Landing Analysis during Proximity Operations at Near Earth Asteroids: Applications to Post-Hayabusa Missions

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Background & Proximity Operations Objectives

- The post-Hayabusa missions are looking to bring back samples from Near Earth Objects.
  - In doing so, target markers are to be deployed for navigating close to the surface, and science lander(s) will perform in-situ measurements to complement the mothership science returns (ex: MINERVA, MASCOT)

In particular, the Proximity Operations Objectives are:

- To perform shape and gravity determination by
  - Measuring solar radiation pressure perturbations
  - Performing Radio Science Experiment to refine the target gravity field
  - Obtaining a 3D reconstruction of the target using onboard cameras
- To map the target surface by
  - Identifying landmarks, faults, size of surface features, surface composition, etc. using onboard instruments
- To identify sampling sites and prepare for deploying probes/landers on the surface

Physical Parameters of Targets Studied: Wilson-Harrington and 1999 JU3 types

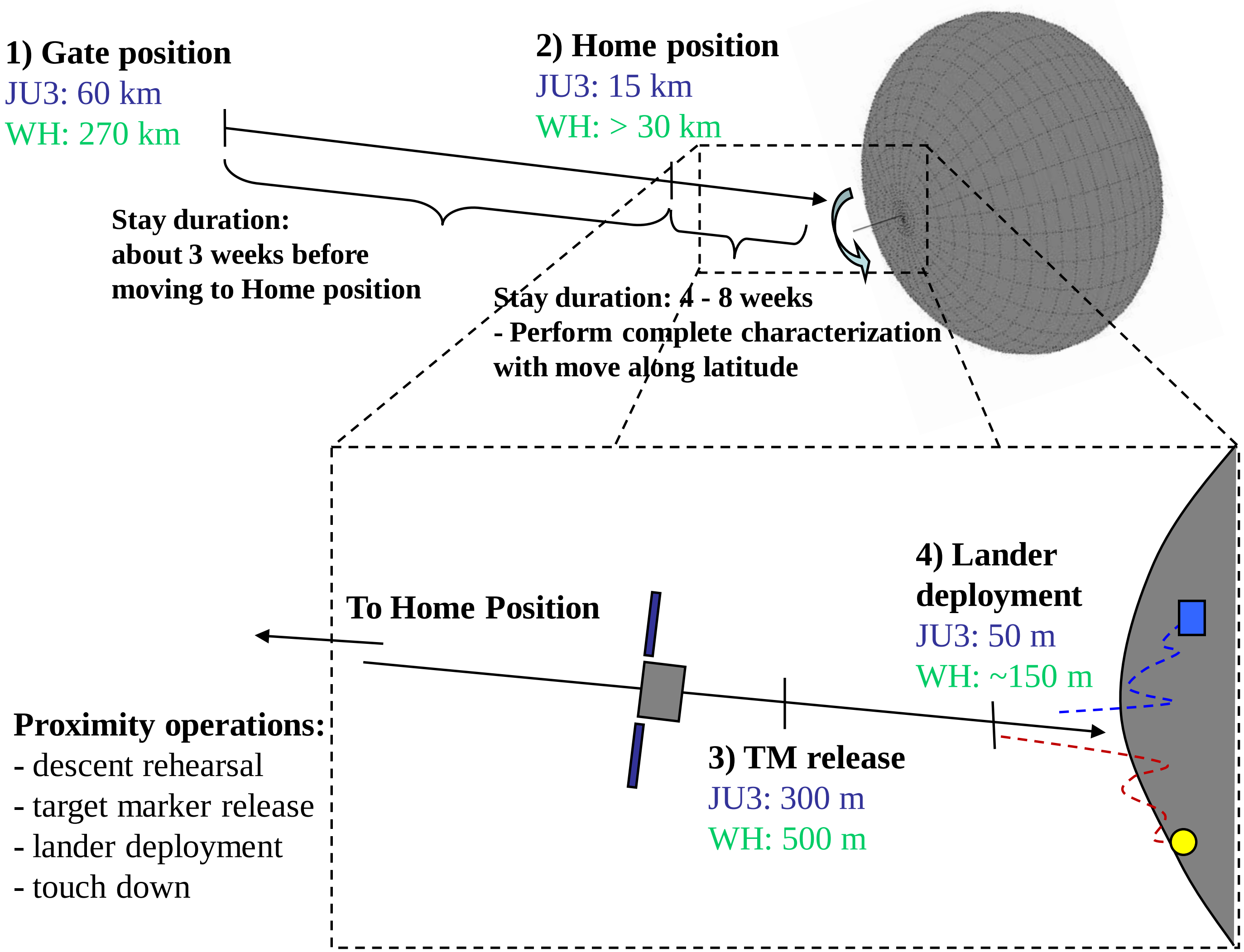
Parameters	Wilson - Harrington	1999 JU3	Itokawa (as a reference)
Asteroid (radius values [a,b,c] in km)	[2.2, 1.8, 1.8]	[0.46, 0.39, 0.35]	[0.28, 0.15, 0.12]
Asteroid density (g/cm^3) [Baseline assumed]	1	1.3	1.9
Spin period (hrs)	6.1	7.63	12.1
Spin axis (J2000)	90*	(330, 20)	(128.5, -89.66)
Equilibrium points/Resonance radius (km) (distance from the center of mass)	± 3.0; ± 2.85 / 2.90	± 0.78; ± 0.76 / 0.76	± 0.51; ± 0.48 / 0.485
Altitude of stable direct orbit (km) (distance above the local surface)	3.54	1.00	0.75
Tangential velocity on the stable direct orbit (cm/s)	92	20	8
Escape velocity from local surface (cm/s)	135	32	14
Safe impact speed assumed (cm/s) (50 % escape velocity)	67	16	7
Maximum altitude derived for deployment, with a release speed of ~ 5 cm/s (m)	500	150	25

• TBD

Blue area: derived properties for landing study

source: M. Abe, JAXA/ISAS

Rendez-vous Timeline



To briefly detail the sequence of events leading to proximity operations:

1) After some rendezvous maneuvers, the mothership is to stay at the Gate Position for preliminary observations.

2) It will then move to Home Position for detailed mapping.

3) After about 2 months, descent rehearsals will be attempted, leading to the deployment of target markers for navigation.

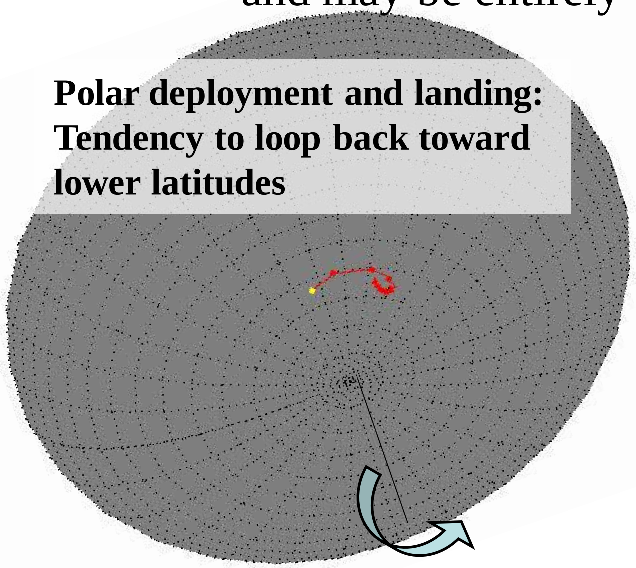
4) Landers will then be deployed, followed by the mothership touchdown to gather samples.

Preliminary Approach Assessment

- Surface features may naturally dictate where to approach the target…

However… the target dynamics give some preliminary pros and cons…

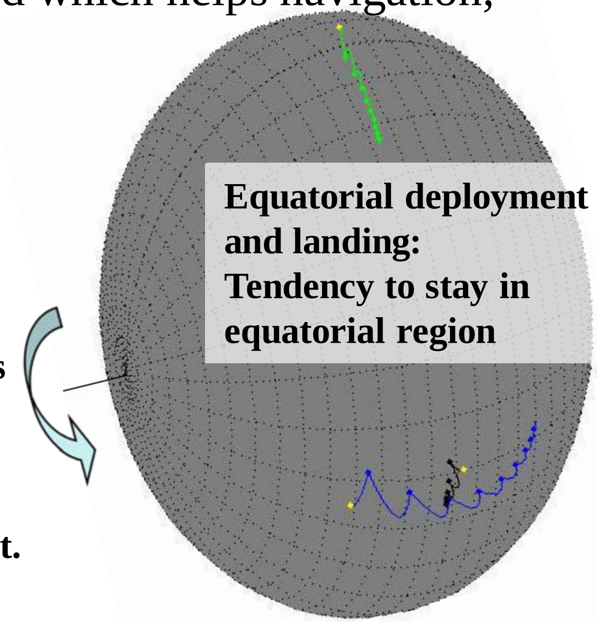
- Hovering along the target intermediate axis may give better stability (Scheeres, 2000)
  - JU3 stable resonance orbits are at ~400 m, WH has quasi stable ones at ~1km.
- Perturbations from gravity gradient are less on flatter sides.
- Loose material may gather near equatorial regions due to surface equilibria (Guibout, 2006; Bellerose, 2008)
- Polar landing are associated with slower surface speed which helps navigation, and may be entirely under sunlight.



Colored hopping trajectories are landing simulations with 80% restitution on impact (worst case) (E. Asphaug, 2006)

Yellow dots represents release locations which are 50 m above surface.

Release condition is 45 deg from the mothership, at 5 cm/s toward the target.



Deployment
Uncertainties and Assumptions

- For target physical parameters:
  - Observations of targets give effective dimensions. The type, apparent and absolute magnitude give approximate densities
    - C-asteroid (1999 JU3) vary from 1 g/cm^3 to 1.7 g/cm^3
    - Wilson-Harrington density may vary from 0.6 g/cm^3 to > 1g/cm^3

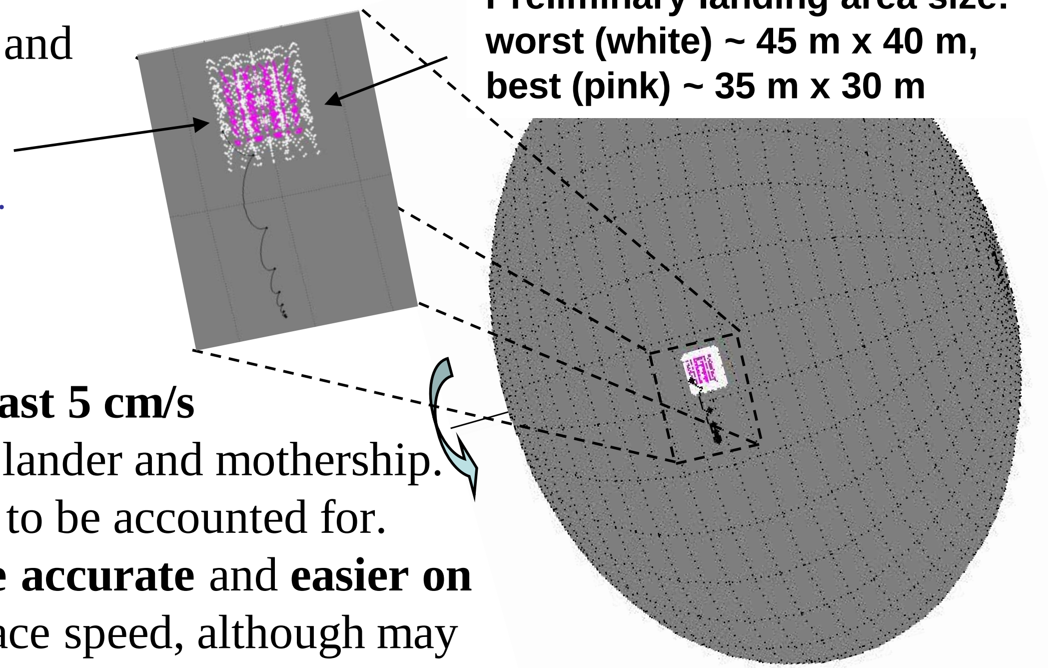
      → **It is recommended to include 20-30% margin for all proximity operations**

- Deployment errors are derived from Hayabusa… using LIDAR, Laser Range Finders (LRF), and target marker (TM) navigation.
  - The lateral and vertical velocity errors are kept within 2 cm/s and 3 cm/s, respectively.
  - The lateral position error goes up to 30 m, but could be as low as 10m.
  - The vertical position error is more accurate (even by using RCS micro-thrust to compensate two out of three RW failures), taken as 5-10 m.
    - This accounts for instruments, operations, velocity corrections by RCS, human errors, ...
  - Attitude errors vary up to 1 deg, with negligible errors on attitude rates.
  - The release speed needs to be higher than 3 cm/s.

- Other assumptions:
  - Only ballistic landing is considered for this study.

Some Results and Discussion

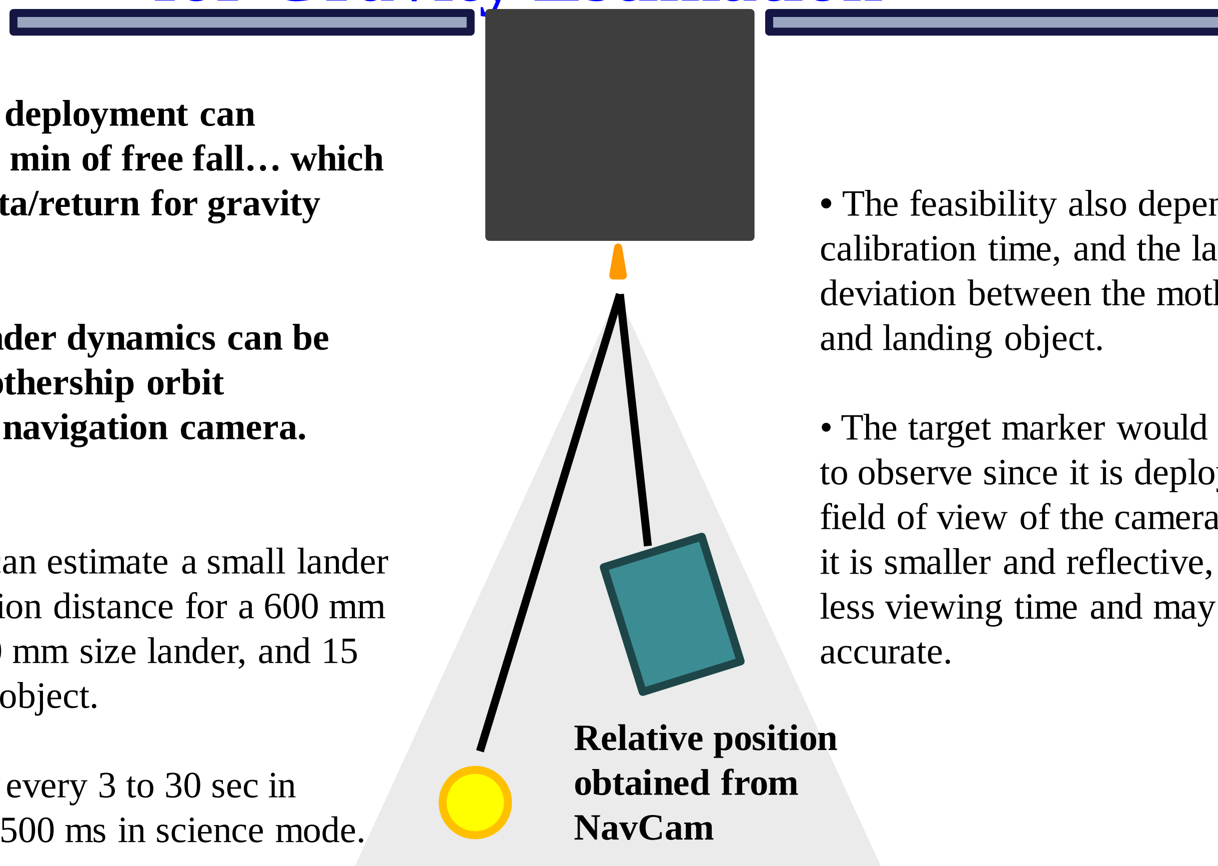
- From orbital dynamics with 50% escape velocity as maximum impact condition, the safe altitudes for deployment are taken as:
  - 150 m for 1999 JU3, 500 m for Wilson-Harrington
- To reduce the overall landing area, and further reduce impact speed, closer deployment altitudes are preferred.
- Landing analysis using simulations and linearized error propagations, gives
  - JU3: 50 m deployment,
  landing area can be as small as 35 m x 30 m.
  - WH: 1-200 m deployment,
  landing area is ~ 50 m x 45 m.



To consider…

- The **release speed** needs to be **at least 5 cm/s** toward the target for **safety** of both lander and mothership.
- A **small lateral impact** speed need to be accounted for.
- Landing near the **pole** may be **more accurate** and **easier on the GNC system** due to lower surface speed, although may require double **time for mapping**.
- Polar landing may imply **thermal control** issues.
- Equatorial regions may be “attractive”, and thus modify probes/landers trajectories.

Target Marker as Landing Probe & Lander Science Opportunity for Gravity Estimation



Target marker or lander deployment can provide between 10 to 20 min of free fall… which can give extra science data/return for gravity estimation.

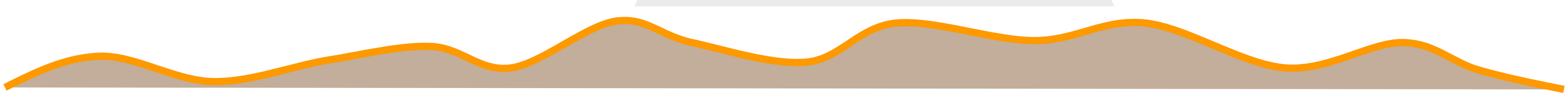
The target marker or lander dynamics can be retrieved through the mothership orbit determination, using the navigation camera.

- Using the NavCam, we can estimate a small lander motion up to 40 m separation distance for a 600 mm size lander, 30 m for a 300 mm size lander, and 15 m for a target marker size object.

- The images can be taken every 3 to 30 sec in navigation mode, or up to 500 ms in science mode.

- The feasibility also depends on calibration time, and the lateral deviation between the mothership and landing object.

- The target marker would be easier to observe since it is deployed in the field of view of the camera, although it is smaller and reflective, providing less viewing time and may be less accurate.



Courtesy: JAXA/ISAS

Thank you!

I hope you had a good symposium ☺

If you have any questions,

please email me!

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