go, borrow a Mars network and don't forget about frequency coordination with all the radars pinging at it !!!

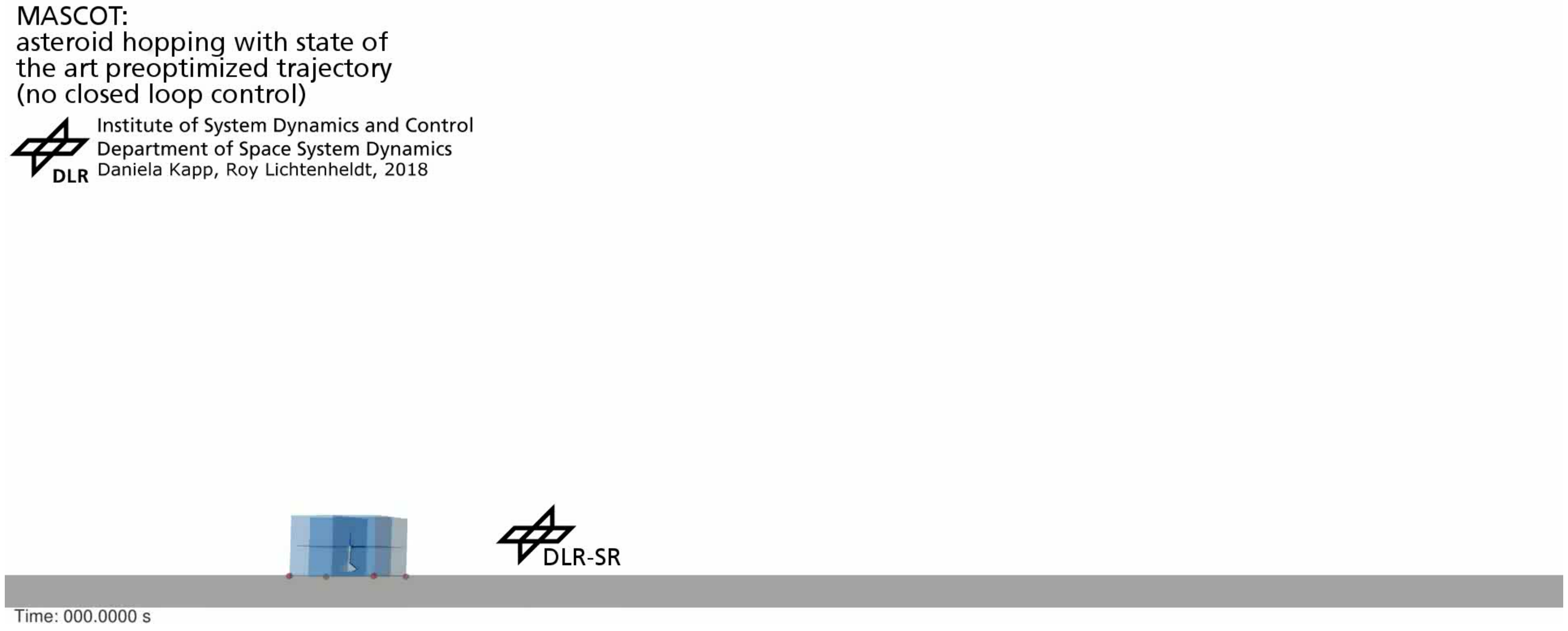
- btw, we'll transpond

Mobility v.2.0

- video of
    - Advanced Mobility Control →
        - immediate positioning of instrument FoV
        - faster traverses by skipping self-righting



- Open-loop Mobility →
    - semi-random walk
    - surface science



both options remain !