HVIS2015 – Session 11 – #20

Spacecraft for Hypervelocity Impact Research – an Overview of Capabilities, Constraints, and the Challenges of getting there

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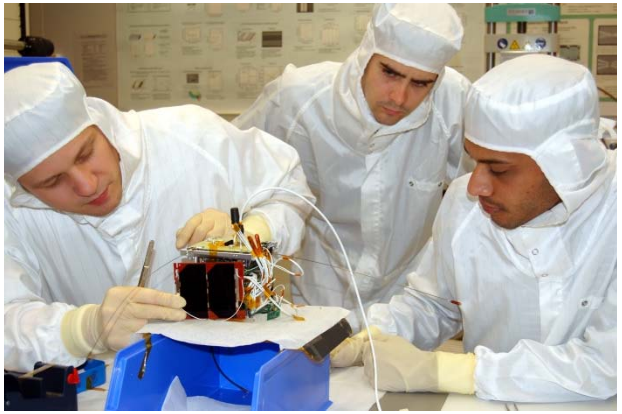
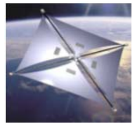
Task: get the HVI community up to speed …??...
… *on small spacecraft*

so,… small spacecraft… –

- what are they doing anyway?
- what can I get from them? …except an impact flash…
- how do I make ‘em?
- …and how fast can they go?

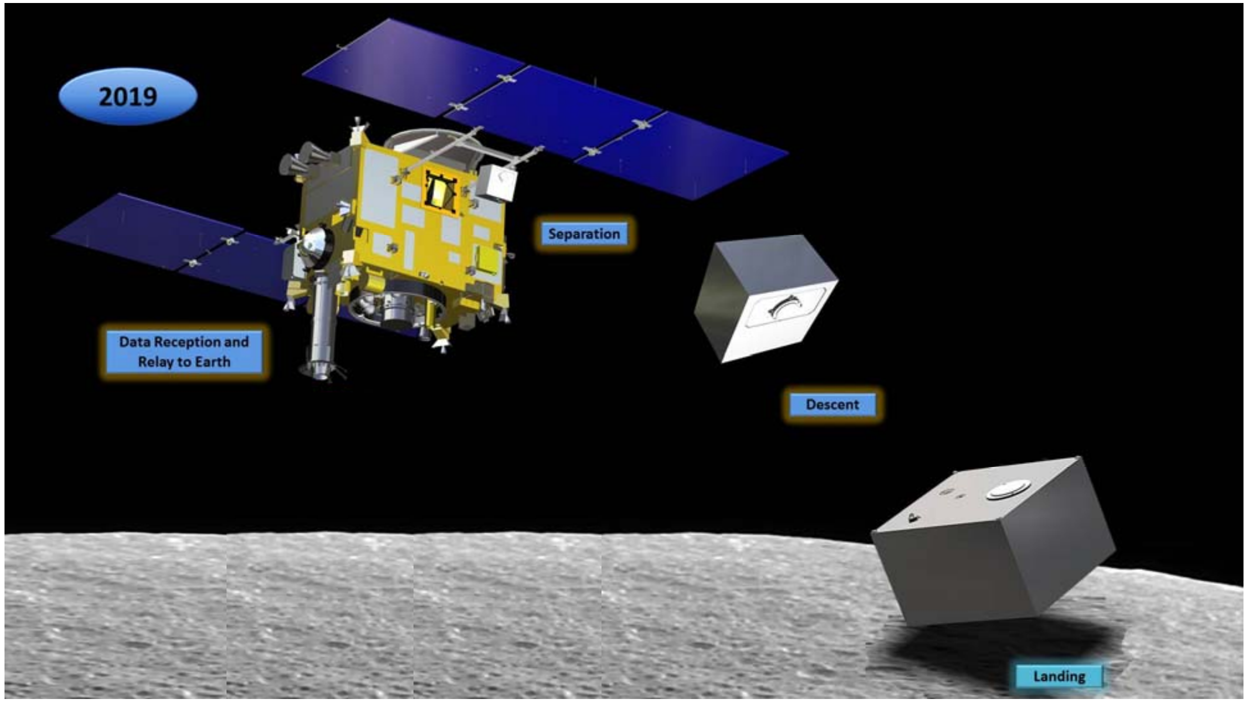


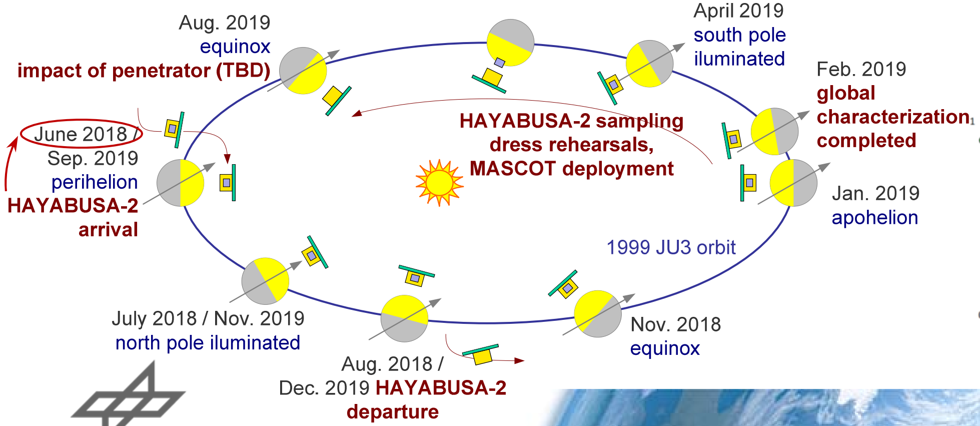


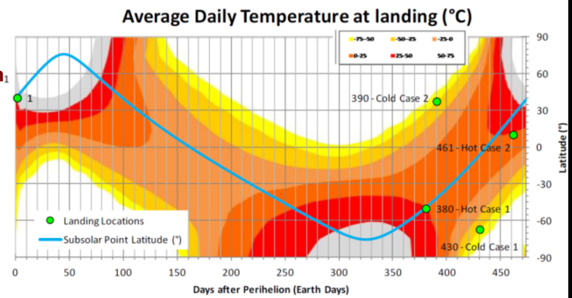
Note: velocities *will* increase throughout this presentation

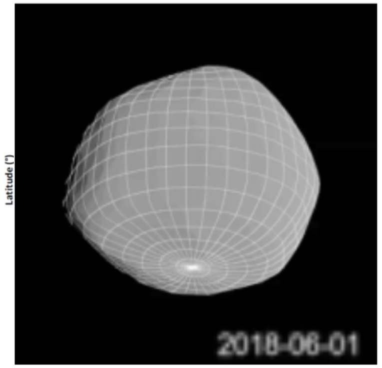
MASCOT – Mobile Asteroid Surface Scout

- launched Dec. 3rd, 2014 aboard HAYABUSA2
- target asteroid 1999 JU_3
- arrival in June 2018
- separation at 100 m & 0.05 m/s lateral velocity
- free-fall to surface
- impacts at ~0.2 m/s
  - $v_{esc} \approx 0.5$ m/s





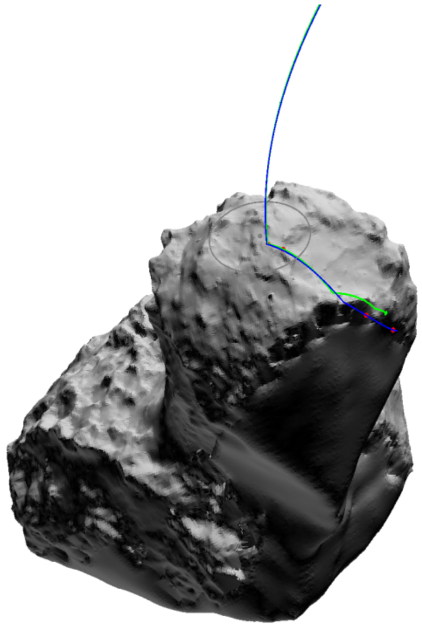


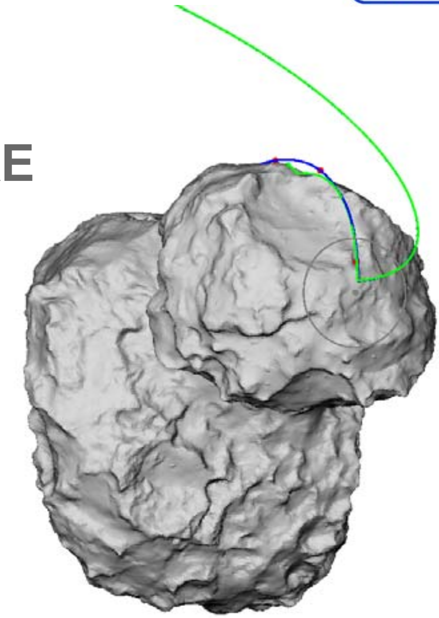


1999JU3 model:
T.G. Müller et al, 2010

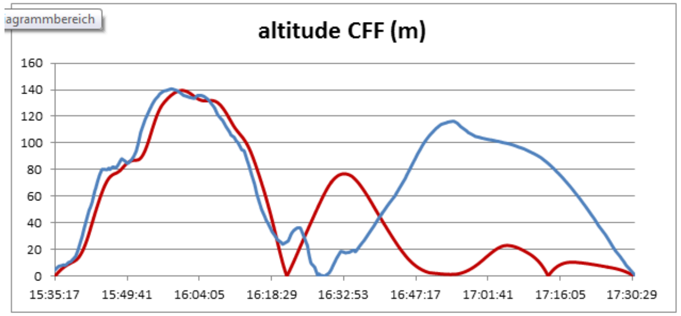
"Today, we didn't just land once,…"
– the landings of PHILAE

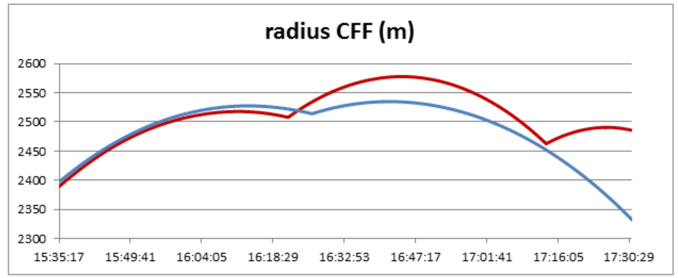
- launched March 2nd, 2004 aboard ROSETTA
- target 67P/Churyumov-Gerasimenko
- arrived on August 6th, 2014
- separation at 22500 m & 0.19 m/s lateral velocity
- free-fall to surface
- impacts at 1 m/s
- rebounds at 0.38 m/s
- bounces again at 0.03 m/s
- final landing Nov. 12th, 2014 17:32 UTC
  - $v_{esc} \approx 0.5 \dots 1$ m/s

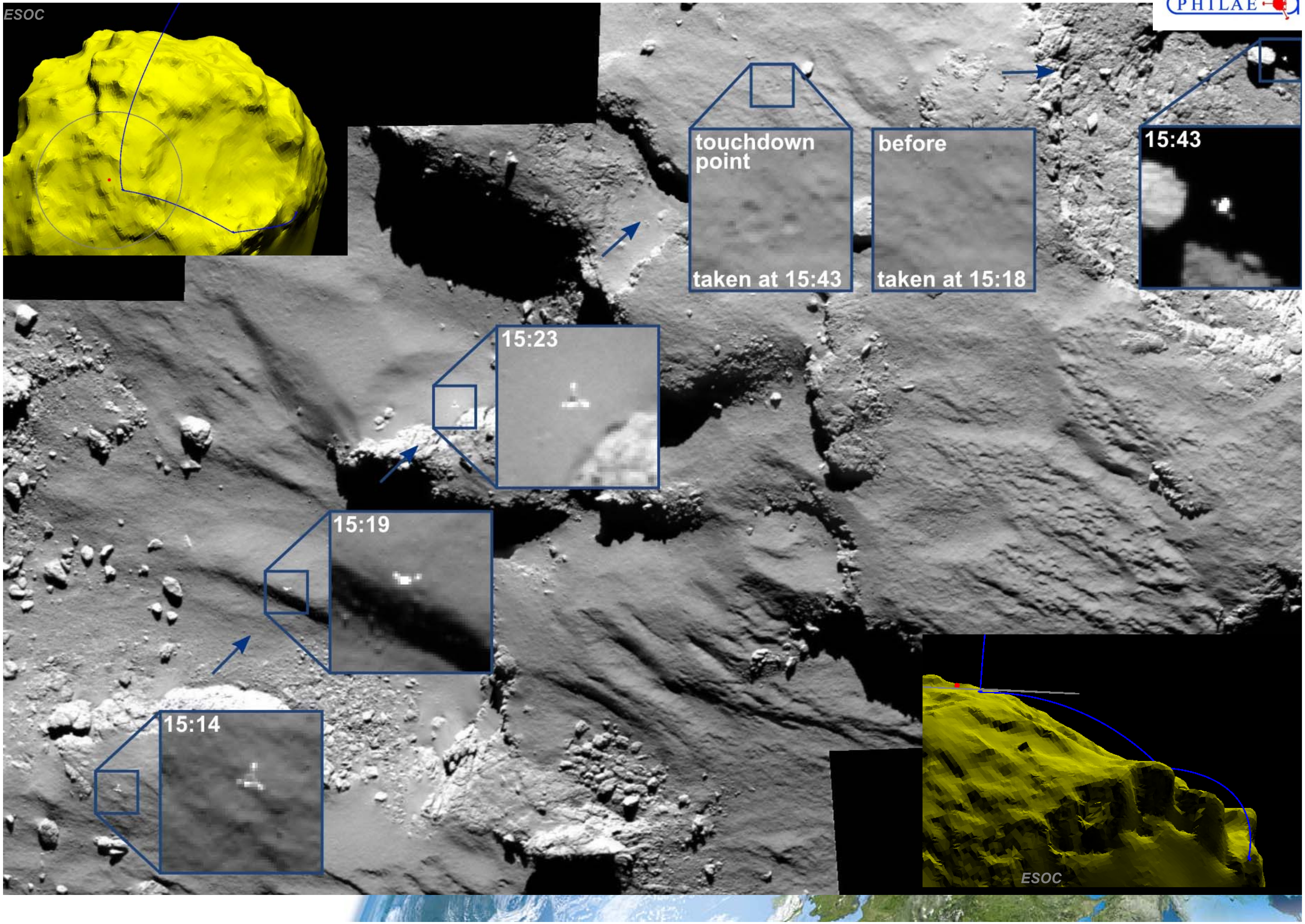




Altitude,and radius for ESOC (**blue**) and SONC (**red** , **green**) reconstructions. Timing of the 2nd collision in the SONC reconstruction is forced to 16:20 UTC, in ESOC reconstruction computed as the intersection with the shape model of the trajectory determined with the optical observations.

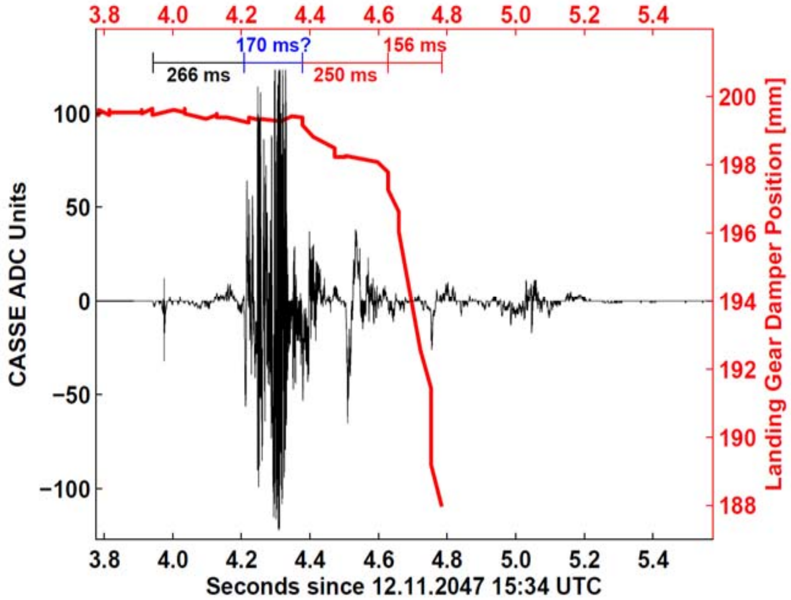





ESOC
touchdown point
taken at 15:43
before
taken at 15:18
15:43
15:23
15:19
15:14
ESOC

…and what about hypervelocity impacts? – things can only get β…

← designed to bounce !

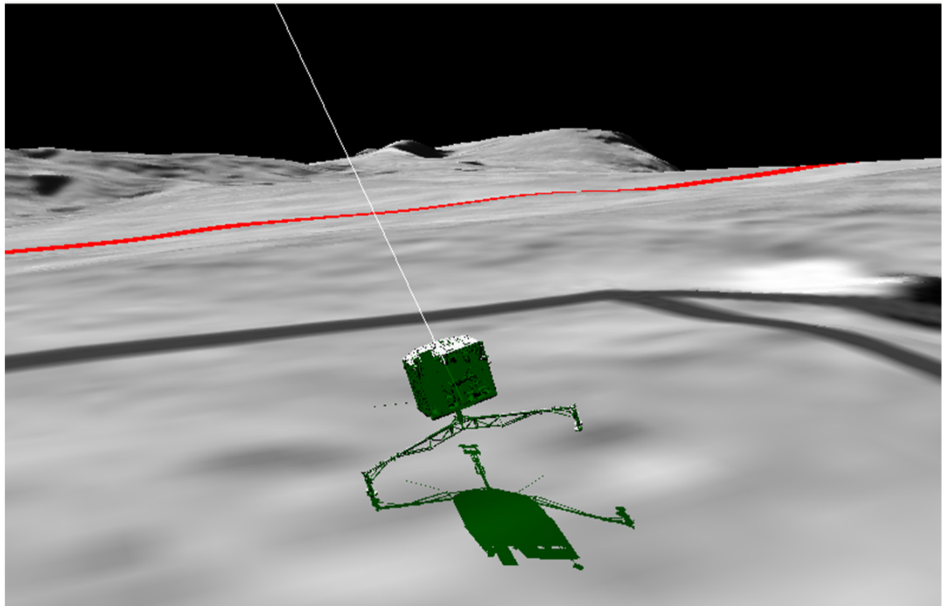


Touchdown signals at Agilkia.
Black: vertical acceleration of the +Y foot;
CASSE, sampling rate: 5 kHz @ 8 bit, acceleration peaks clipped by ADC.
Red: position of damping tube; linear potentiometer,
read-out intervals 10…100 ms, read-out terminated at 188 mm position.
Blue: combined data with a higher systematic uncertainty.
Note:

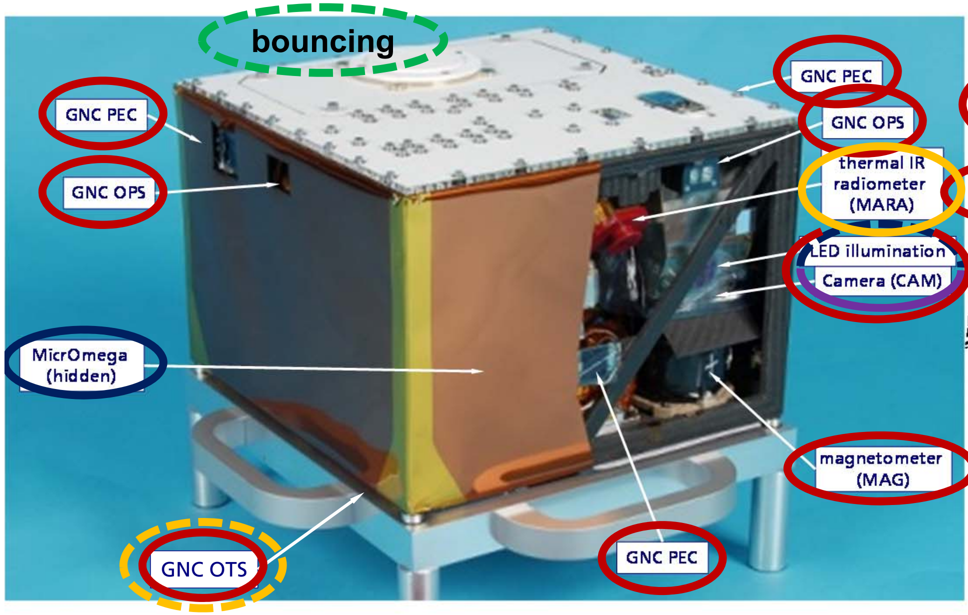
- velocity before deceleration ~1 m/s
- 200 → 198 mm in 0.250 s ≈ 0.008 m/s
- 198 → 188 mm in 0.156 s ≈ 0.064 m/s
- velocity after bouncing off ~0.38 m/s

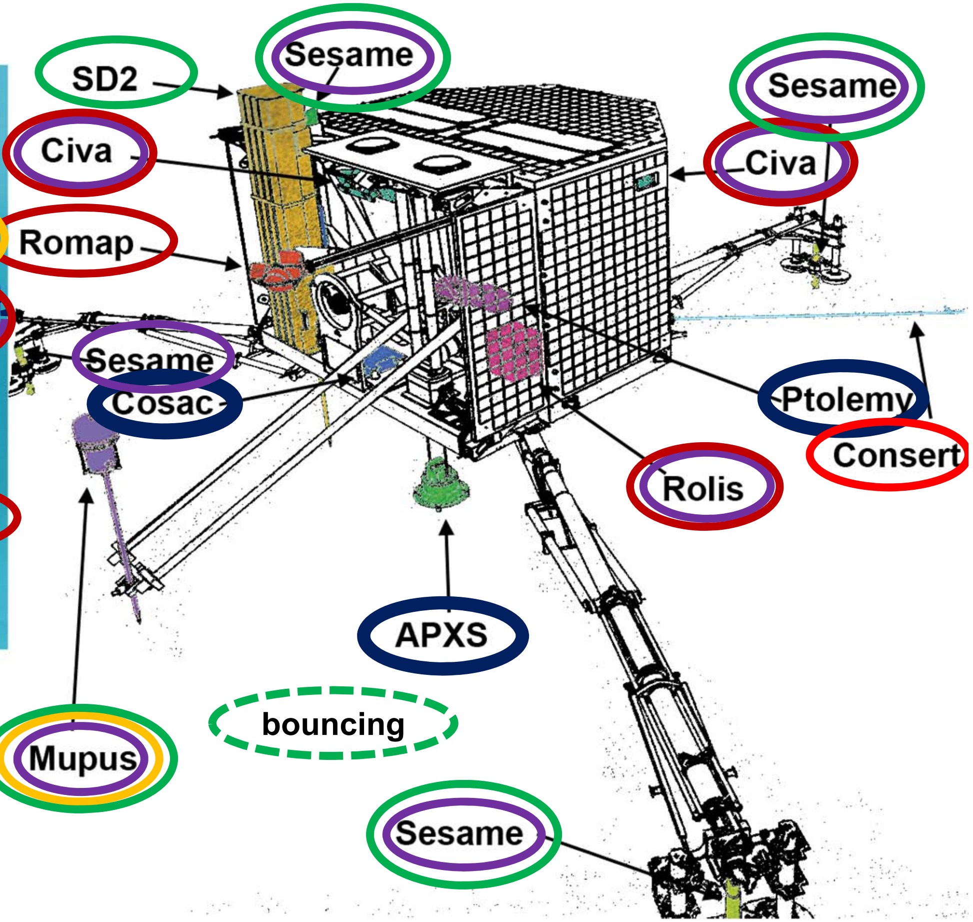
surface impact response…

- a first constraint on internal cohesion
- time profile indicates depth profile of regolith, granularity, cohesion (overlaid)
- with footprint photography, indicates mobility of rubble and/or dust layers
- records sliding against boulders …



more on the target – lander instruments





target body properties addressed…

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

a ***β*** *understanding of small solar system body materials*

→ **kinetic impact(or efficiency) modelling**

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

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all roads lead to Didymoon: AIDA – AIM & DART

AIM –
Asteroid Impact Monitoring

- determine binary asteroid orbital and rotation state
- analyze size, mass and shape of both binary asteroid components
- analyze geology and surface properties
- observe the impact crater and derive collision and impact properties (requires DART)
- Narrow Angle Camera, Micro Laser Altimeter, Thermal IR Imager, NIR spectrometer
- orbit ~15 km, for DART to 100 km

DART –
Double Asteroid Redirection Test

- deflect an asteroid by kinetic impact and measure deflection better than 10%
- miss distance from target object center of mass <25 m
- impact point knowledge <1 m (AIM likely required to confirm, cf. Deep Impact flyby imagery)
- final imaging <1 m resolution
- single-string spacecraft
- one imager = navigation camera
- heritage from New Horizons, APL work on Standard Missile, LORRI

AIDA – Asteroid Impact & Deflection Assessment – the synergy of independence

- DART to strike *Didymoon*, the smaller, Ø150 m object of binary NEA (65803) Didymos in October 2022
  - >300 kg impact at 6.1 **k**m/s (yes, finally it‘s a ‘**k**‘ ! :-) expected to change Didymoon‘s period by >0.5%
- effects observation by AIM nearby before, during, after & with back-up from Earth by eclipsing binary lightcurve

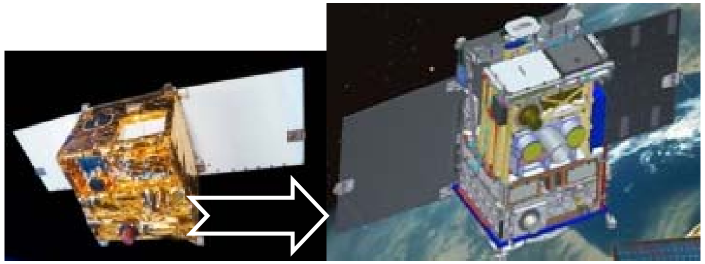
…and then you‘ll really get β !

http://esamultimedia.esa.int/docs/gsp/AIDAProjectOptions_v1a.pdf

ASTEROIDFINDER – take a daily look at what’s coming in

AsteroidFinder – closing the daytime observations gap

- observe sky at elongations of 30…60° from the Sun
- point source detection optimized, on-Si-intensified FT-CCD
- field of view ~(2 °)² , 4 * 1 Mpixel, passively cooled to -80°C
- up to 720 fields imaged per day, on-board register-stack preprocessed
- Sun-synchronous low Earth orbit – going at **7.5 km/s !** ☺
- not continued beyond Phase B2 ☹ …but keep an eye on NEOcam! ☺

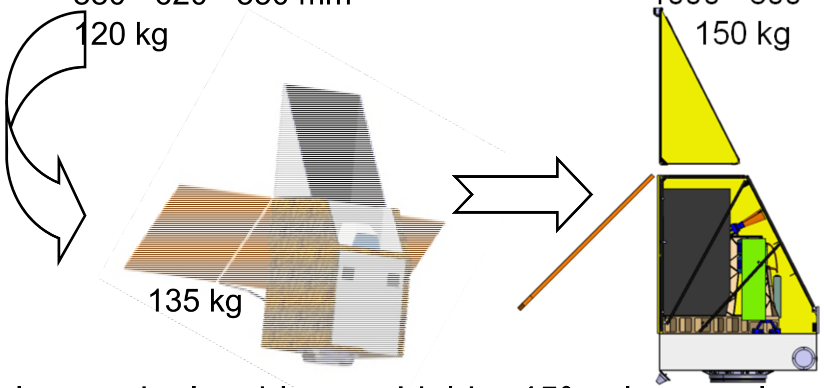


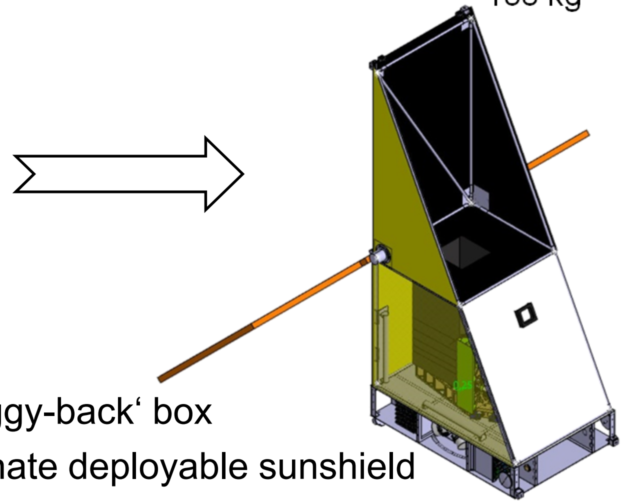
BIRD
22. Oct. 2001
620 · 620 · 550 mm³
92 kg

TET
22. Jun. 2012
880 · 620 · 550 mm³
120 kg

AsteroidFinder(/SSB)
‚piggy-back‘ launch
1000 · 800 · 800 mm³
150 kg

AsteroidFinder
dedicated launch
2120 · 1000 · 800 mm³
138 kg



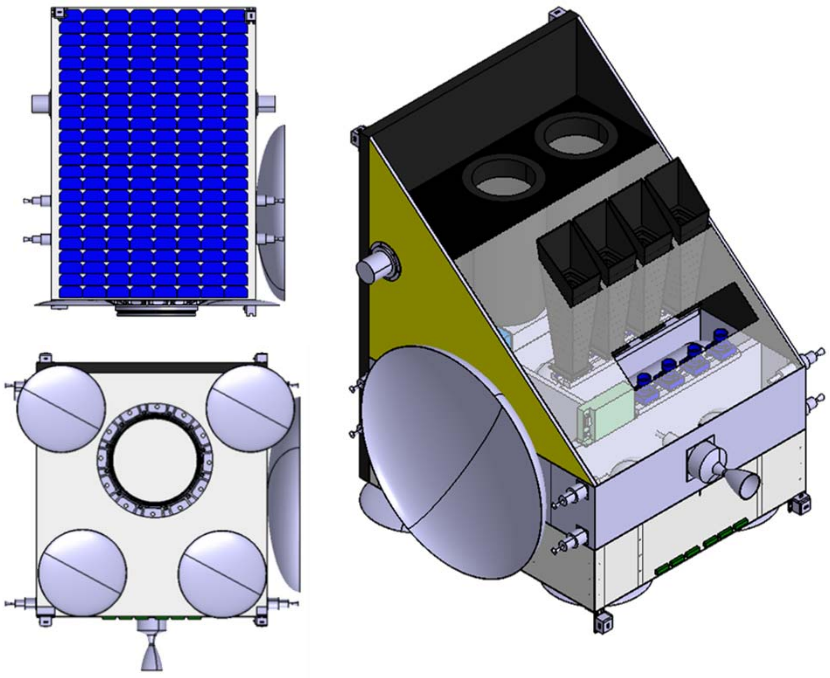


1st iteration: TET envelope + deployable sunshield + 45° solar panel

2nd iteration: TET-driven smallest common denominator ‚piggy-back‘ box

3rd iteration: dedicated launch & eliminate deployable sunshield

ASTEROIDSQUADS/*i*SSB – oh, wait, there's another one coming!



Practice makes perfect

- simplified derivate of 2nd & 3rd AsteroidFinder iteration, keeping piggy-back envelope
- added propulsion ~450 m/s
- pick a large launcher that needs a lead bag test payload
- launch test profile: likely GTO
- take a lighter payload to reach escape velocity plus a little bit, **~11.2 km/s**
- let the launcher test timeline pick the target
- *no science criteria in target asteroid selection*!

Dimension	1m x 0,78m x 0,7m
Sunshield	50 degree
Mass	179kg for Δv ~450 m/s 200 kg for Δv ~800 m/s
Payload	2 x High Resolution Cameras 4 x Middle Range Camera 4 x Wide Angle Camera
Communication	1 x Ka-band antenna 2 x X-band antenna 4 x Interlink antenna
ACS	Propulsion (8 x 1N thrusters, 1x 400N thruster)

integrate needs for launch vehicle tests, guidance testing, operations training, civil defence exercises

- combine necessary but for a standalone stakeholder sometimes inconvenient or expensive activities
- connect end-to-end, telescope to impact flash analysis, planetary defence exercise with real game input
- drive for cheap, short flight time, ≤ ~90 days mission – *a brief but complete experience*

not an official project – done as a 2-weeks spare time concurrent engineering exercise for the PDC2011

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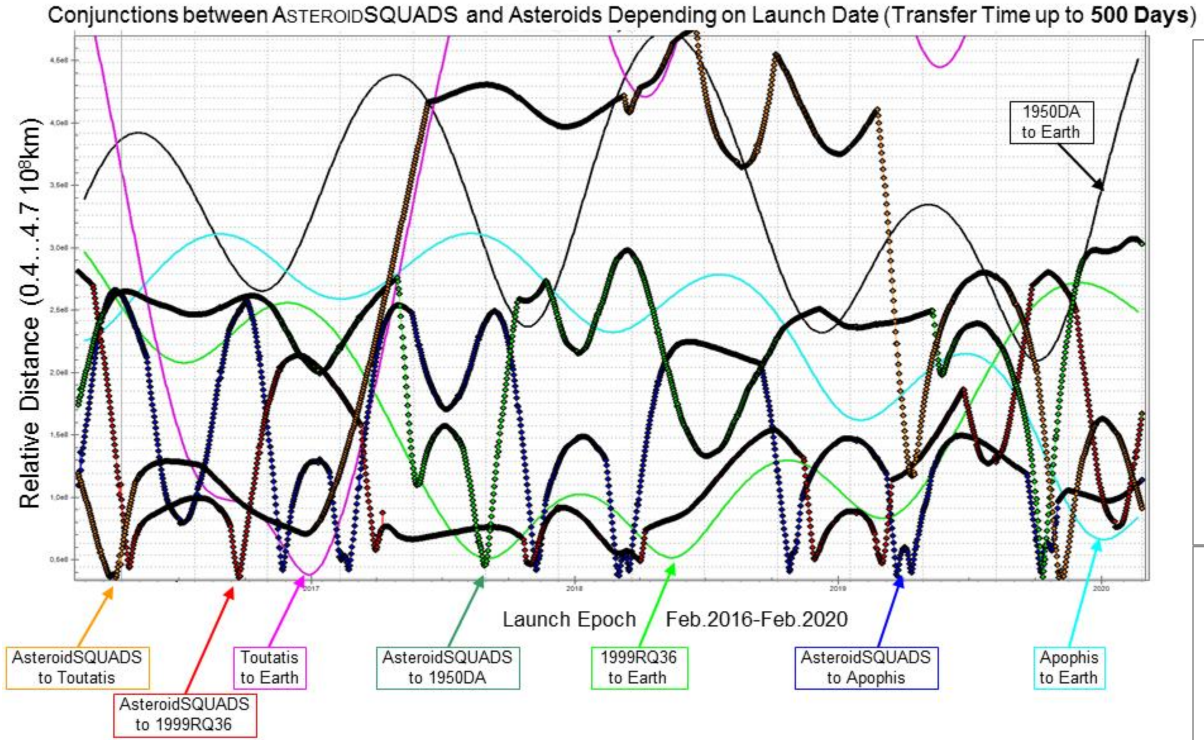
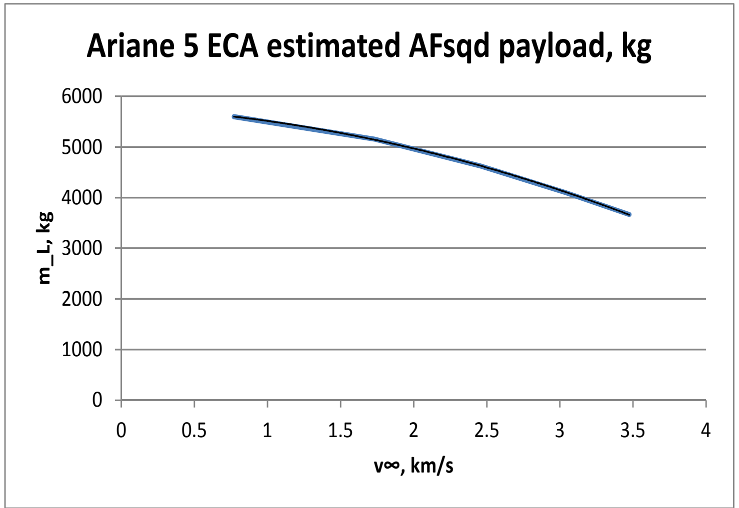
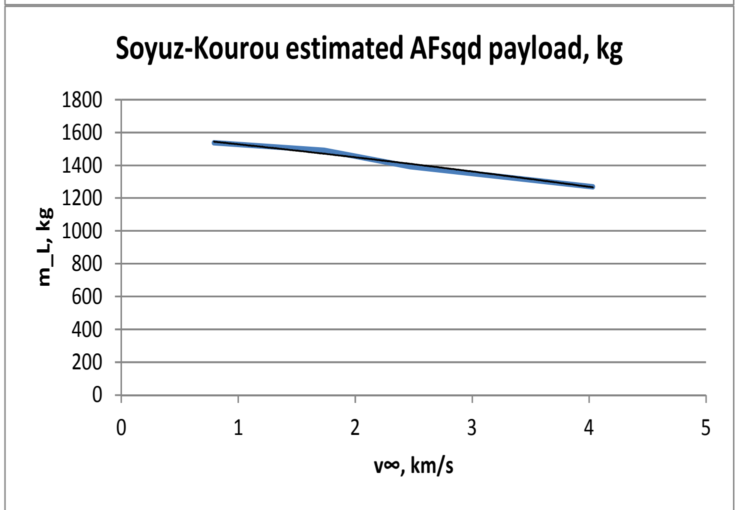
ASTEROIDSQUADS/*i*SSB – more things to follow







science <u>not</u> excluded

- design can be adapted for most escape-capable launchers
- planetary & HVI science can 'join up' at any point
- interplanetary piggy-back rides happened
- …maybe just wait for an opportunity

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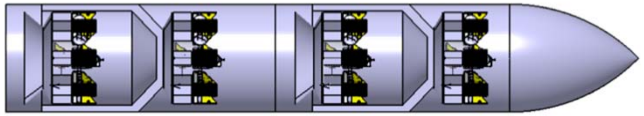
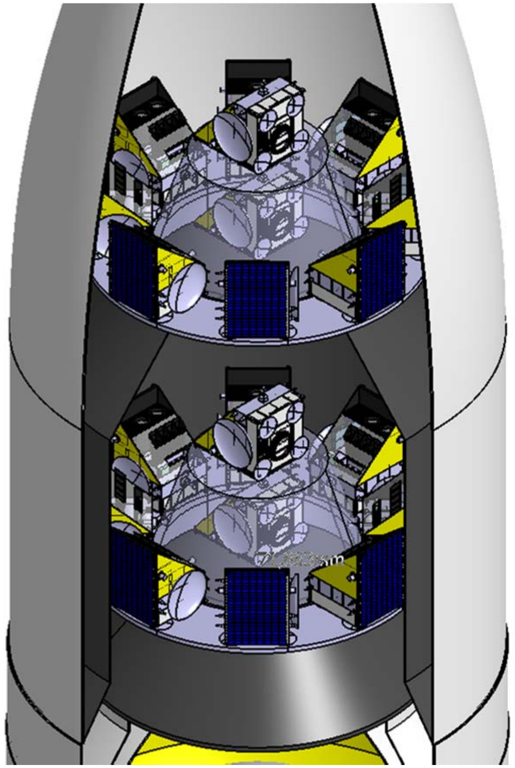
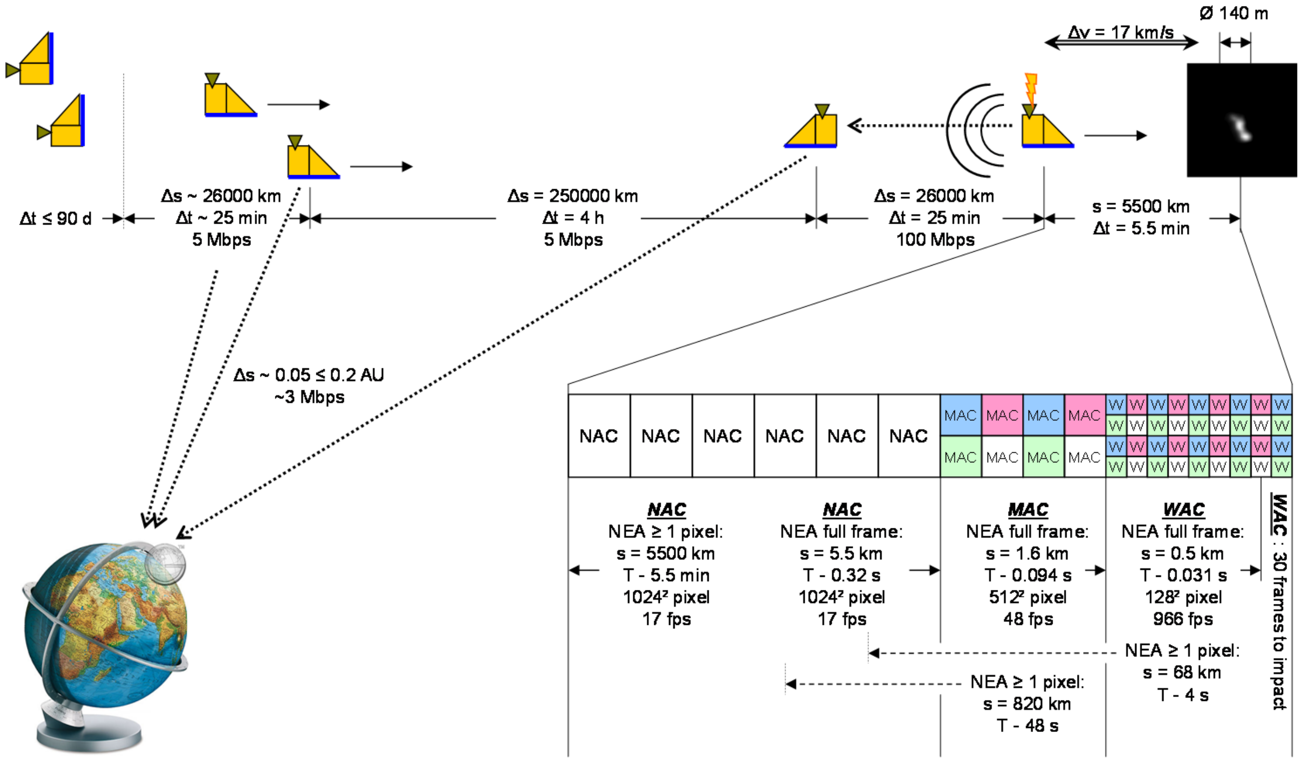


ASTEROIDSQUADS/iSSB
– ?? …and another one,… …and…!?





take as many as you like (or the launcher lets you have up there at C_3 >0)

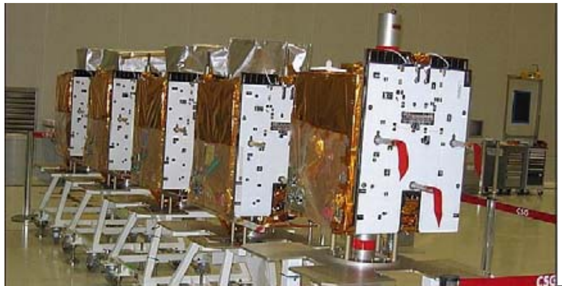
- use standard secondary payload infrastructures, e.g. ASAP or ESPA
- use spent final-velocity launcher items as kinetic impactor mass: upper stage, dual-launch structures, etc.
- just get in the way of a randomly selected asteroid, average Earth intersection velocity difference **23 km/s**

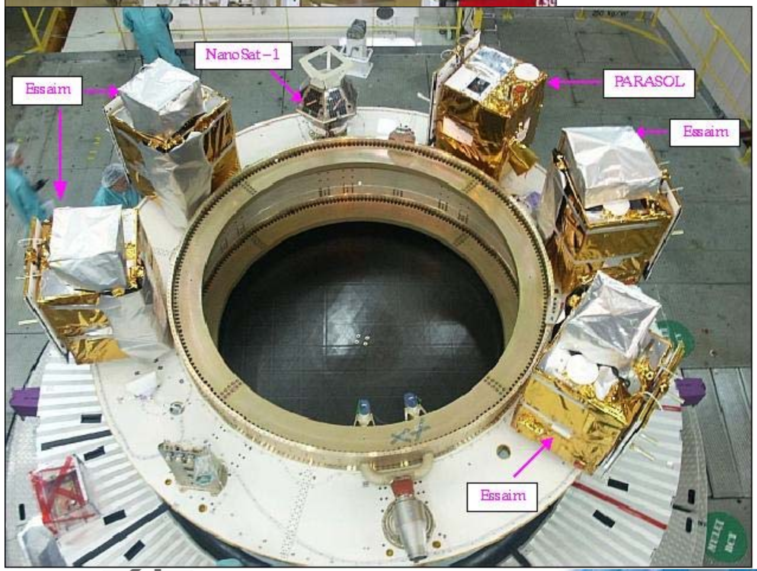
…and then you might get a lot β ;-)

Why small spacecraft? – well, you might as well ask…

Why get a really fast launch?

Why get a really cheap launch?



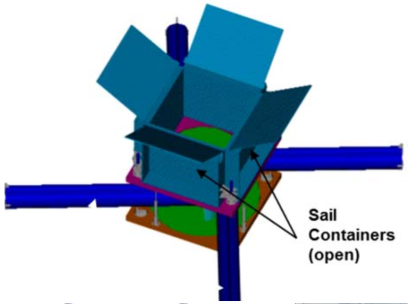


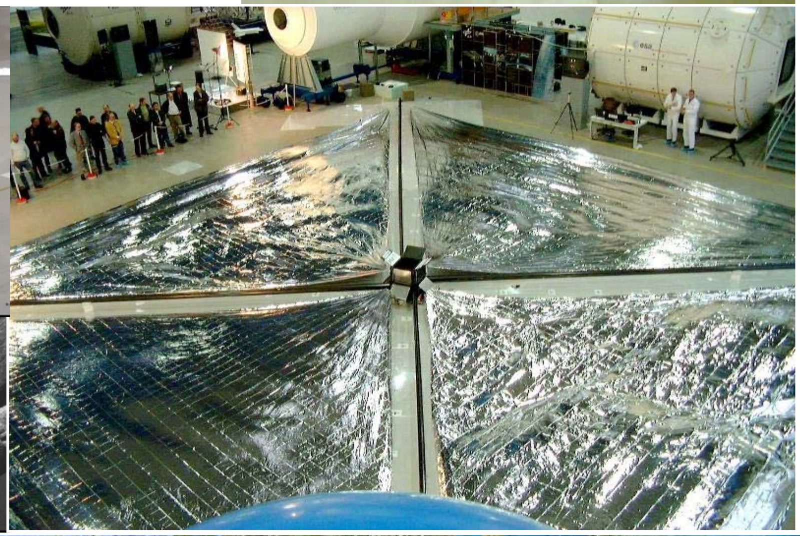
images: NASA, eoportal.org

The December 7th,1999 DLR/ESA Solar Sail Ground Demonstration

(20 m)² push-out boom, hoisted sail

- you need space – the European Astronaut Center hall next to the ISS model
  - Deployment Module: 24 kg
  - CFRP booms (4 x 14m, 101 g/m): 6 kg
  - Sails (20 m)², 4-12 µm foil: 5 kg
  - Dimensions: 60cm x 60 cm x 65cm





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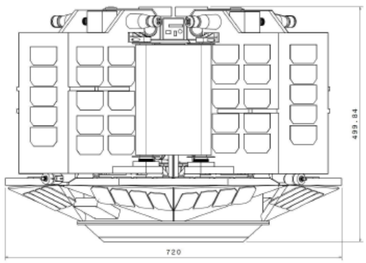
images: W. Seboldt

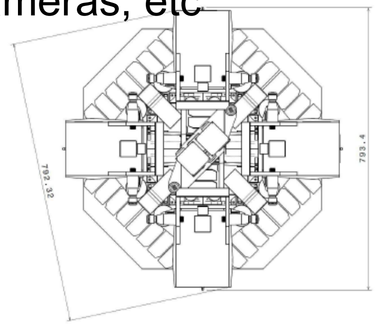
The 3-Step DLR-ESA GOSSAMER Road to Solar Sailing

The GOSSAMER Roadmap
step 1 – deployment

GOSSAMER-1 – in-orbit deployment demonstrator

- (5 m)² sail area, all deployment-related mechanisms
- 1-boom, 2-quadrant EM in operation * →
- 1-boom EQM under construction now for extensive qualification testing to be finished by end of 2015
- proven MASCOT-style concurrent AIV approach **
- PFM detailled design progressed beyond PDR
- free-flyer independent spacecraft (really 5-in-1)
- "piggy-back" launch to LEO, <50 kg total ↓
- extensive instrumentation: 6 hi-res video cameras, etc.



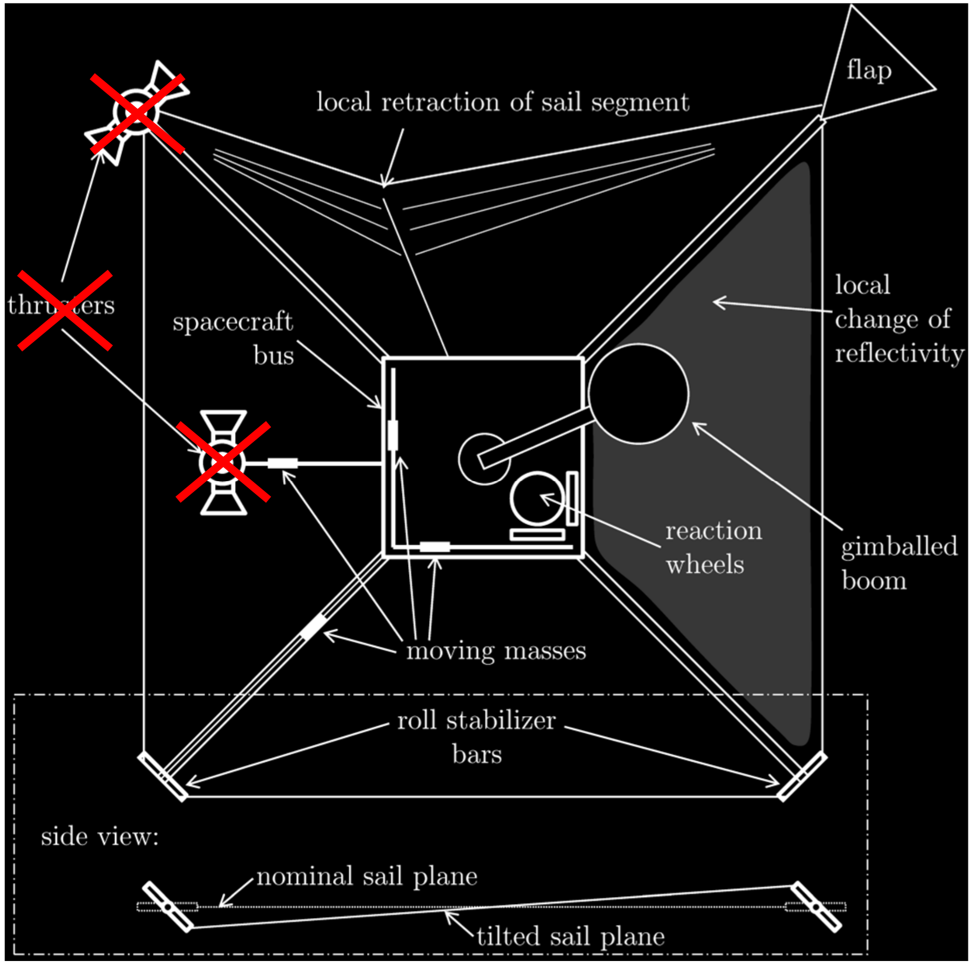


* IAA-PDC-15-P-**20,** *P. Seefeldt et al,* Large Lightweight Deployable Structures …

** IAA-PDC-15-P-**66,** *C.D. Grimm et al,* On Time, On Target – …

images: P. Seefeldt

The GOSSAMER Roadmap
step 2 – control



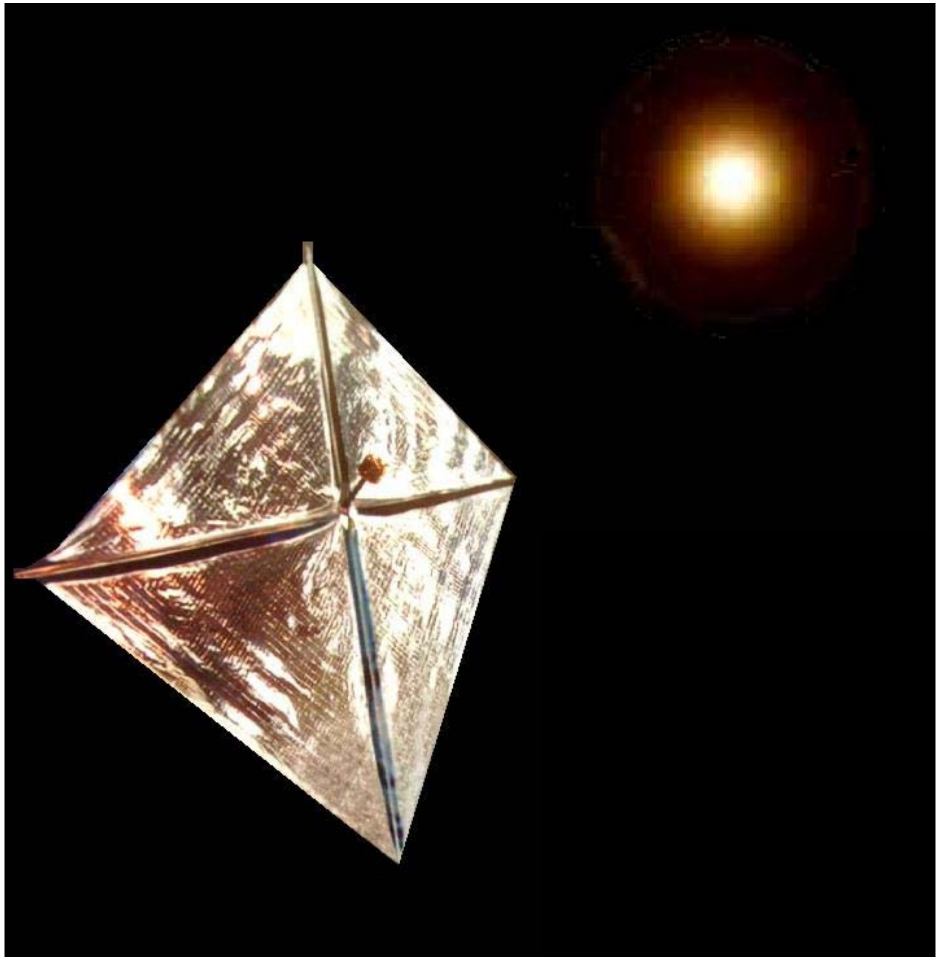
GOSSAMER-2 – in-orbit attitude & thrust vector control demo

- (20 m)² sail area
- orbit where solar radiation pressure is dominant – high LEO, MEO, GTO
- implementation of several (all?) control methods and all relevant mechanisms
- **find out what's the best – 1, 2,…, many combined?**
- ~2 years after GOSSAMER-1 flight: requires MASCOT-style concurrent AIV & project management *
- PFM free-flyer for "piggy-back" launch
- mass & undeployed size compatible with ASAP-micro & ESPA envelopes

* IAA-PDC-15-P-**66,** *C.D. Grimm et al,* On Time, On Target – How the Small Asteroid Lander MASCOT Caught a Ride …

sail drawing: B. Dachwald

The GOSSAMER Roadmap
step 3 – proving the principle

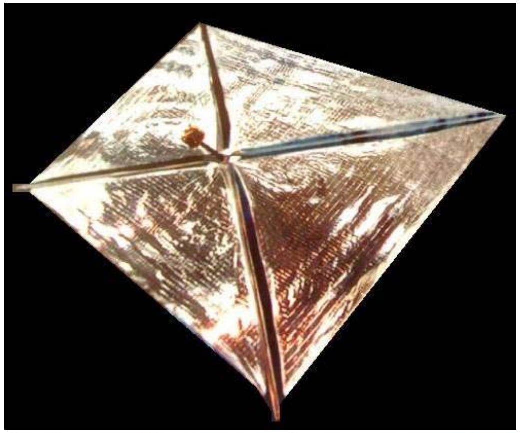


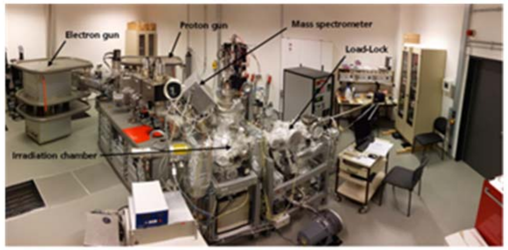
GOSSAMER-3 – all-up proof test science mission readiness demonstrator

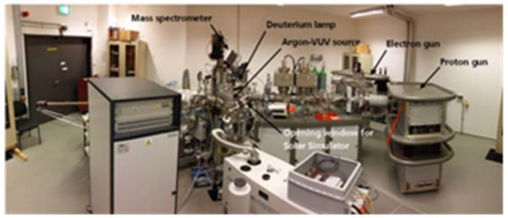
- (50 m)² sail area
- initial orbit high enough to spiral out (sail up) – high LEO, MEO, GTO, LTO, $L_{1/2}$TO
- applies best control method(s)
- **prove that sails can operate science missions successfully**
  - ***tiny* science payload: small imager & sail-environment interaction**
- ~2 years after GOSSAMER-2 flight: again, MASCOT-style concurrent AIV*
- PFM free-flyer for “piggy-back” launch
- mass & undeployed size compatible with ASAP-micro & ESPA envelopes
- **instrumentation to observe sail ageing in space, as long as it lasts**

* IAA-PDC-15-P-**66,** *C.D. Grimm et al,* On Time, On Target – …

GOSSAMER-3 quality assurance – sail monitoring, pointing verification







GOSSAMER-3 – instruments wish list

a *tiny* **science**(…-like) payload to **observe sail ageing** *

- wide-angle camera to observe **sail deployment and long-term foil behaviour** and provide **proof images for attitude control, pointing stability & accuracy**
- sensor to observe **interaction of a sail with solar wind's & geomagnetic field**
- sensor to observe **plasma, particle and energetic radiation sail environment**
- sensor to observe **large area foil reflectivity ageing**, e.g. **thermal equilibrium**
- sensor to observe **small-scale space weathering mechanisms of foil ageing**
- sensor to observe **core spacecraft (electronics)** electro**magnetic signature**
- sensor to observe **illumination changes and Sun glints off the sail surface**
- sensor to register **space debris and natural dust impacts on the sail foil**

* IAA-PDC-15-P-**20**, *P. Seefeldt et al,* Large Lightweight Deployable Structures for Planetary Defence: …

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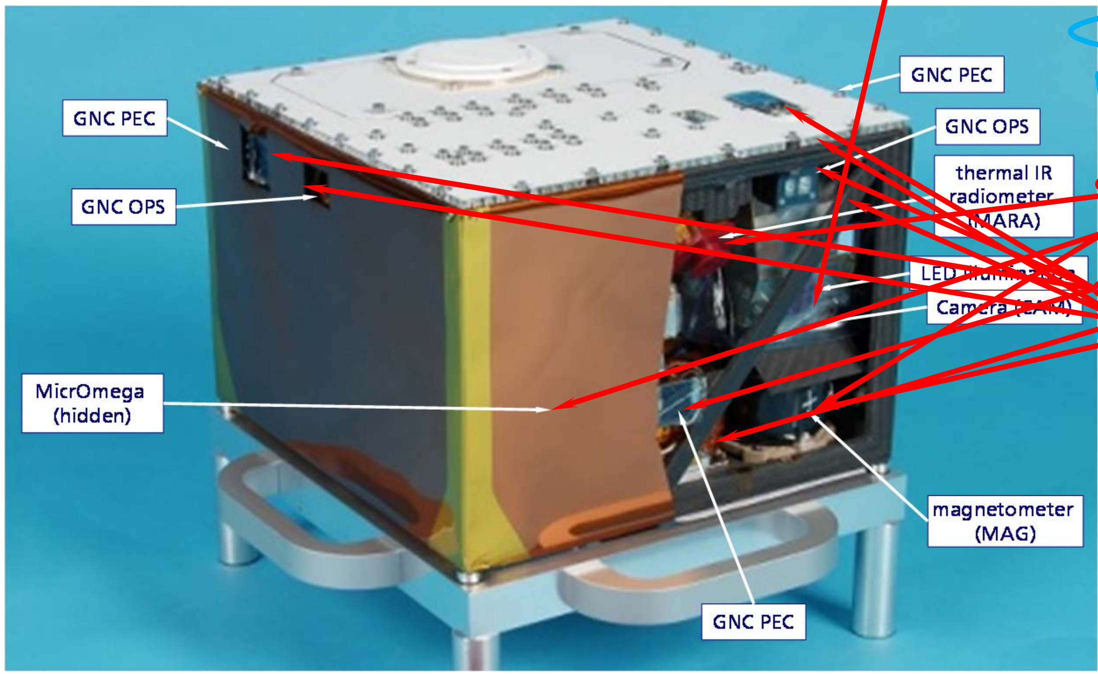
GOSSAMER-3 quality assurance – oh! ☺ , a ready-made*** instruments package !?

*MASCOT Flight Spare instruments capabilities***

a *tiny*(…-like ;-) **science** payload**,*** to **observe sail ageing** *

- wide-angle camera to observe **sail deployment and long-term foil behaviour** and provide **proof images for attitude control, pointing stability & accuracy**



- **interaction of a sail with solar wind's & geomagnetic field**
- **plasma, particle and energetic radiation sail environment**
- **large area foil reflectivity ageing**, e.g. **thermal equilibrium**
- **small-scale space weathering mechanisms of foil ageing**
- **core spacecraft (electronics)** electro**magnetic signature**
- **illumination changes and Sun glints off the sail surface**
- **space debris and natural dust impacts on the sail foil**

GOSSAMER-3 instruments left to be added

⊕ additional MAG instrument, 2 sensors spaced by ~1 m at 1 or 2 boom ends

⊕ e.g. Spherical EUV and Plasma Spectrometer (SEPS), 2 on opposite booms

⊕ e.g. acoustic pick-ups at rigging nodes, structural vibration accelerometers

* IAA-PDC-15-P-**20**, *P. Seefeldt et al,* Large Lightweight Deployable Structures for Planetary Defence: …

** IAA-PDC-15-P-**64,** *J.T. Grundmann et al & the MASCOT Team*, Mobile Asteroid Surface Scout (MASCOT) –…

*** IAA-PDC-15-P-**65,** *C. Lange et al,* Technology and Knowledge Reuse Concepts to Enable Responsive NEO Characterization …

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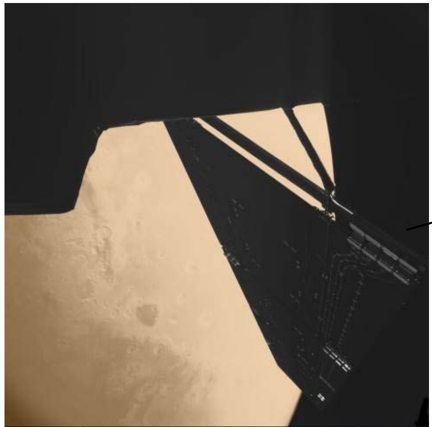
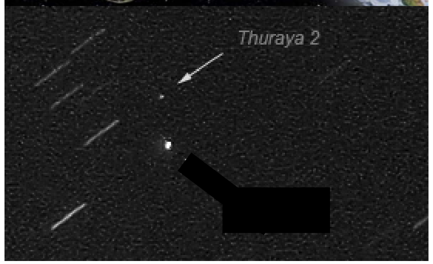
why not GOSSAMER-3 & MASCOT FS ? – a mission events wish list*



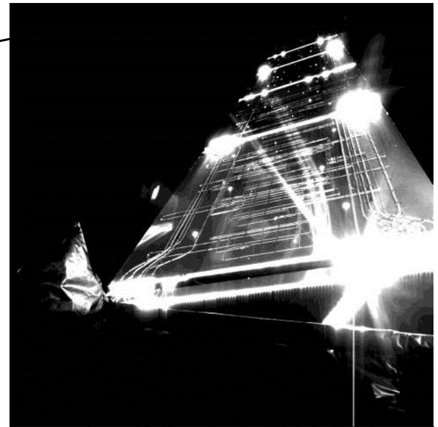


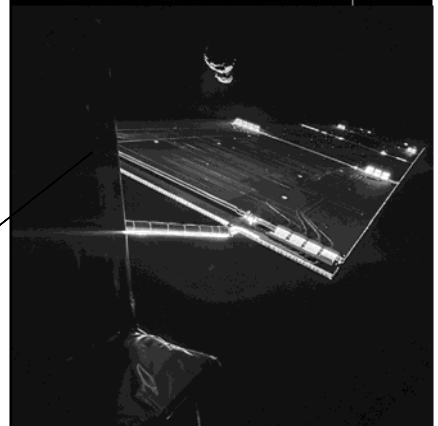
minimum mission
- get launched cheap, deploy & spiral up
- explore & improve sailing skills
- fly-by visit a target on time & look at it right

nominal mission
- explore practical flying in Earth-Moon system
- "all-up" navigation accuracy proof test
- low-altitude lunar gravity-assist fly-by

extended mission
- transfers to Earth-Sun L_1, L_2 & pole-sitter
- demonstrate spaceweather Displaced- L_1

extended extended mission
- fly out to a convenient NEA – coorbital?
- rendezvous & drop MASCOT FS
- …some grand finale…





* IAA-PDC-15-**04-17**, *J.T. Grundmann et al*, From Sail to Soil – Getting Sailcraft Out of the Harbour on a Visit to One of Earth's Nearest Neighbours

not an official project – done as a 4-weeks spare time concurrent engineering exercise for the PDC2015

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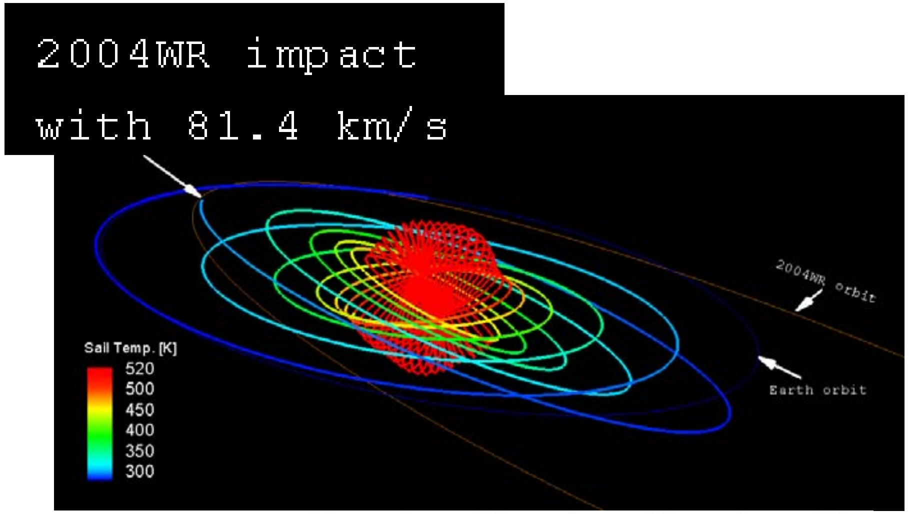
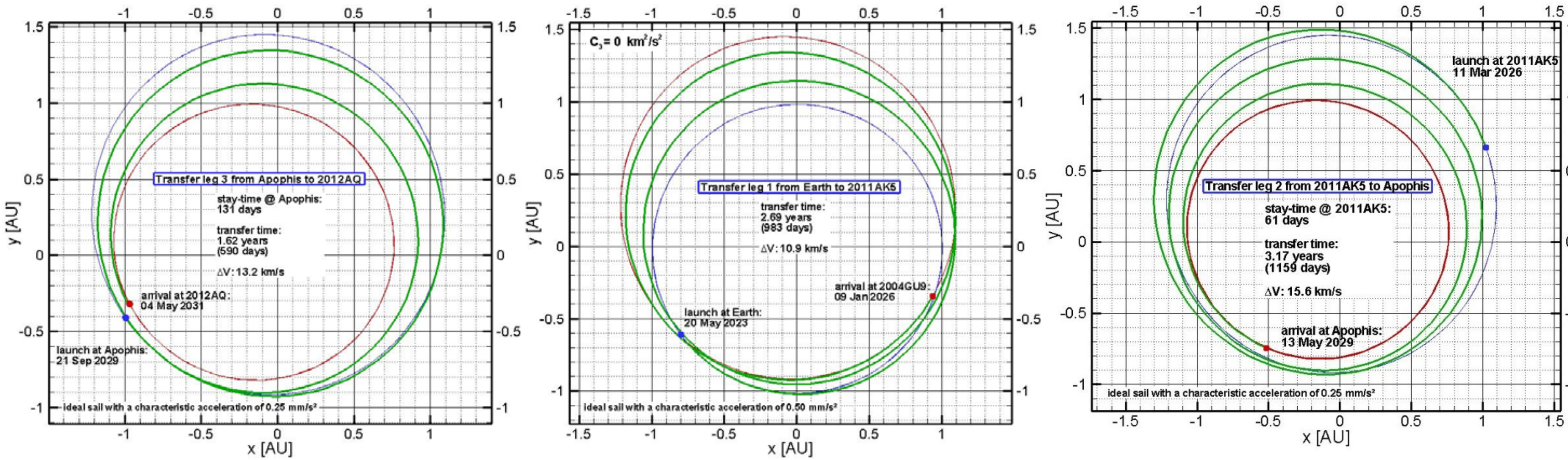
additional images: Boeing BSS via Gunter's SP, M. Langbroek

Why solar sailing? – well, you might as well ask…

Why a 300 kg piggy-back launchable >75 km/s Kinetic Impactor?

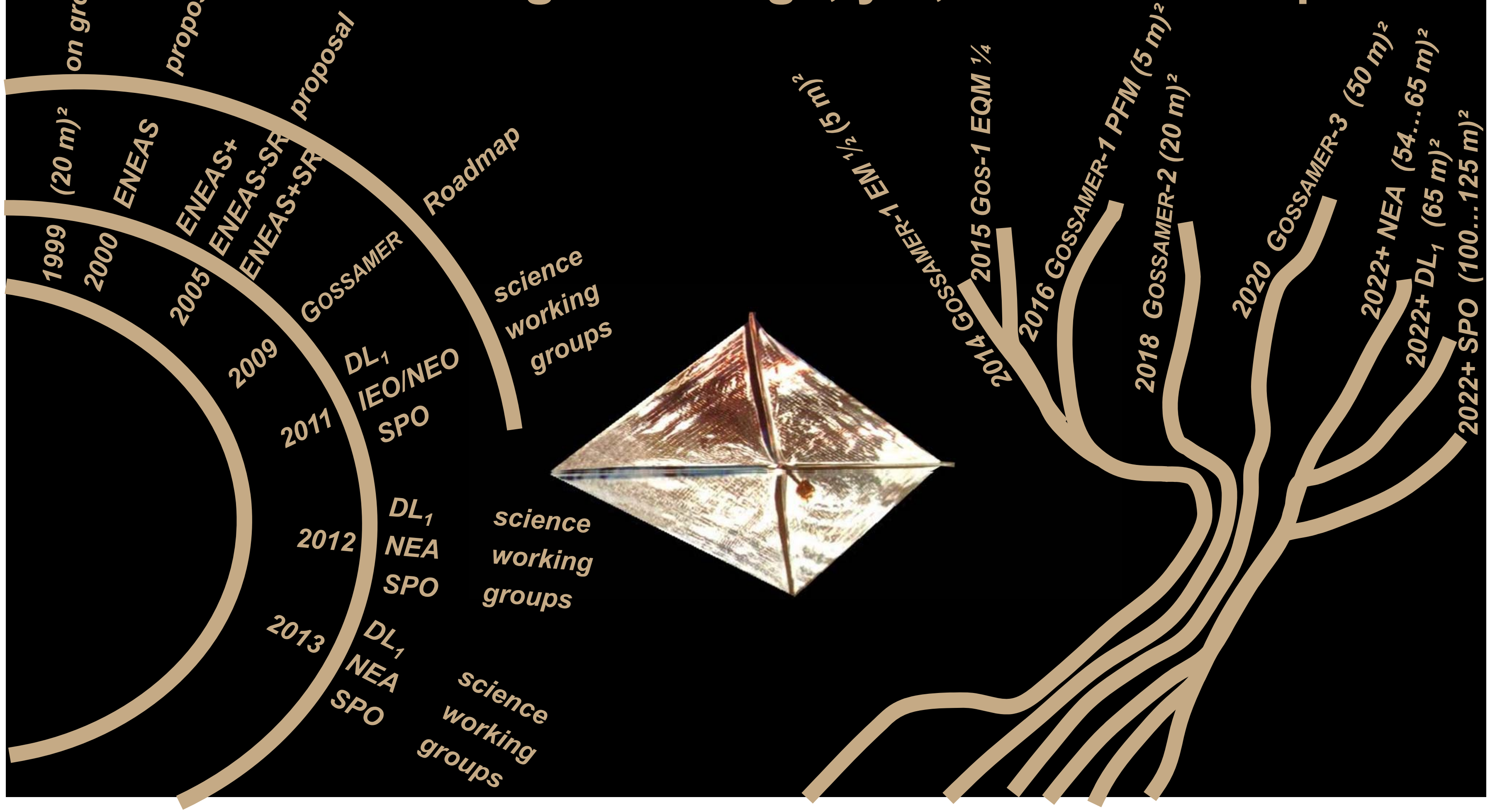


Why rendezvous
3 NEAs in <10 years?
(sample-return option included)



trajectory plots: B. Dachwald

solar sailing at DLR – no flight heritage, yet, but a roadmap…



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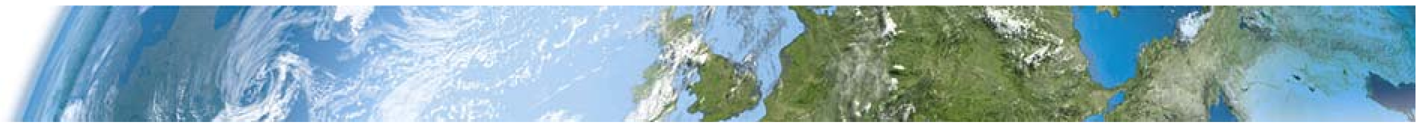


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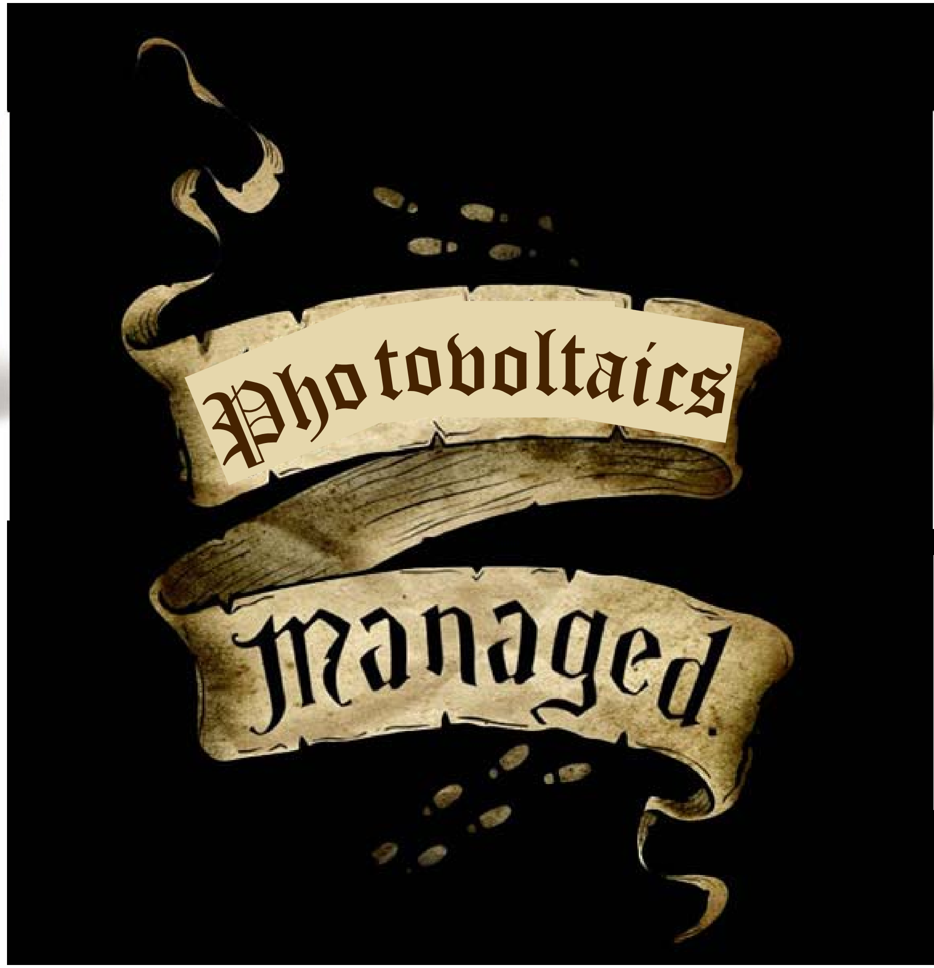
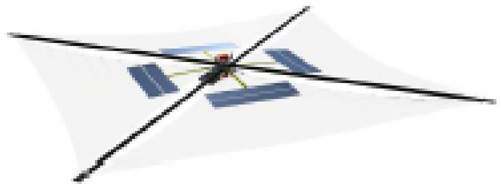
BREMEN
The
GOSSAMER
ROADMAP
Lorna '12

the GOSSAMER Roadmap for Solar Sailing – *an Epilogue*





…to save a bit of it. ☺

<u>*note & remember*</u>: 100 feasibility studies → 20 detailed designs → 1 flight

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Questions?

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