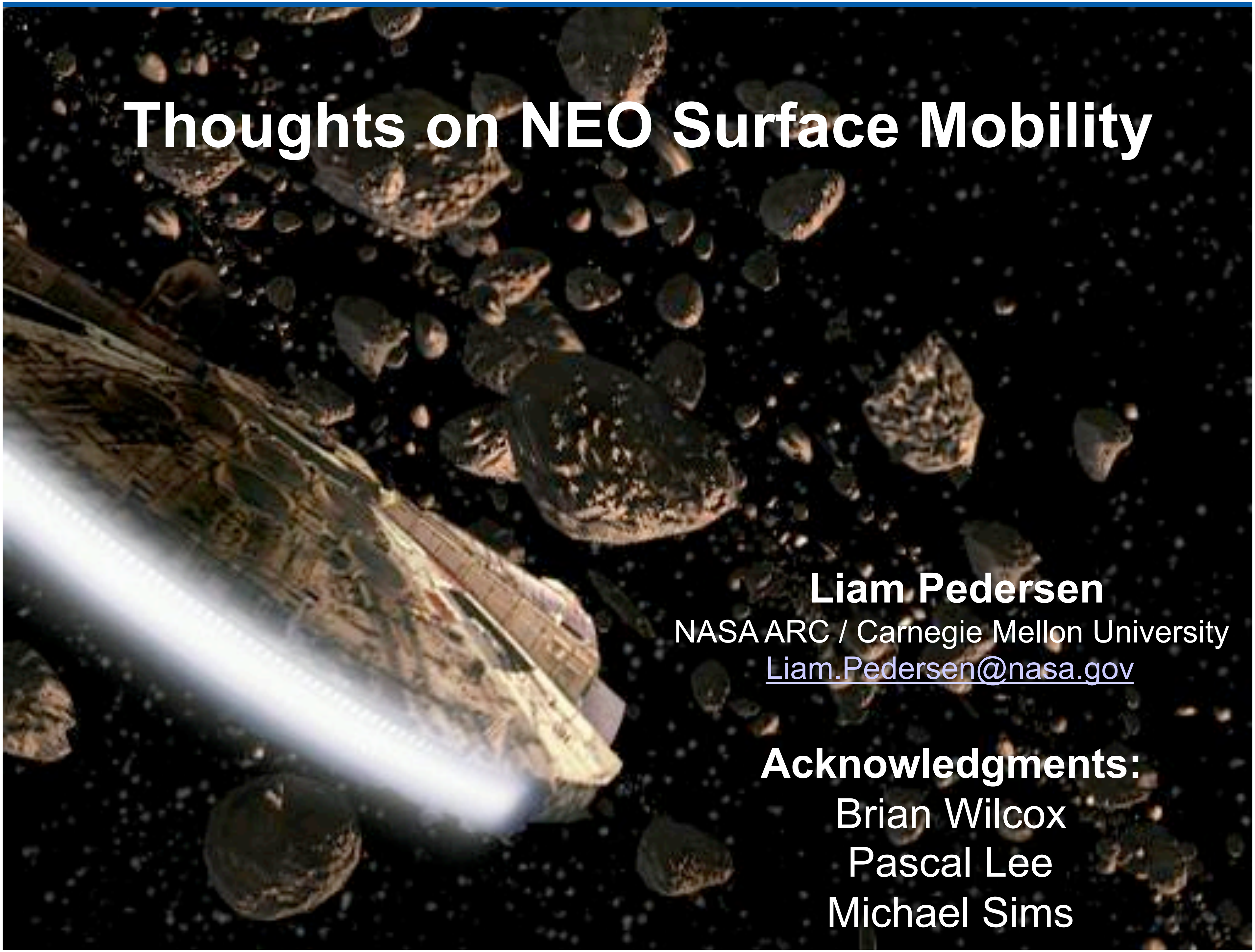


Thoughts on NEO Surface Mobility

Liam Pedersen
NASA ARC / Carnegie Mellon University
Liam.Pedersen@nasa.gov

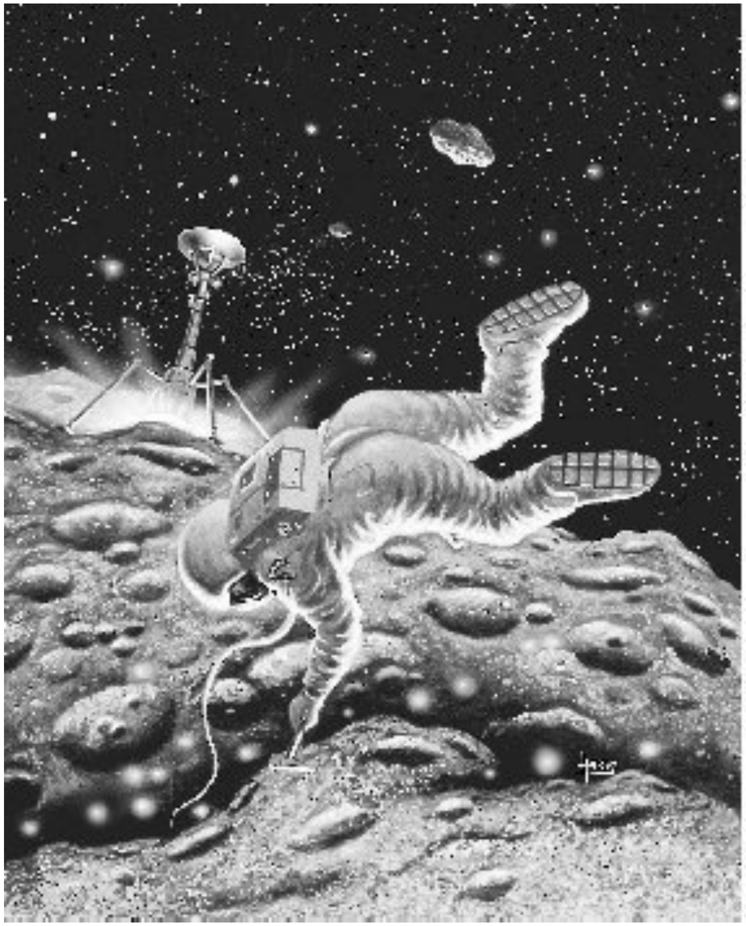
Acknowledgments:
Brian Wilcox
Pascal Lee
Michael Sims

A little physics… (Wilcox)

For a spherical body of radius 50m and density 2000 kg/m3, the escape velocity is 4.9 cm/s. Orbital velocity is 3.5 cm/s. Equivalent to falling less than 0.1mm on Earth.

Acceleration of gravity on surface, for same example, is 2.4μg. If launched off surface at 1 cm/s, it would take ~14 minutes to return to surface.

Threshold where centrifugal force on equator = gravity force is when spin period is <2.5 hours (independent of radius, depends only on density).

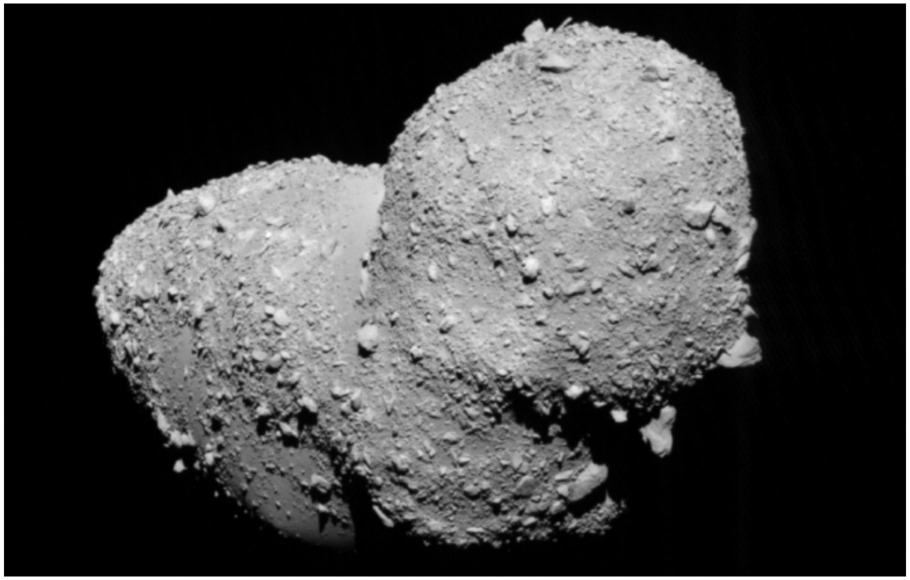


A human, exerting 1% of Earth-normal standing force, would reach escape velocity in ½ second.

Rubble Piles

"Rubble Pile" model proposed after observation that most large NEOs don't spin faster than the gravitational-centrifugal threshold.

Many smaller (~100 m) NEOs do spin faster than gravitational-centrifugal threshold and so may be monolithic. But some NEOs may be easily burst.



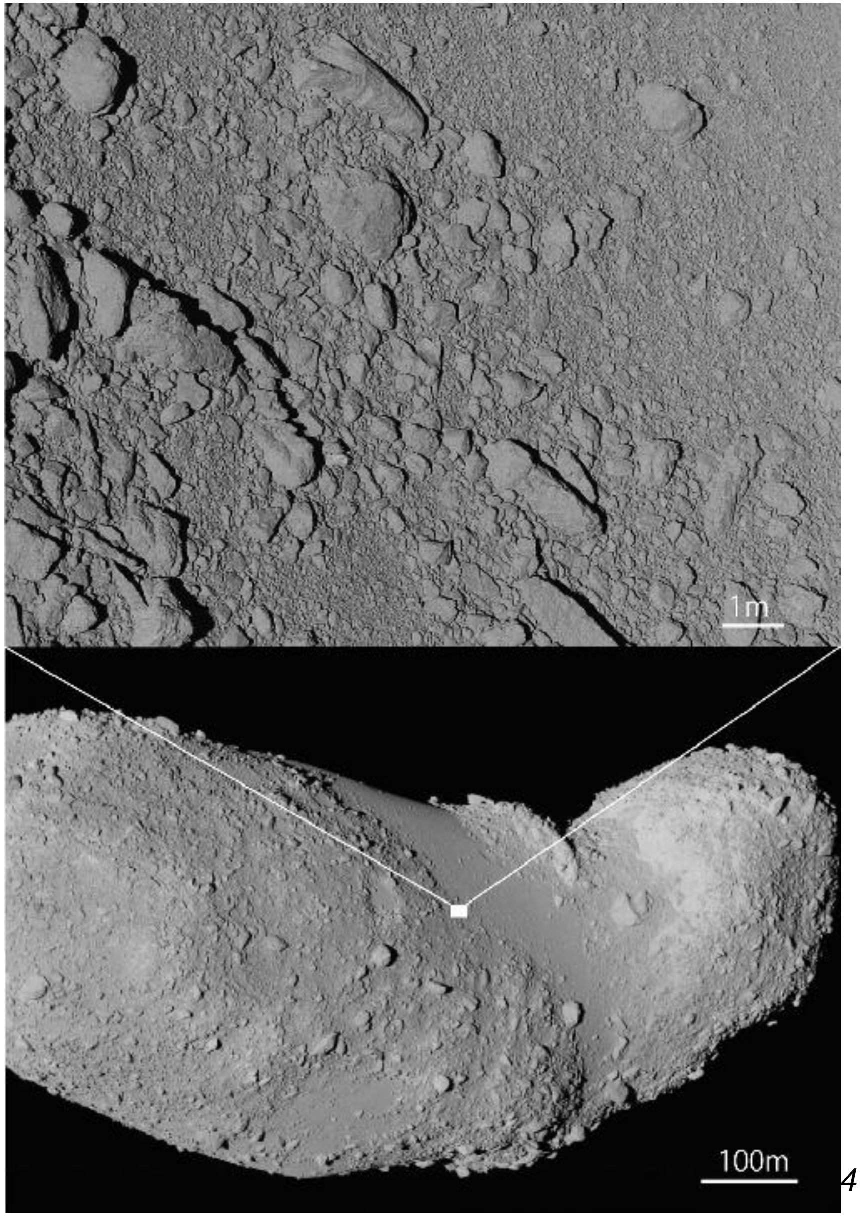
Regolith

Broken particles on surface

Unknown depth

Gravitationally bound

May know spin rate of target well prior to mission – possible that monolithic targets could be selected presumably with large areas w/o regolith.

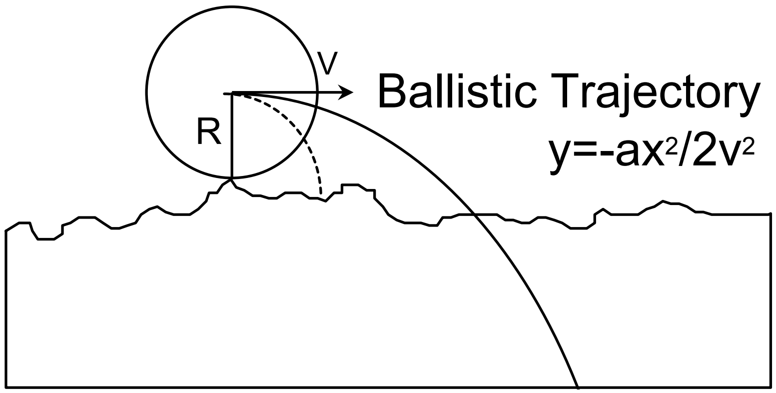


Wheels

Slow rolling will maintain surface contact

- Requires ballistic trajectory remain within distance R of contact point :

  $v < (Ra)^{1/2}$



a = 10ug, friction = 0.3:

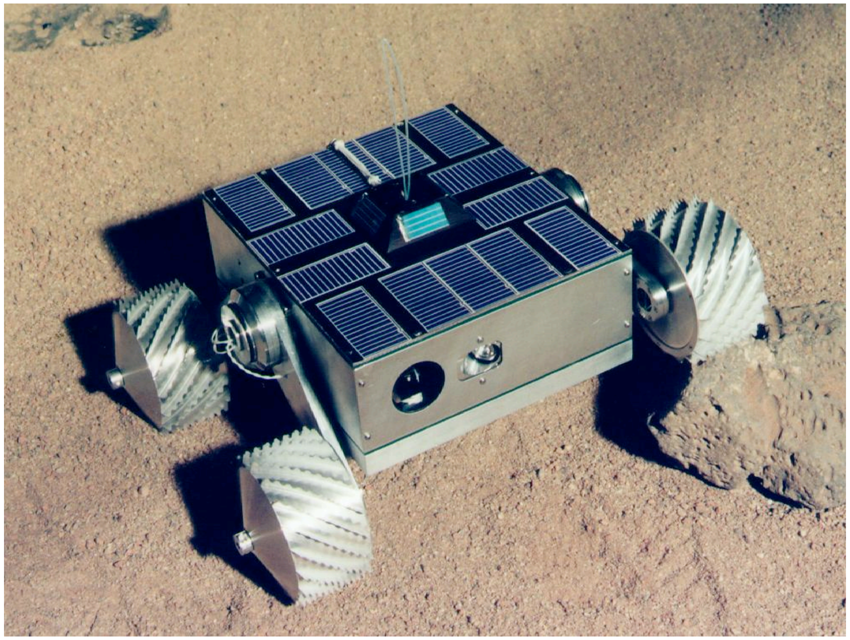
Wheel Radius	**30 mm**	**1.0 m**
Max speed	1.7 mm/s	10 mm/s
Time to reach max speed	1 min	6 min
Distance to reach max speed	5 cm	170 cm

JPL Nanorover

Built as payload to MUSES-CN Asteroid mission (renamed Hayabusa), cancelled following failures of MPL and MCO spacecraft

1.3kg, solar power (no batteries), color camera, NIR spectrometer, simple LRF.

Actuated wheel struts to actively maintain traction, reduce bouncing, self righting, and <u>hopping.</u>



Hopping

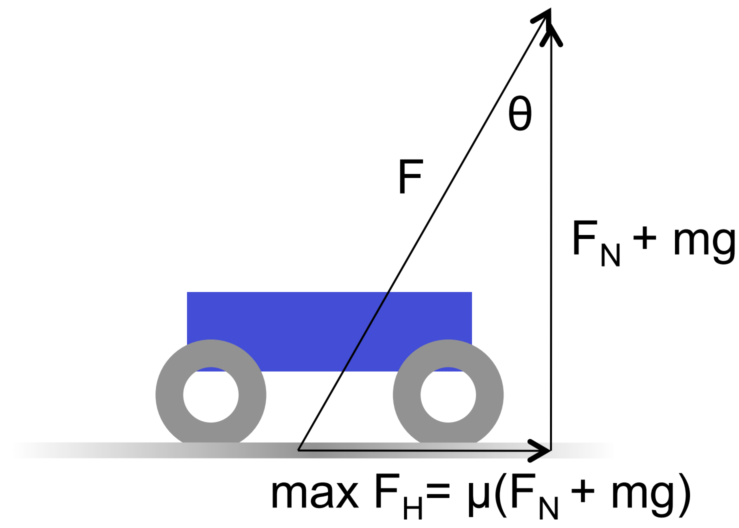
•Use inertia to exert greater forces

•Max hopping angle:

$\tan\Theta = \mu$

Issues:

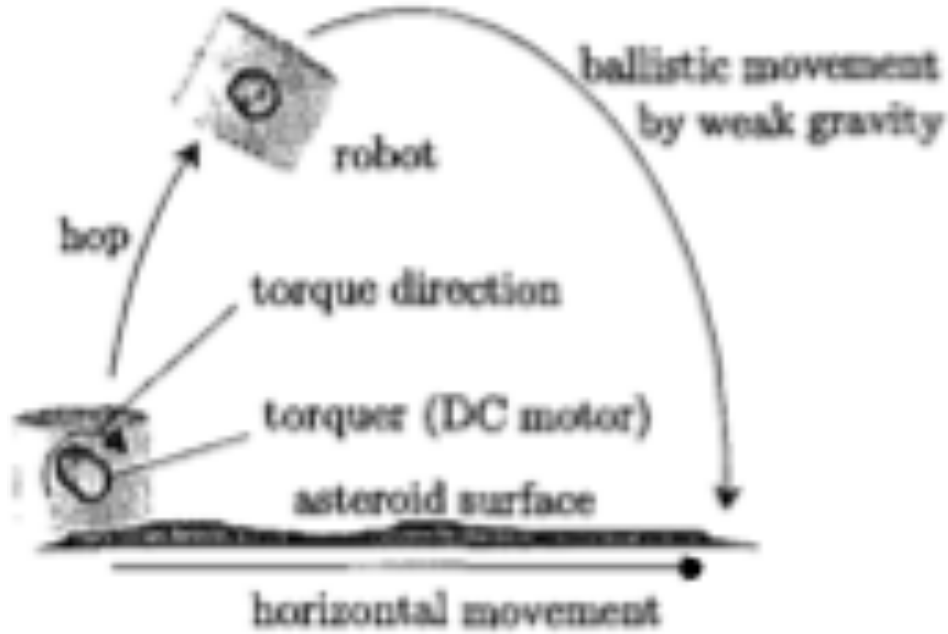
- Determining and maintaining pose
- Gravity modeling, trajectory and uncertainty propagation
- Landing impact absorption (bouncing can last an hour)



Hopping Speed	1 cm/s	5 cm/s
Height	0.5 m	12 m
Distance	0.6 m	14 m
Time	3 min	16 min

10ug gravity, 0.3 friction coefficient, 16 deg from vertical hop

MINERVA (Hayabusa, lost in space)



Proceedings of the 2004 IEEE
International Conference on Robotics & Automation
New Orleans, LA • April 2004

Development of Autonomous Rover for Asteroid Surface Exploration

Tetsuo YOSHIMITSU
Institute of Space and Astronautical Science
Yoshinodai 3-1-1, Sagamihara, Kanagawa 229-8510, Japan
Phone: +81-42-759-8069, Fax: +81-42-759-8473, Email: kikko@nnl.isas.ac.jp

Free Flyer

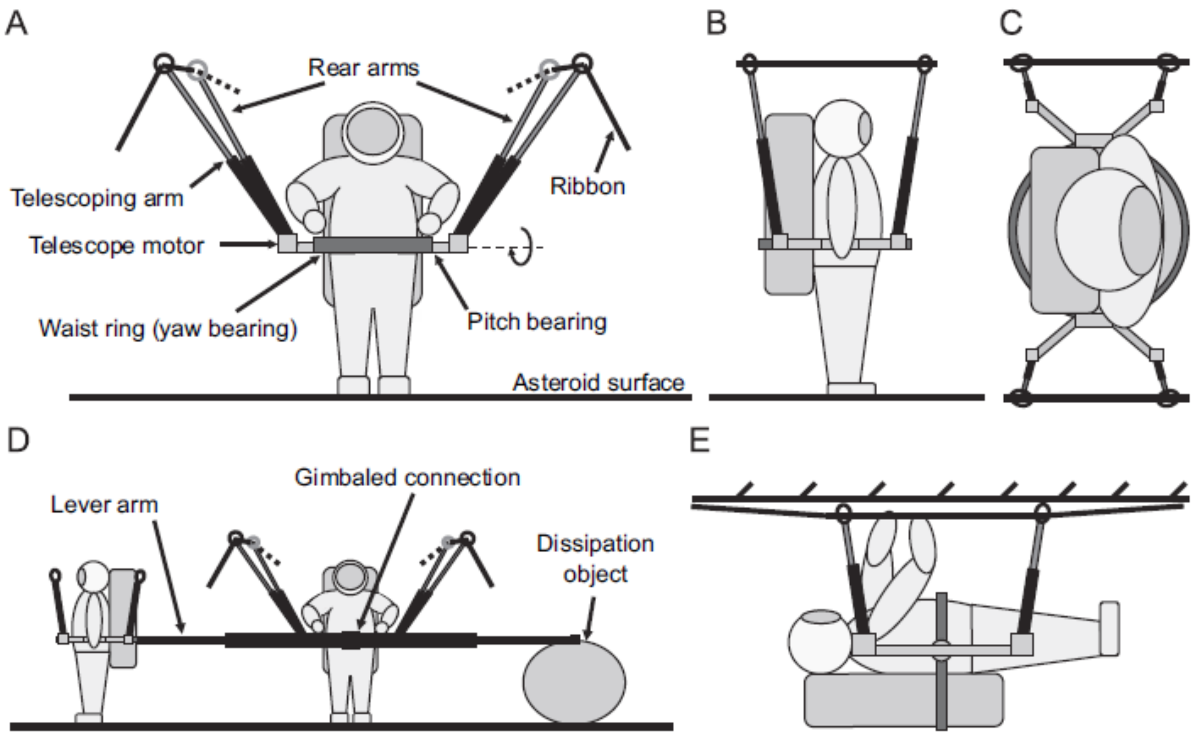
- Fast, controllable
- Expends propellant
- Thrusters, ACS, etc
- Disturbs surface regolith
- Constantly station-keeping unless at rest on surface

AERCam-Sprint, NASA, 1997

Asteroid radius	0.1km	1.0km	10km
Orbital velocity at surface	9.2×10^{-2} m/s	0.92 m/s	9.2 m/s
Surface velocity with P = 30h	0.6 cm/s	6 cm/s	60 cm/s

Circumferential Rope Tether

• The ropes have to be reeled out around body before landing on the asteroid
• 2 x 150kg Vectran cords for astronauts on 3km radius asteroid

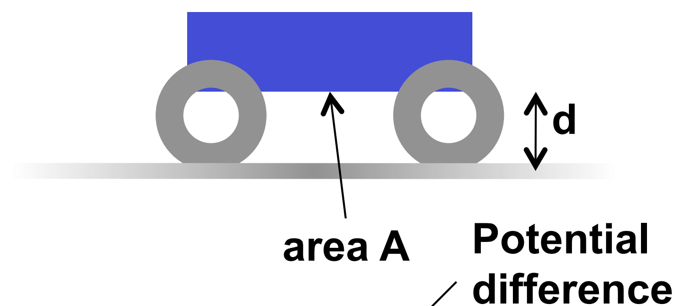


Ian Garrick-Bethell, Christopher E. Carr "Working and walking on small asteroids with circumferential ropes" Acta Astronautica 61 (2007) 1130-1135.

Electro-static adhesion?

Generate potential difference between rover and body surface. Electrostatic attraction allows wheeled mobility at increased speed.

- How to generate and maintain P.D.? Electron beams?
- High voltages
- Electrostatic dust elevation and adhesion
- Suitable for bodies rotating too rapidly to keep regolith covering?



$$F = \frac{1}{2}\Delta\phi^2 \varepsilon_0 A / d$$

Potential difference	500kV
Area	0.25m^2
Distance	0.25m
Electrostatic Force	1 N
Weight of 50kg rover at 10^{-5}g	0.005 N
$F_{electostatic}$/Weight	225
Speed increase factor	15

Concluding Remarks

Surface navigation is primarily a mobility problem

BUT localization a challenge (if needed)

- Very different surface perspective
- Rapidly changing lighting
- Poorly defined vertical