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

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Prologue
A Winter Fairy Tale…

…that really happened
... 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 apartment blocks, 718 educational institutions, 293 hospitals and polyclinics, 100 cultural institutions, 43 sports sites damaged to require urgent repairs, renovation, restoration. The 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)
“Today, we didn’t just land once,...”
– the landings of PHILAE

- launched March 2\textsuperscript{nd}, 2004 aboard ROSETTA
- target 67P/Churyumov-Gerasimenko
- arrived on August 6\textsuperscript{th}, 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
  - $v_{\text{esc}} \approx 0.5 \ldots 1$ m/s
  - final landing Nov. 12\textsuperscript{th}, 2014 17:32 UTC
- complex landing gear ☺
- energy absorbers ☺ & anchoring (failed)
- hold-down thruster (out of gas...)
**PHILAE – lost & found**

- primary mission science program success
- 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!
diving down to Ryugu

- 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
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
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

SPS Trojan lander strawman payload power-time & energy profile

- 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
GOSSAMER-1
characteristic acceleration estimation

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

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

→ Constraints driven design!
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 < 2.4
• 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
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 $i >> 60^\circ$
- 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-multipled CCD ASTEROIDFINDER camera is good at tracking NEAs
- ... add terminal guidance & propulsion