Small Landers and Separable Sub-Spacecraft for Near-term Solar Sails

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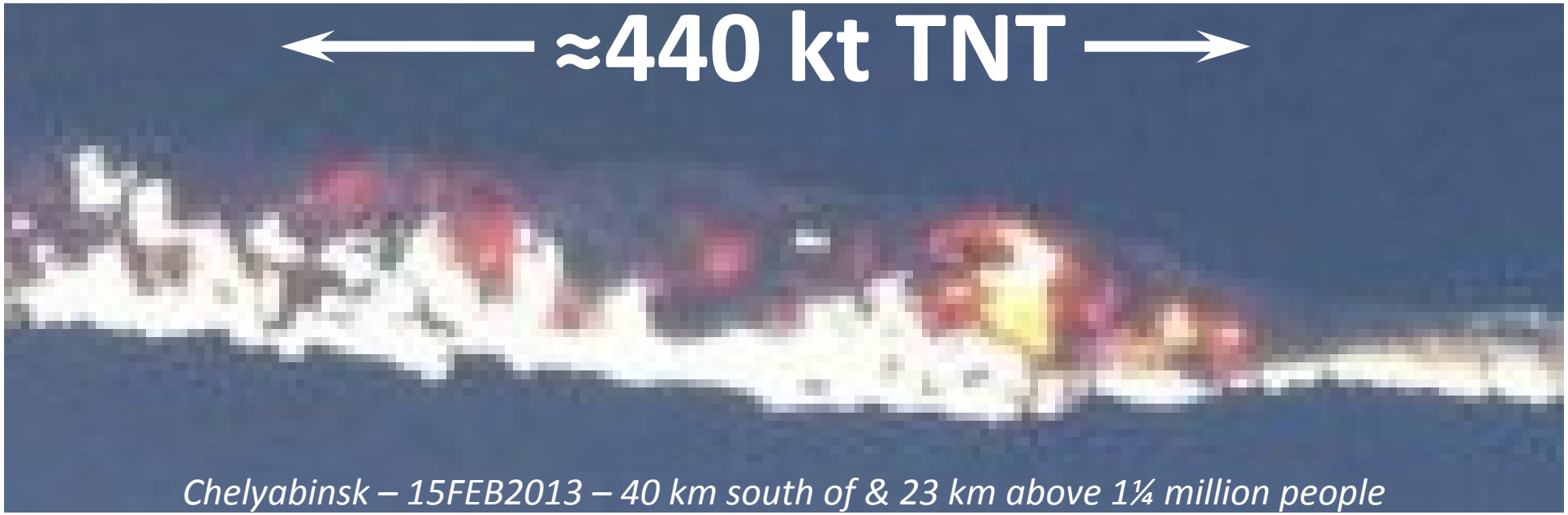
Prologue

A Winter Fairy Tale… *…that really happened*


Добро пожаловать
в мир знаний!
Д З Ю Д О
... ?? ... fairy tale !?!


… Yes.
… why?



Chelyabinsk – 15FEB2013 – 40 km south of & 23 km above 1¼ million people

…and no-one got killed…

…neither immediately nor by delayed effects; but: 2 heavily injured, 112 hospitalized for treatment, in total 1491 seen by medical staff, of which *only* 311 were children
6040 appartment blocks, 718 educational institutions, 293 hospitals and polyclinics, 100 cultural institutions, 43 sports sites damaged to require urgent repairs, renovation, restoration

city heating network –at daily maximum temperatures of -15ºC and windows smashed in thousands of buildings– did *not* collapse

…and all around, >100 km of blue icy-clear morning sky just before sunrise

asteroids matter.

…so let‘s go see some…

How to get your scientific spacecraft up there? – Step 1: Decide…

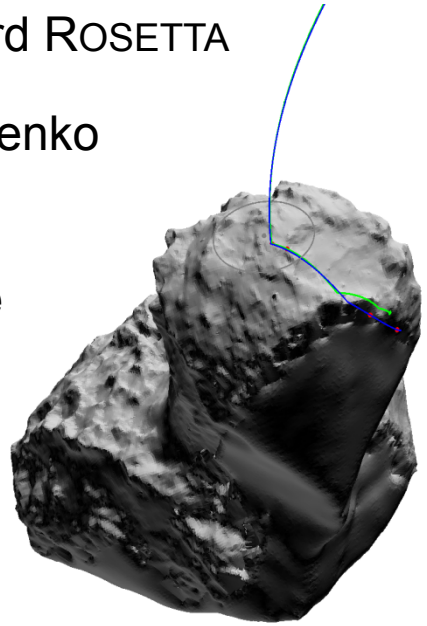
Method (A) – or – Method (B)

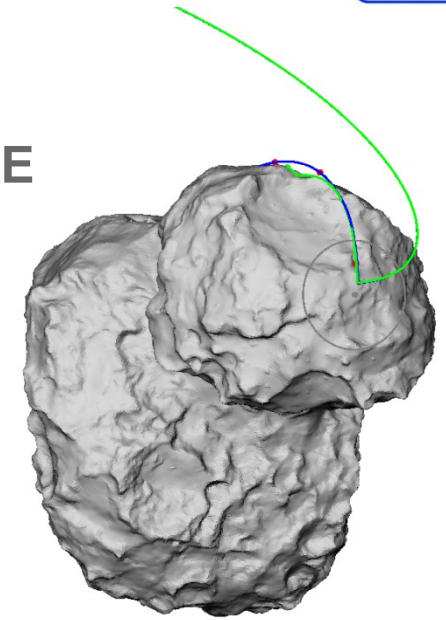
(*Note*: not to scale)

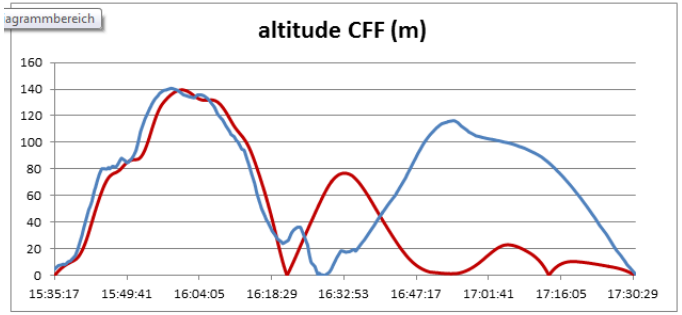
ACCOUNTANT-GERNERAL'S WARNING: Taking decisions may irreversibly affect your financial health.

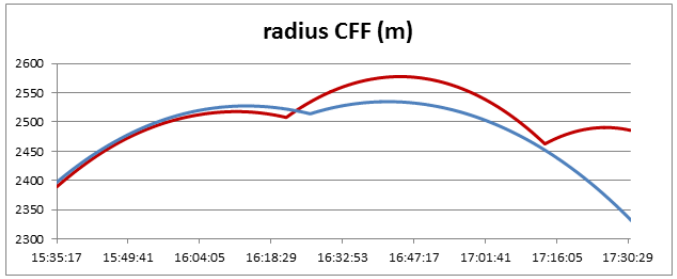
"Today, we didn't just land once,…" – the landings of PHILAE

- launched March 2nd, 2004 aboard ROSETTA
- target 67P/Churyumov-Gerasimenko
- arrived on August 6th, 2014
- **separation at 22500 m altitude**
  & 0.19 m/s lateral velocity
- **free-fall to surface**
- **touch-down at 1 m/s**
- rebounds at 0.38 m/s
- bounces again at 0.03 m/s
  - $v_{esc} \approx 0.5 \ldots 1$ m/s
  - final landing Nov. 12th, 2014 17:32 UTC
- **complex landing gear** ☺
- **energy absorbers** ☺ **& anchoring** (failed)
- **hold-down thruster** (out of gas…)





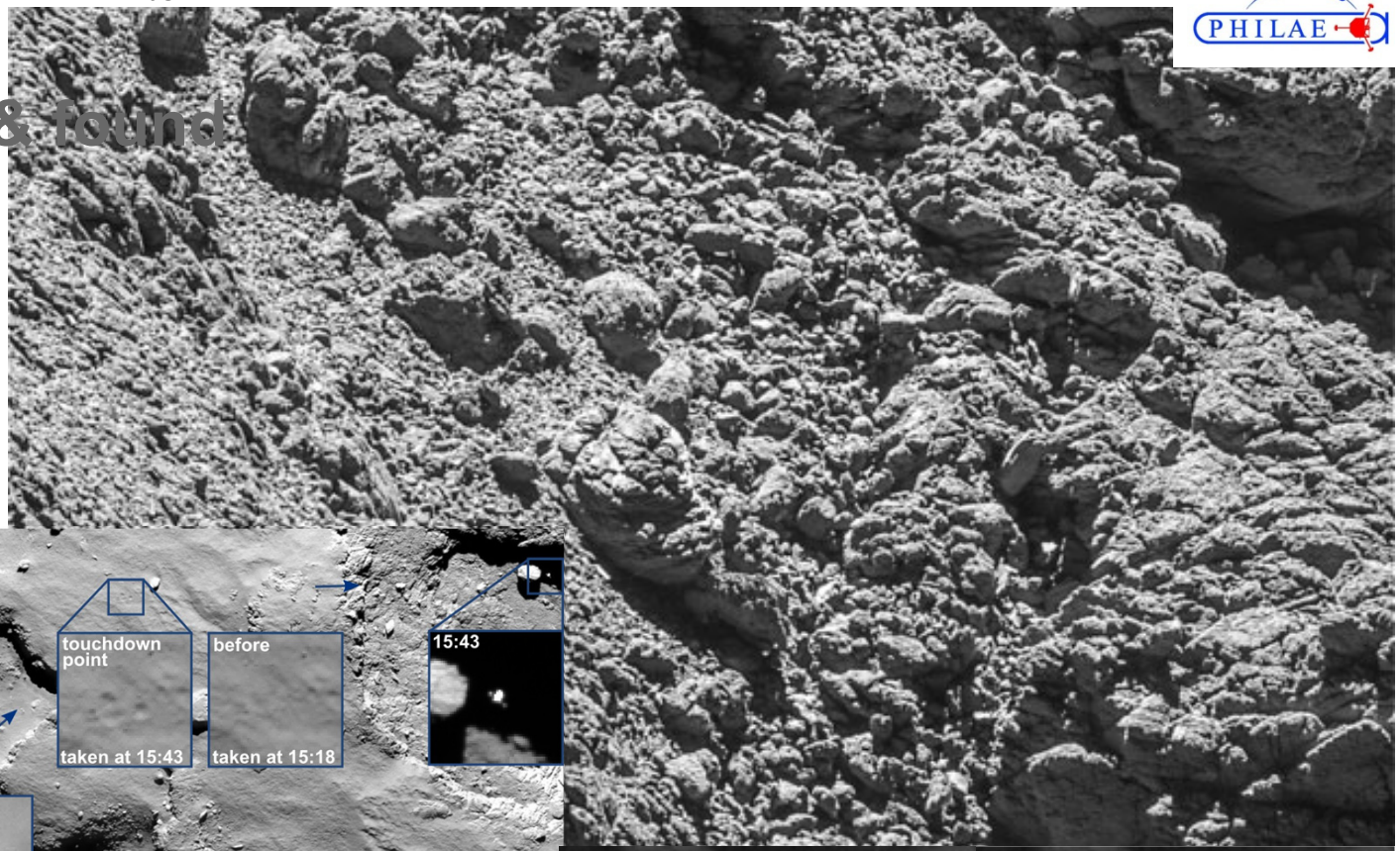


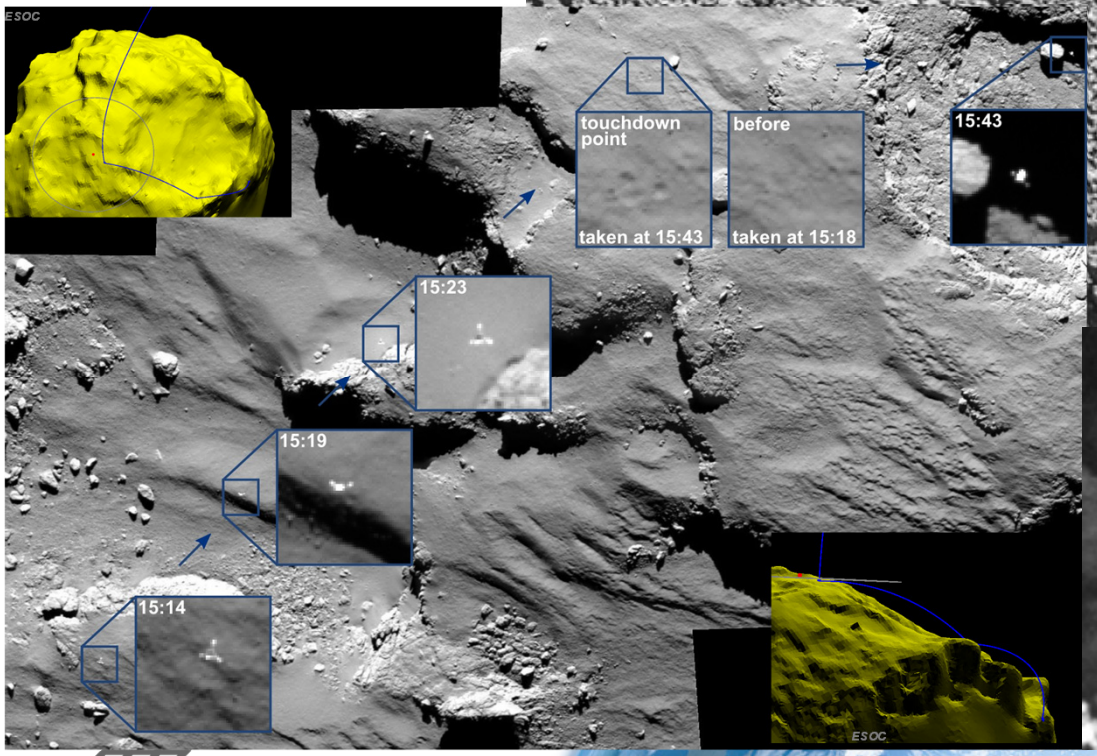


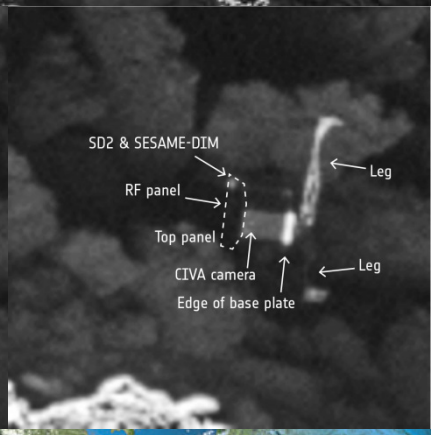
Altitude,and radius for ESOC (blue) and SONC (red / green) reconstructions.
Timing of the 2nd collision in the SONC reconstruction is forced to 16:20 UTC, in ESOC reconstruction computed as the intersection with the shape model of the trajectory determined with the optical observations.

PHILAE – lost & found

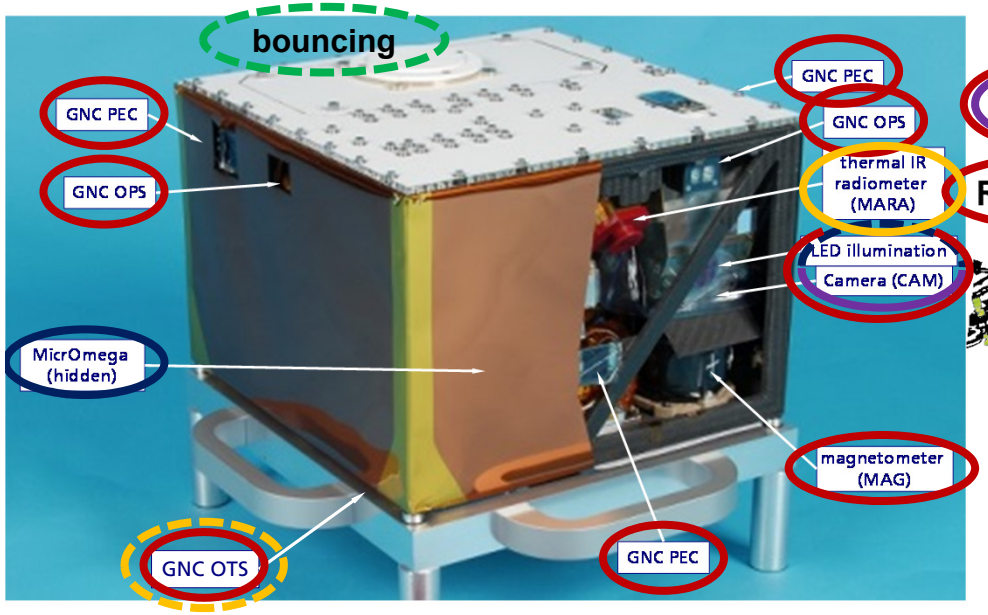
- primary mission science program sucess
- extended mission lost – stuck in the shadow
- located Sep. 2nd, 2016 in 2.7 km flyby of ROSETTA (1 month before end of mission)

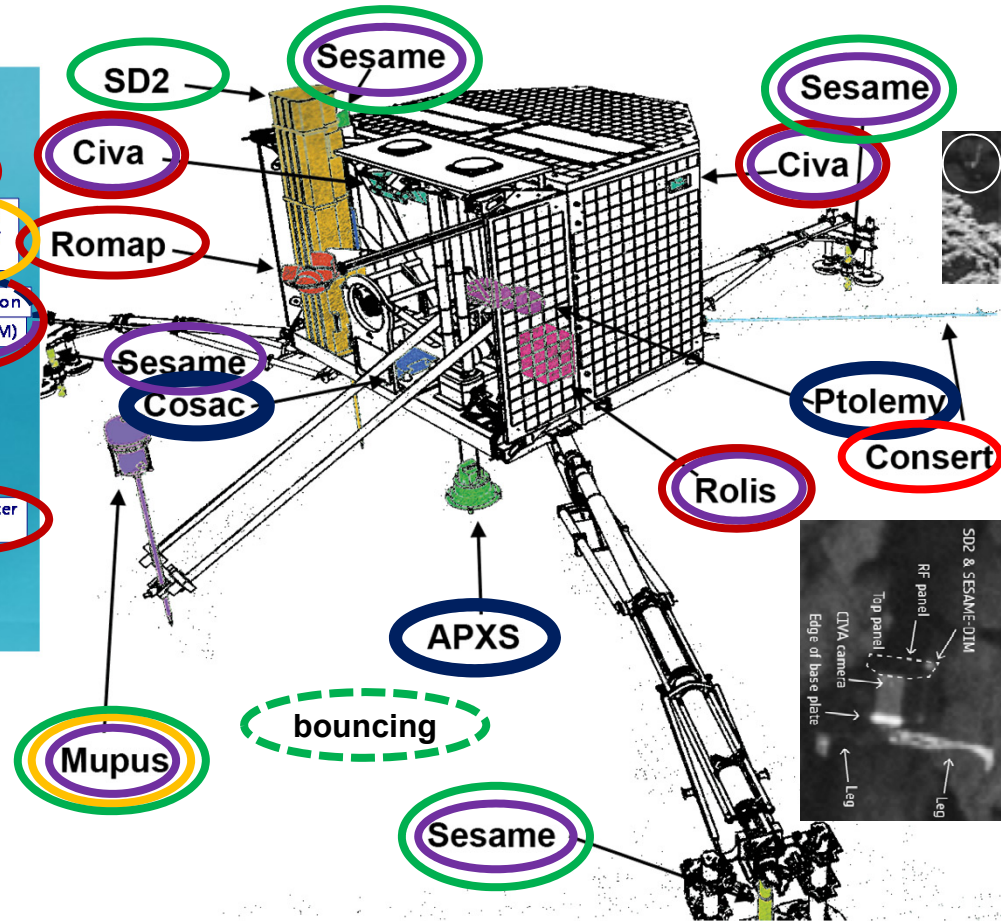






tools of knowledge – lander instruments





target body properties addressed…

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

a better understanding of small solar system bodies

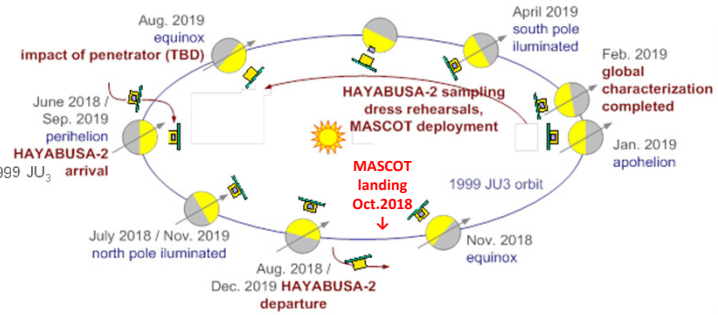
→ **modelling of properties & populations**

→ understanding, utilization, security

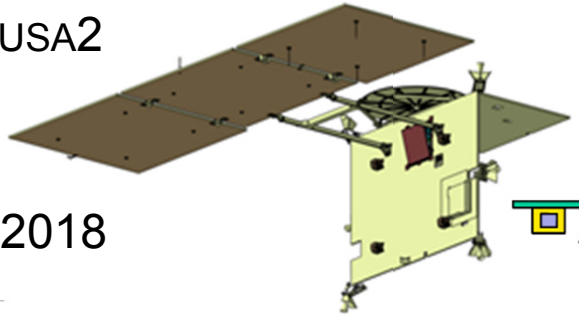
note: no Scout would go outdoors without a compass! →

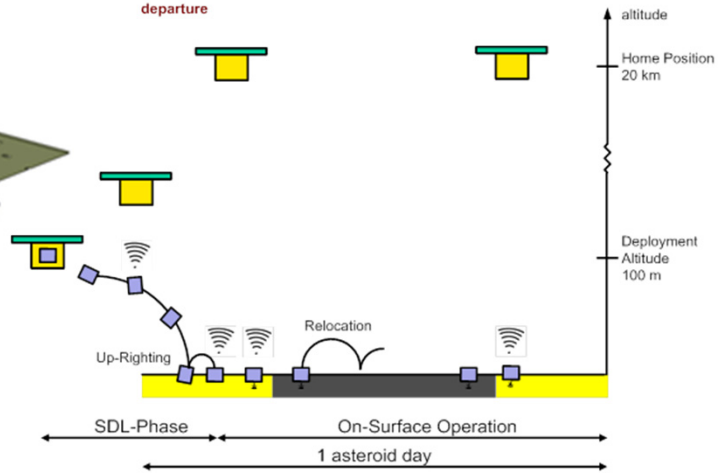
DLR

diving down to Ryugu, the asteroid formerly known as (162173) 1999 JU_3

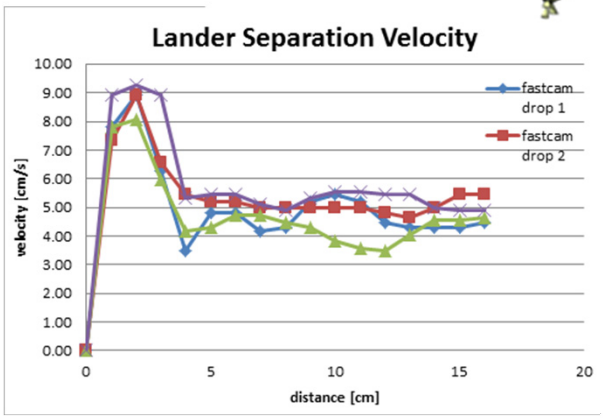


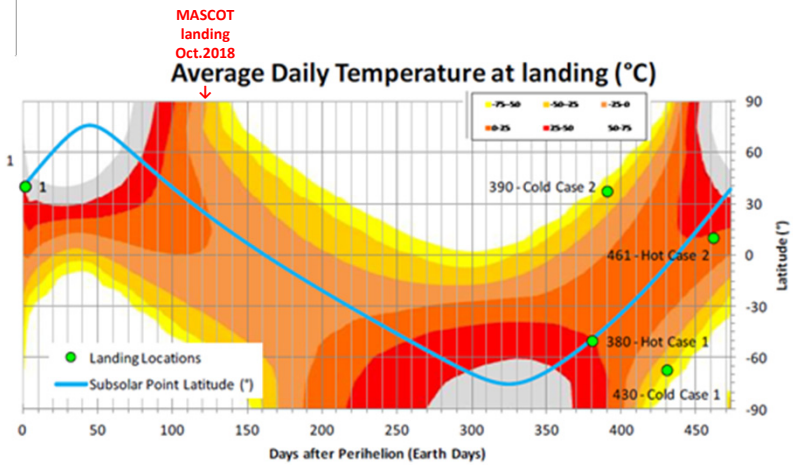
- MASCOT is aboard HAYABUSA2
- launched Dec. 3rd, 2014
- Earth fly-by in Dec. 2015
- HAYABUSA2 arrival in June 2018





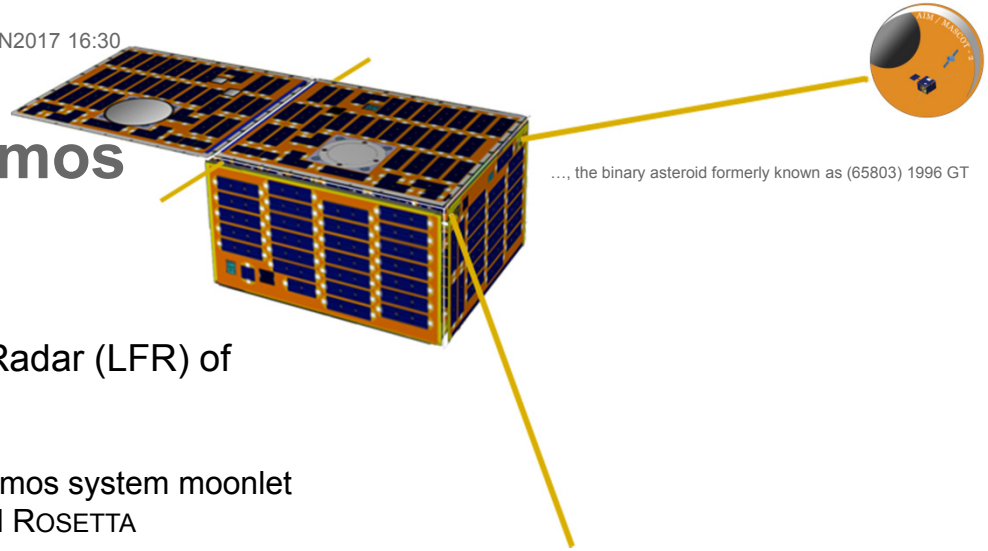
- landing planned for Oct. 2018
- **free-fall from ~100 m**
- one-try primary battery mission





- measurements at the surface planned on 2 asteroid days and at 2 locations

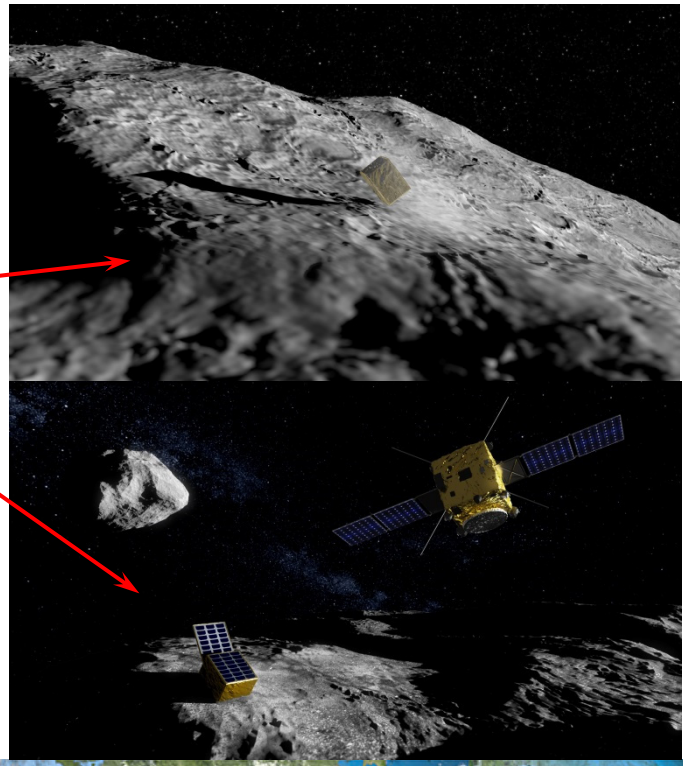
MASCOT2 – AIMing at Didymos



- surface element of the Bistatic Low-Frequency Radar (LFR) of ESA's AIM mission
  - AIM is part of the joint NASA-ESA AIDA mission
  - NASA provides the DART impactor to hit the Didymos system moonlet
  - LFR is a descendant of CONSERT on PHILAE and ROSETTA

- AIM launch Oct./Nov., 2020
- AIM arrival May/Jun. 2022
- MASCOT2 **landing** Aug. 2022 on Didymoon **at a few cm/s**
- DART impact Sep./Oct. 2022 on Didymoon at 6.5 km/s <85 m from MASCOT2 !

- long-term photovoltaic powered mission, >100 days
  - landing at orbital dynamics safest site
  - relocation to LFR optimal operations site by MASCOT Mobility
  - additional solar panel & LFR antennae deployed after relocation



- LFR scans the interior of „Didymoon" in several plane sections before & after the impact of DART
- DACC accelerometer records landing & bouncing, maybe DART
- MASCOT heritage instruments CAM, MARA, MAG conduct longterm observations for seasonal changes in Didymos system

DLR

images: ESA/DLR

far out – a lander study for the Solar Power Sail on a Jupiter Trojan asteroid sampling mission

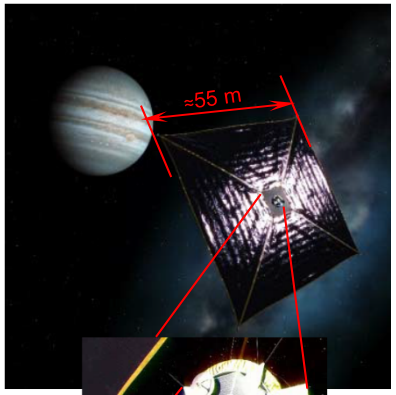
- PHILAE-sized lander
- **fully propelled descent & landing**
- Ø650 · H400 mm main body
- ≤100 kg wet mass

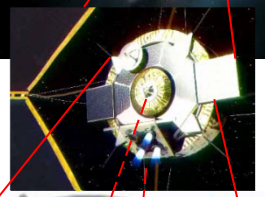
- 21 kg instrument suite for in-situ studies
- 600 Wh required for on-site sequence

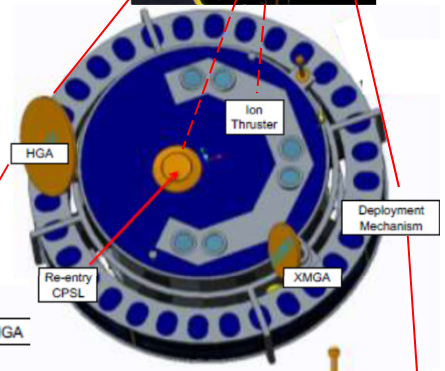
- relocation by hopping, if site unsuitable
- **optional sample-return mission**

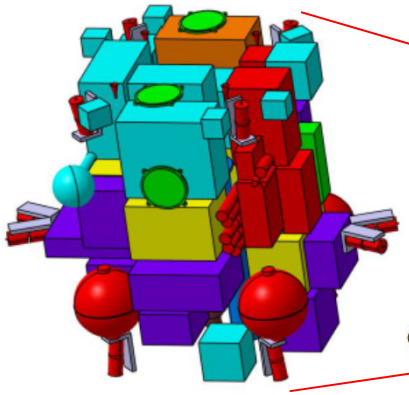
Category	Details	Mass [kg]
Sampling & Distribution system	Horn-shape sampler ~HY2 Pneumatic drill ~OSIRIS-REx Rotating carousel 6 loads Air-guns and tanks	7.0
High Resolution Mass Spectroscopy MULTUM (J) Cosmorbitrap (F)	MS Electrode Gas Chromatograph Electronic Ionizer Electronics	5.0
Microscopy	MicrOmega type IR-microscope	2.5
Panoramic Observation	Wide angle camera IR-imager with periscope	3.4
Context Observations	Close-up imager Thermal radiometer Magnetometer Raman Spectrometer Thermogravimeter	3.0
Total		20.9

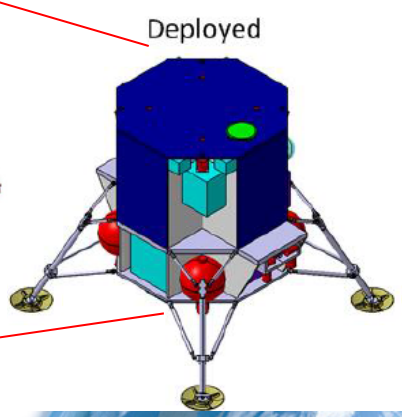
Mori et al., LPSC (2016)

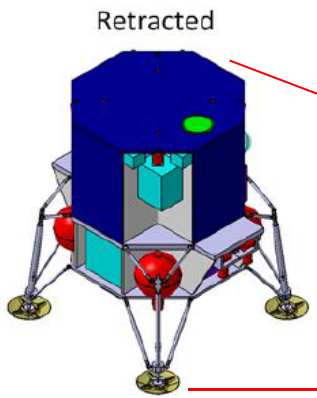


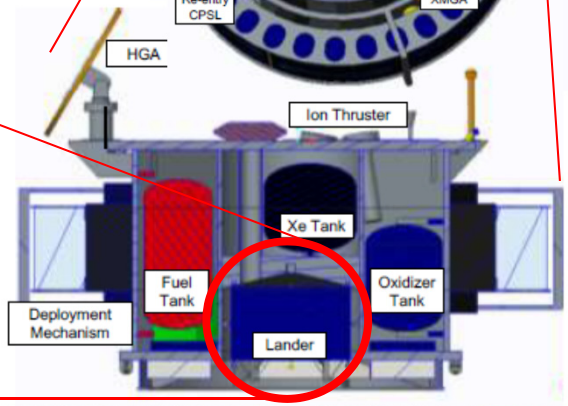












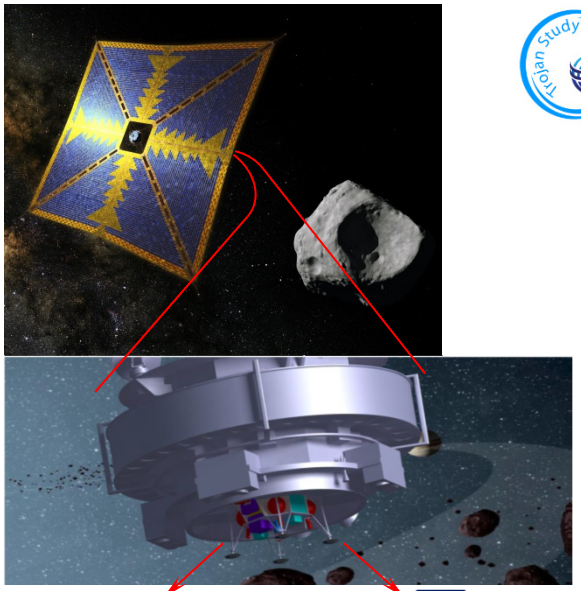
Science
RCS
AOCS
Power
DHU
Communication

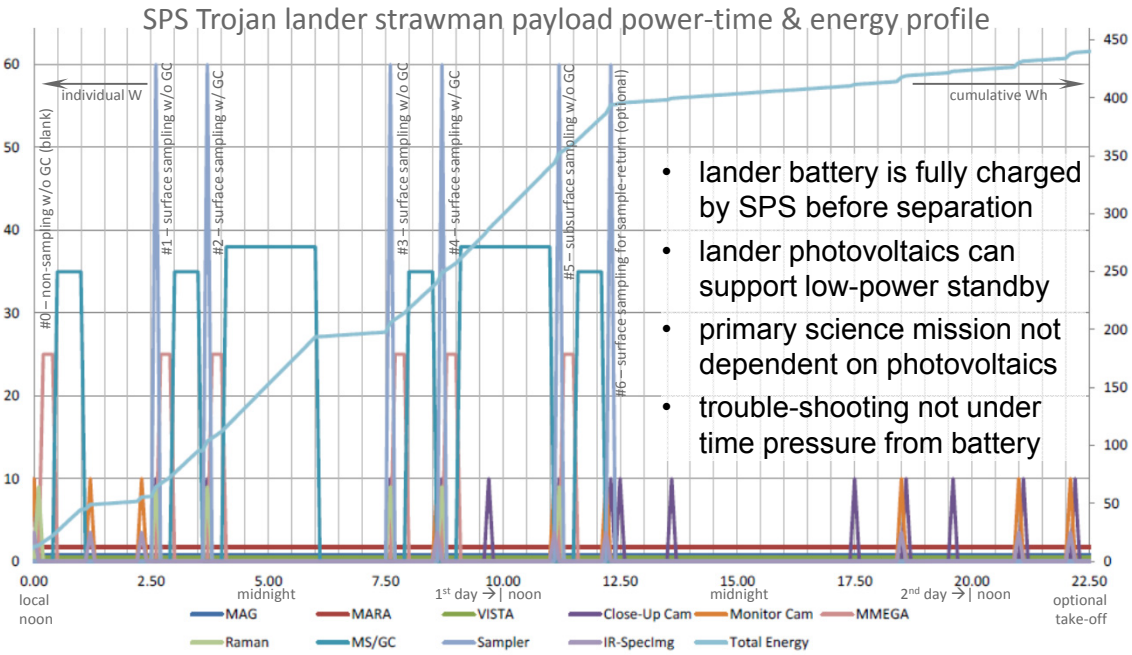
DLR

Images: JAXA/ISAS/DLR Kawaguchi et al. Mori et al., Saiki et al.

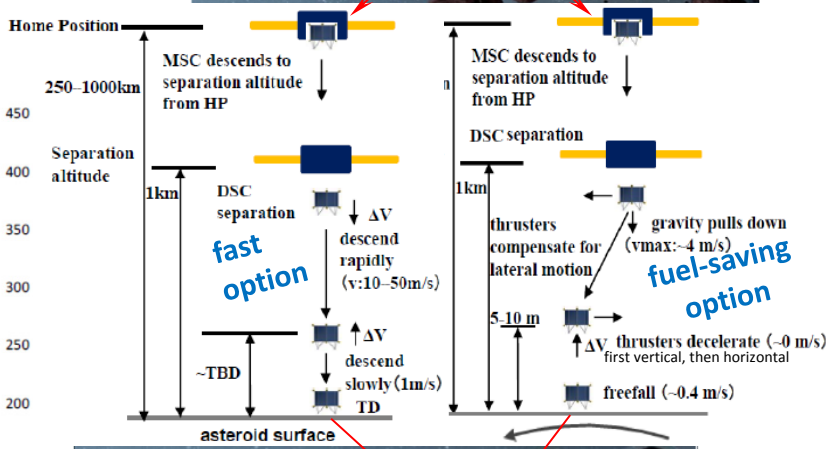
there and back again – SPS Lander operations

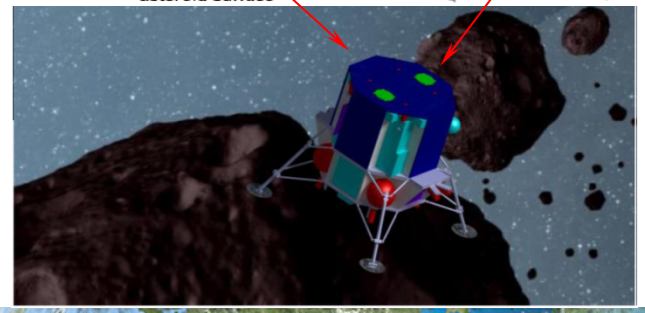
- separation from SPS at ~1 km altitude
- operate for >2 Trojan days → 22.5 h @ 10 h rotation period
- science data transfer from lander to SPS >500 MByte
- sampling by 2 methods into 6-place carousel
- *optional*: sample-return to SPS





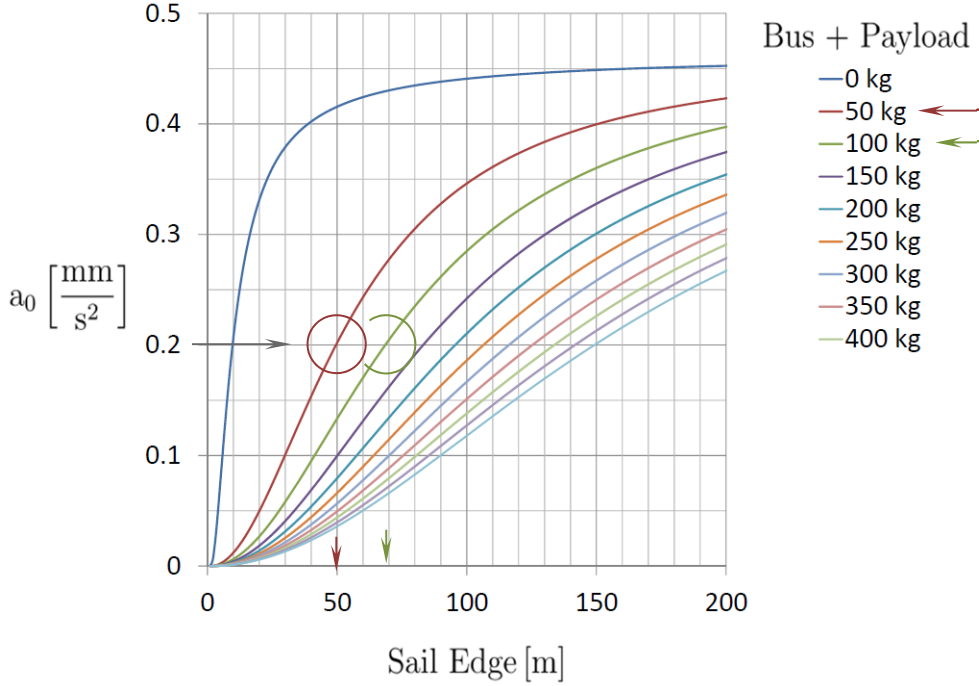
- lander battery is fully charged by SPS before separation
- lander photovoltaics can support low-power standby
- primary science mission not dependent on photovoltaics
- trouble-shooting not under time pressure from battery





Images: JAXA/ISAS/DLR, Kawaguchi et al. Mori et al., Saiki et al., Yano et al.

GOSSAMER-1 characteristic acceleration estimation



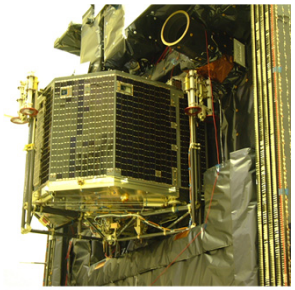
Bus (Gos-1 + X-Band)	≈30 kg
Mother Spacecraft Science Instruments	≈10 kg

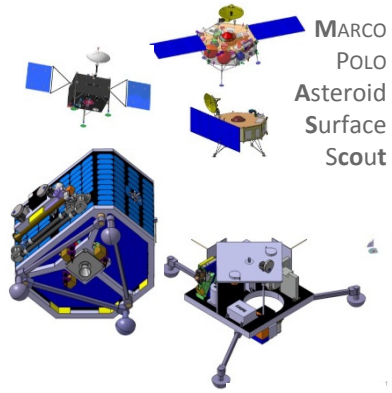
Lander	
PHILAE	98 kg
SPS Lander	100kg
1 MASCOT	10 kg
5 MASCOTs	50 kg

➔ **Constraints driven design!**

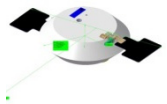
DLR

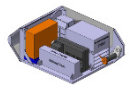
summary & future work



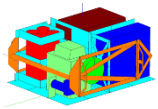


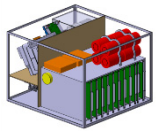
- by small landers, many options exist to bridge the gap from sail to soil:
  - MASCOT – ballistic free-fall from ~100 m to ~1 km NEA
  - MASCOT2 – ballistic drop from another orbit in a binary NEA system
  - PHILAE – free-fall landing with landing gear dampers & hold-down
  - SPS Lander – fully propulsive landing & sample-return launch



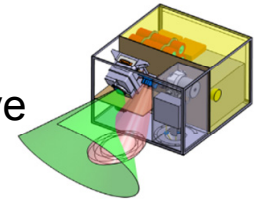


- work continues to create even more options:
  - by adapting to a wider range of target gravity
  - by becoming robust to higher landing velocities





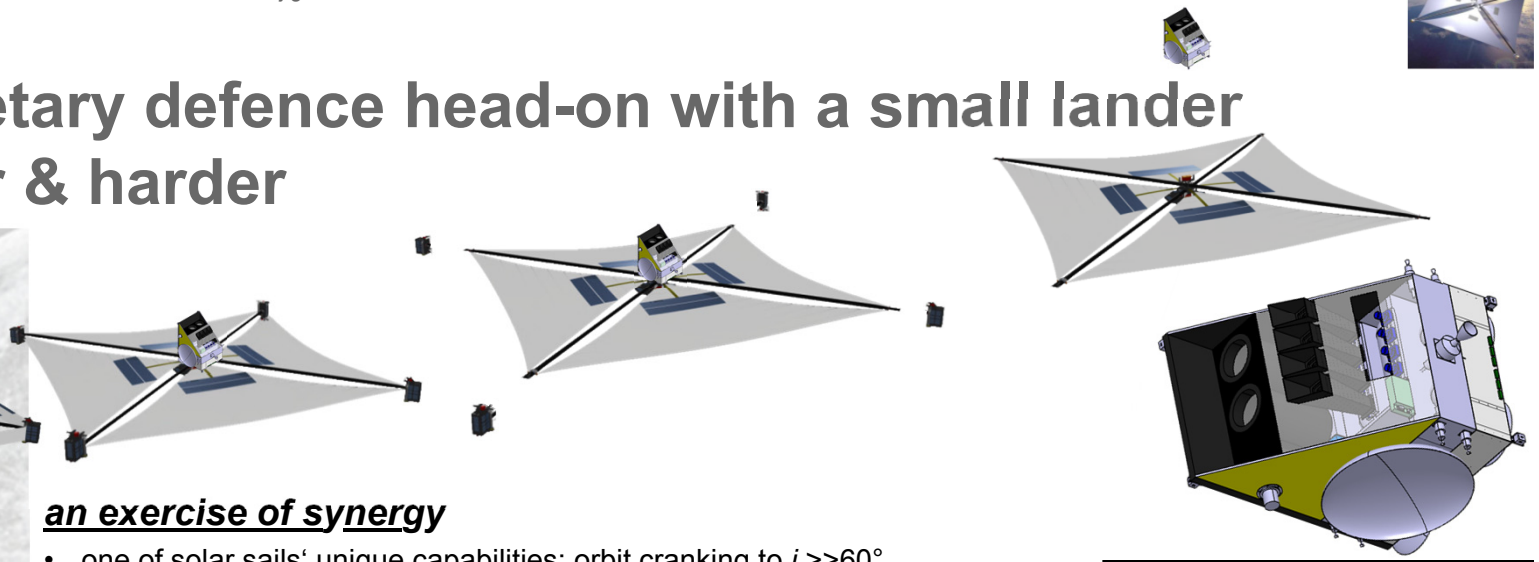
- solar sails enable heliocentric rendezvous access to all asteroids @ a < 2
- small landers can connect rendezvous spacecraft with any target‘s unknowns
- ‘small‘ spacecraft design & philosophy makes exploration affordable & responsive



➔ ‘small‘ solar sails & landers are the key to unlock the treasures of the solar system

back-up slides

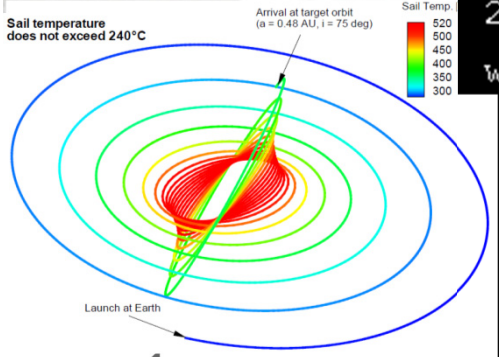
taking planetary defence head-on with a small lander …just faster & harder



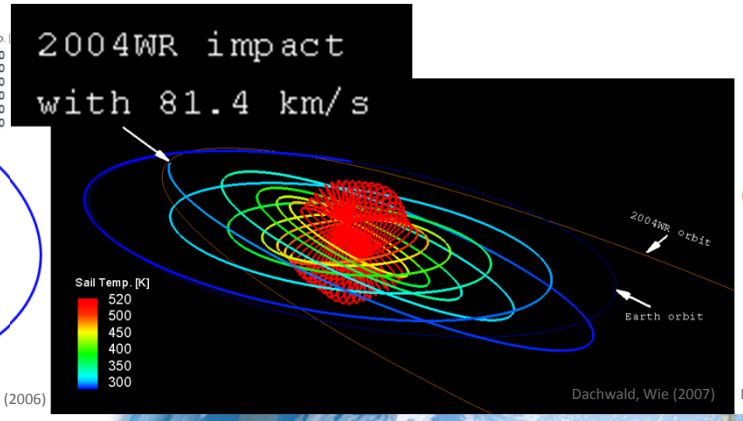
an exercise of synergy

- one of solar sails' unique capabilities: orbit cranking to *i* >>60°
- GOSSAMER solar sails are based on small separating sub-spacecraft
- payload-drop missions have been studied, e.g. Solar Polar Orbiter / Imager
- Kinetic Energy Impactors don't care what they are made of
- a fast e^--multiplied CCD ASTEROIDFINDER camera is good at tracking NEAs
- … add terminal guidance & propulsion

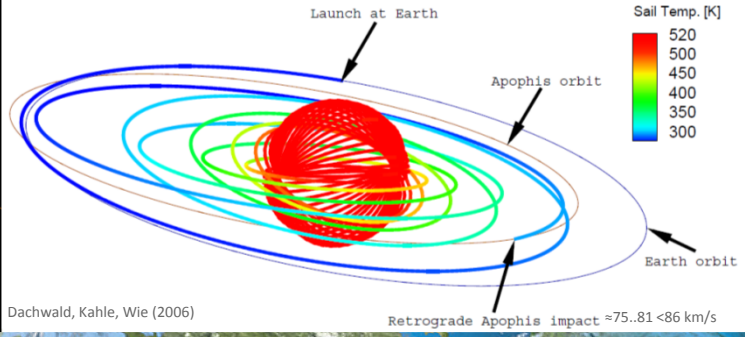
Dimension	1m x 0,78m x 0,7m
Sunshield	50 degree
Mass	179kg
Payload	2 x High Resolution Cameras 4 x Middle Range Camera 4 x Webcam
Communication	1 x Ka-band antenna 2 x X-band antenna 4 x Interlink antenna
ACS	Propulsion (8 x 1N thrusters, 1x 400N thruster)



Dachwald, Ohndorf, Wie (2006)



Dachwald, Wie (2007)



Dachwald, Kahle, Wie (2006)

DLR