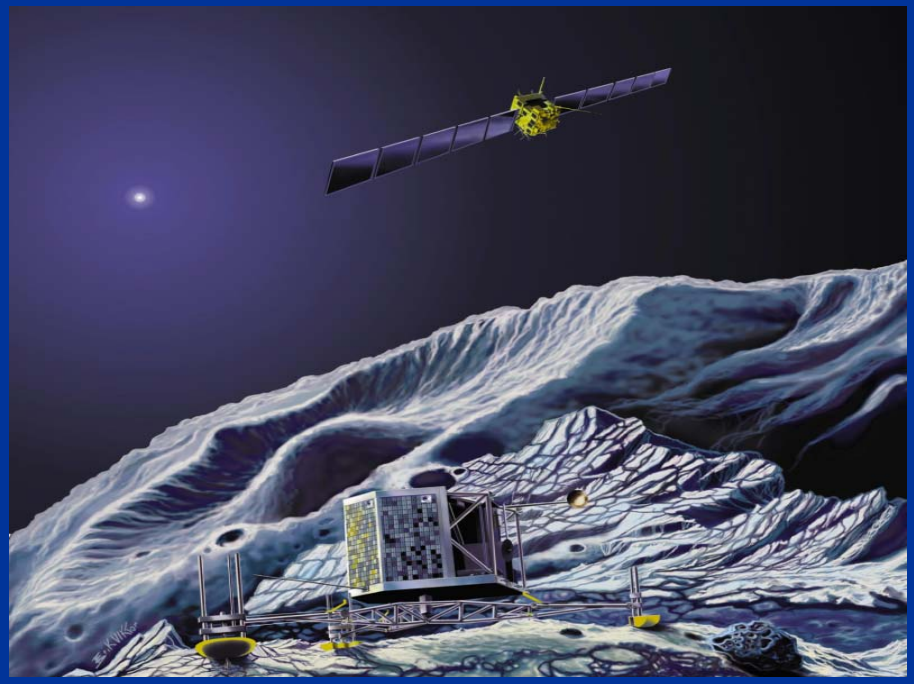
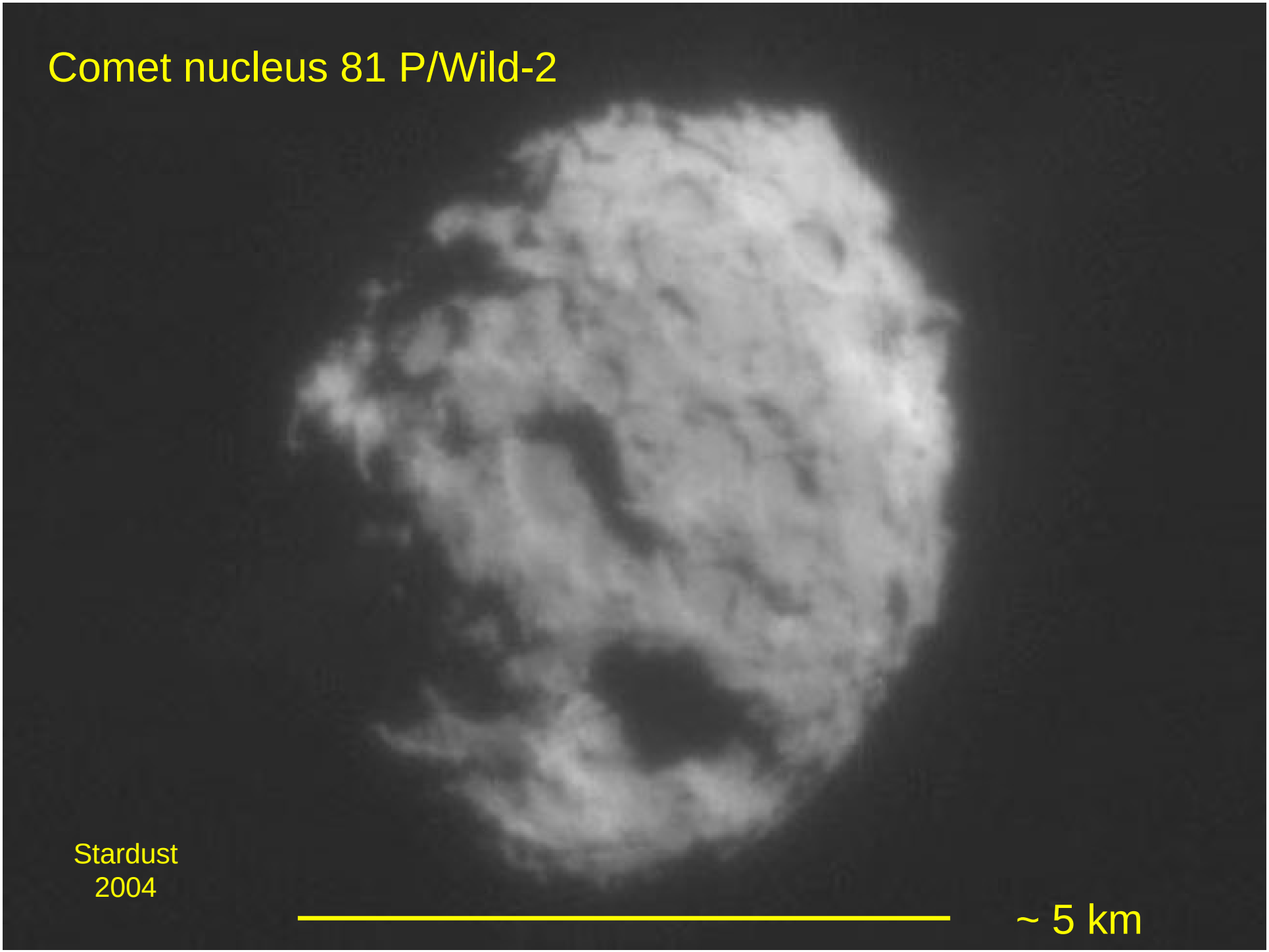
Simulation of the Landing of Rosetta Philae on Comet 67P/Churyumov-Gerasimenko



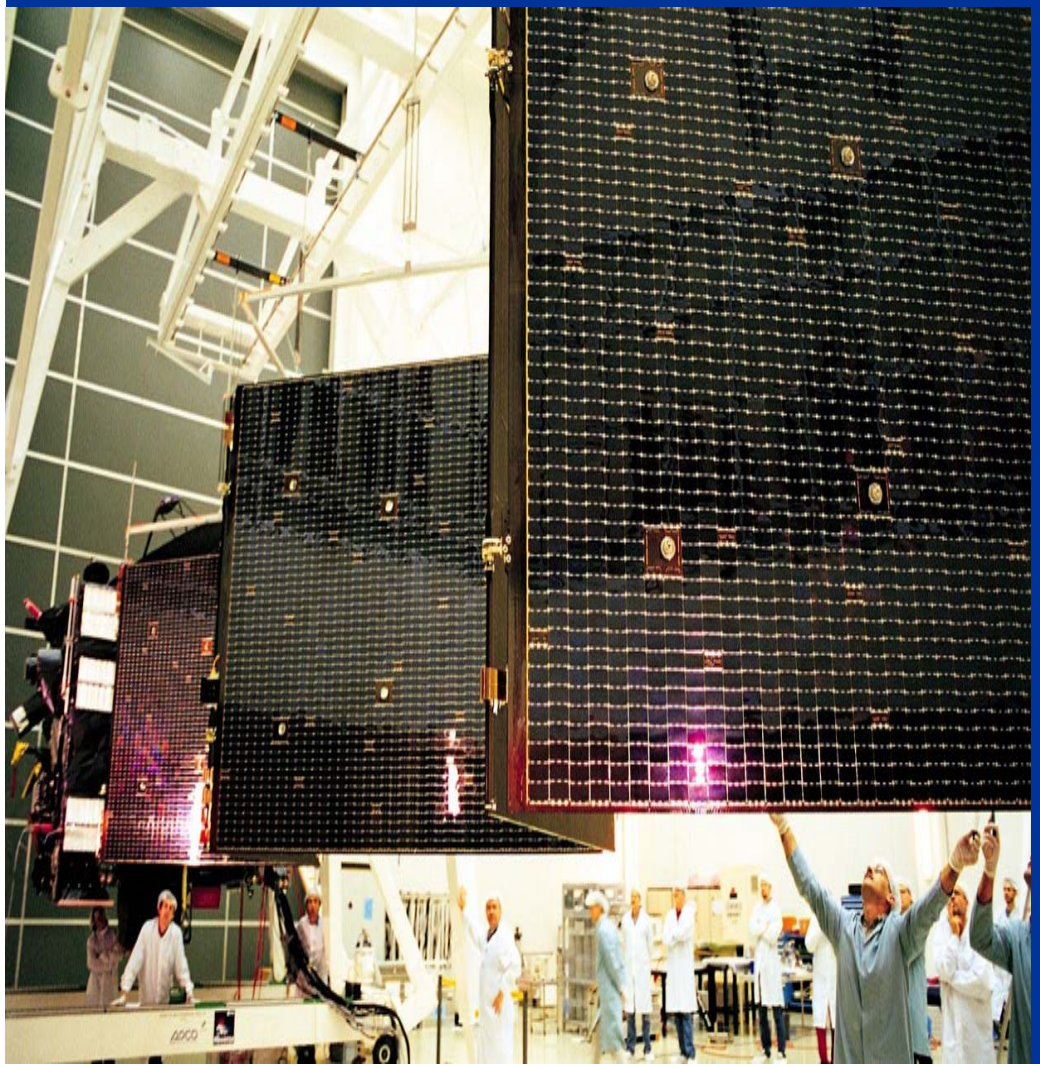
M. Hilchenbach
Max-Planck-Institut für Sonnensystemforschung
Katlenburg-Lindau

SIMPACK USER MEETING 2004, Nov 9-10, Wartburg/ Eisenach / Germany

Comets - tiny imposters


Comet nucleus 81 P/Wild-2
Stardust
2004
~ 5 km

Mission Rosetta:
An ESA corner stone mission
towards a comet nucleus



Mission Rosetta - fact sheet

Mass: 2.9 Tons (1.6 tons fuel)
Size: 3 x 2 x 2 m (solar cells, 32 m long)
costs: (in human recources) about 15.000 years

Science payload:

150 kg on orbiter and
96 kg for the Rosetta Lander Philae

Rosetta orbiter
(hidden behind extended solar panels…)

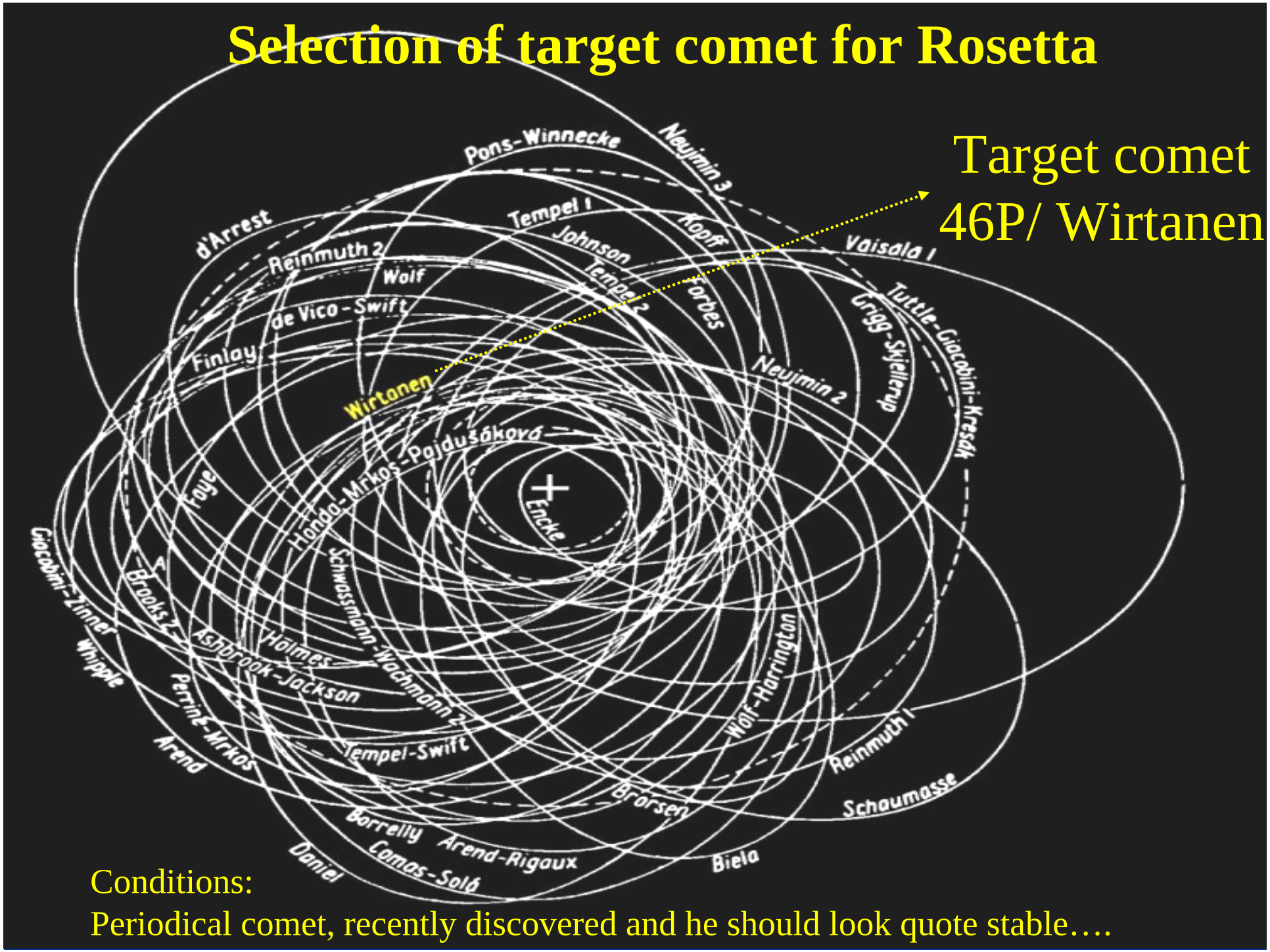
Mission Rosetta: an ESA corner stone mission towards a comet nucleus

Selection of target comet for Rosetta mission….

Short timeline of mission:

start of hardwarephase	about 1996
cancelled launch towards comet 46P/Wirtanen	Jan 2003
launched with new target comet, 67P/Churyumov-Gerasimenko	March 2004
in orbit of comet	June 2014
landing on comet nucleus	Nov 2014

Selection of target comet for Rosetta



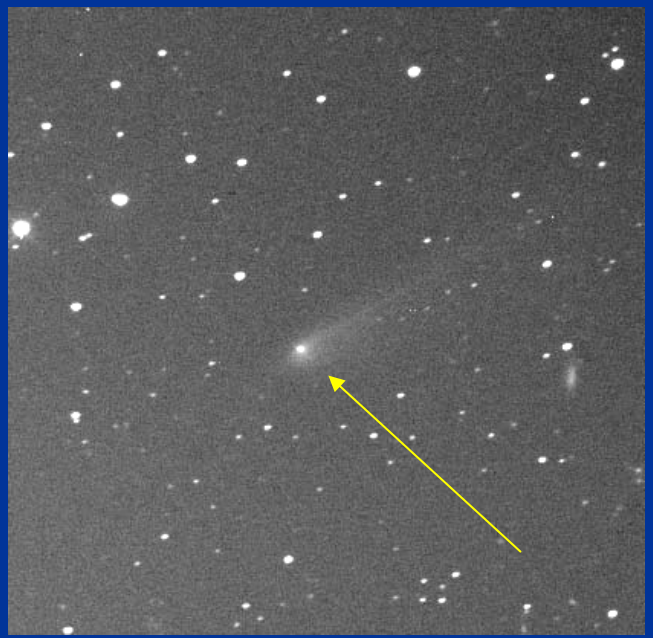
Conditions:

Periodical comet, recently discovered and he should look quote stable….

Selection of new target comet for Rosetta in 2003* :

New target comet: 67P/Churyumov-Gerasimenko

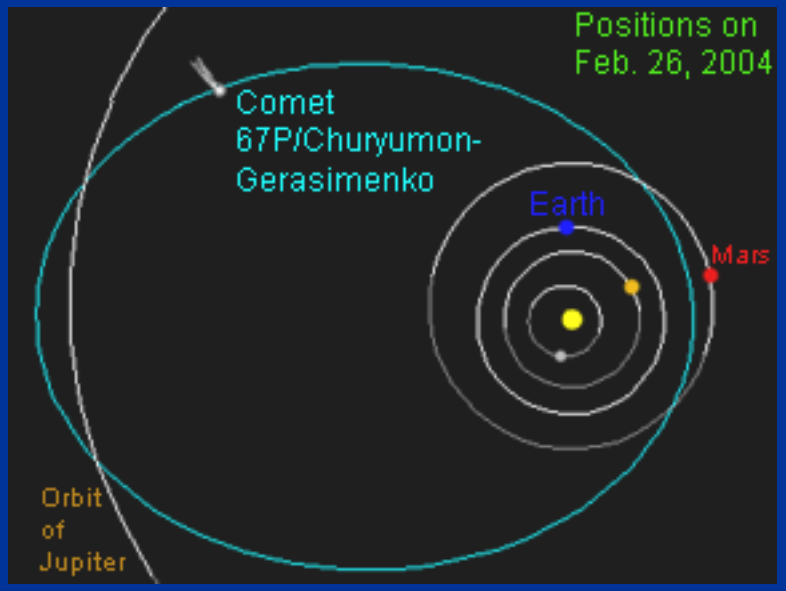
Description			periodic comet - (Jupiter family)
nucleus size		=	3 x 5 km
semimajor axis(a)		=	3.511 AU
eccentricity	(e)	=	0.632
inclination	(i)	=	7.1°
perihelion	(q)	=	1.292 AU
aphelion (Q)		=	5.730 AU



67P/Churyumov-Gerasimenko
February 1st 2003

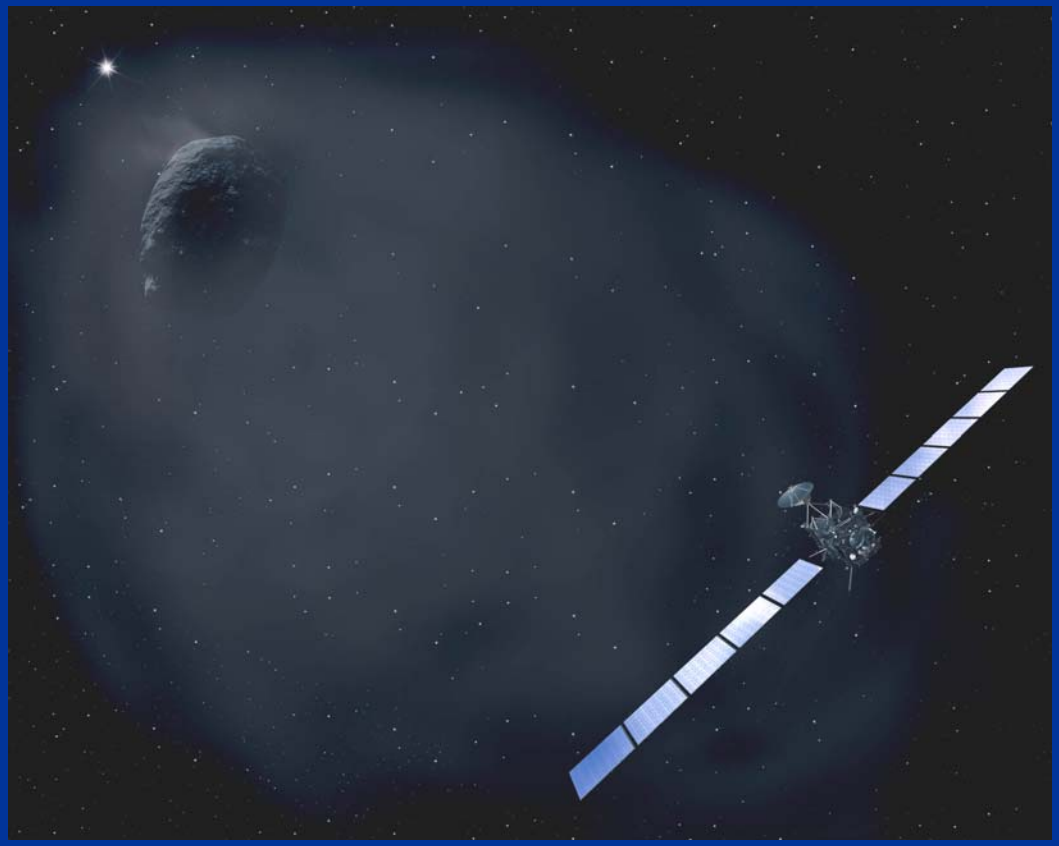
* The 2003 launch was cancelled due to technical problems of Ariane V rocket system.

Approaching comet 67P/ Churyumov-Gerasimenko



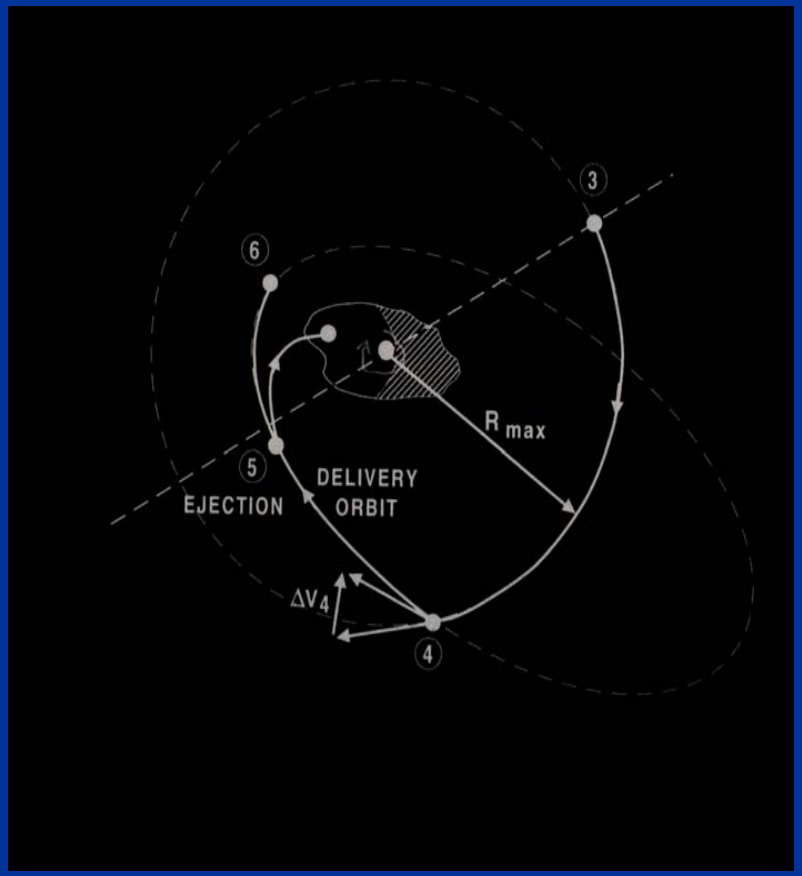
Flight to the comet
(2004-2014: 10 years)

Launch
with Ariane V
2004

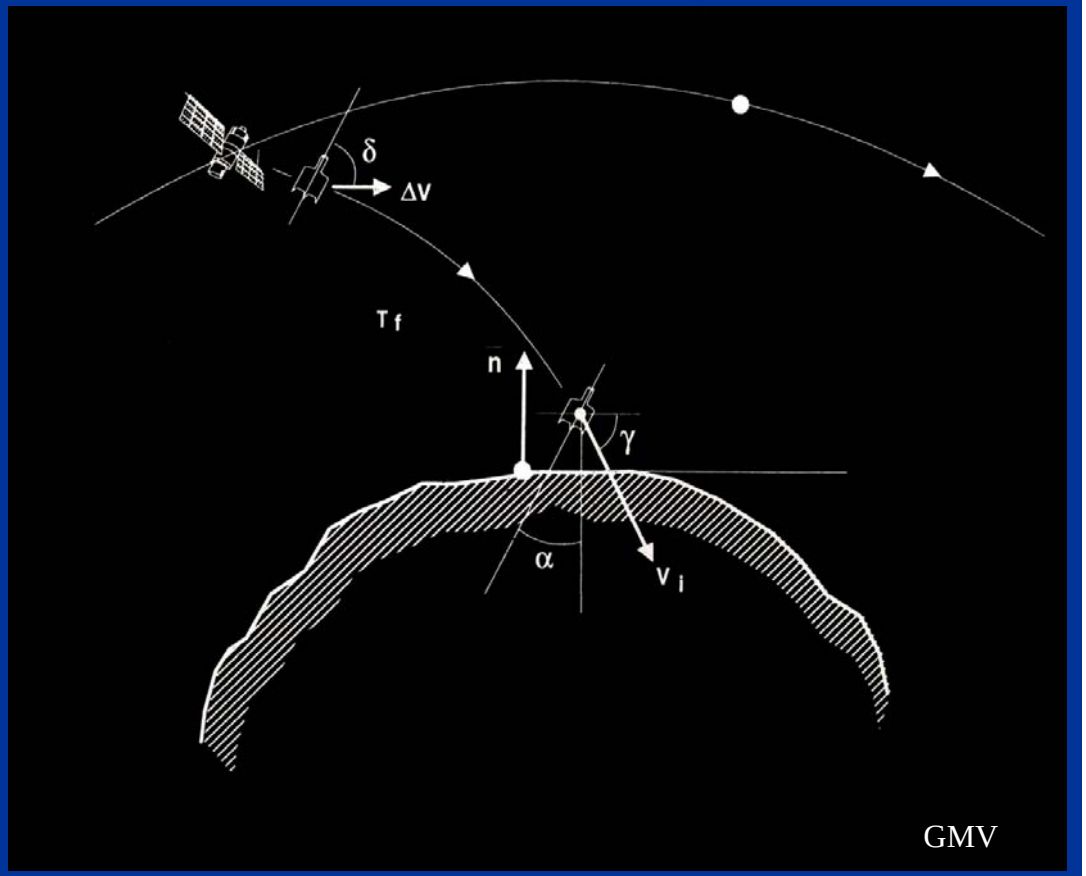


Comet mapping phase
(2014: 3 months)

Rosetta Lander - Mission Analysis

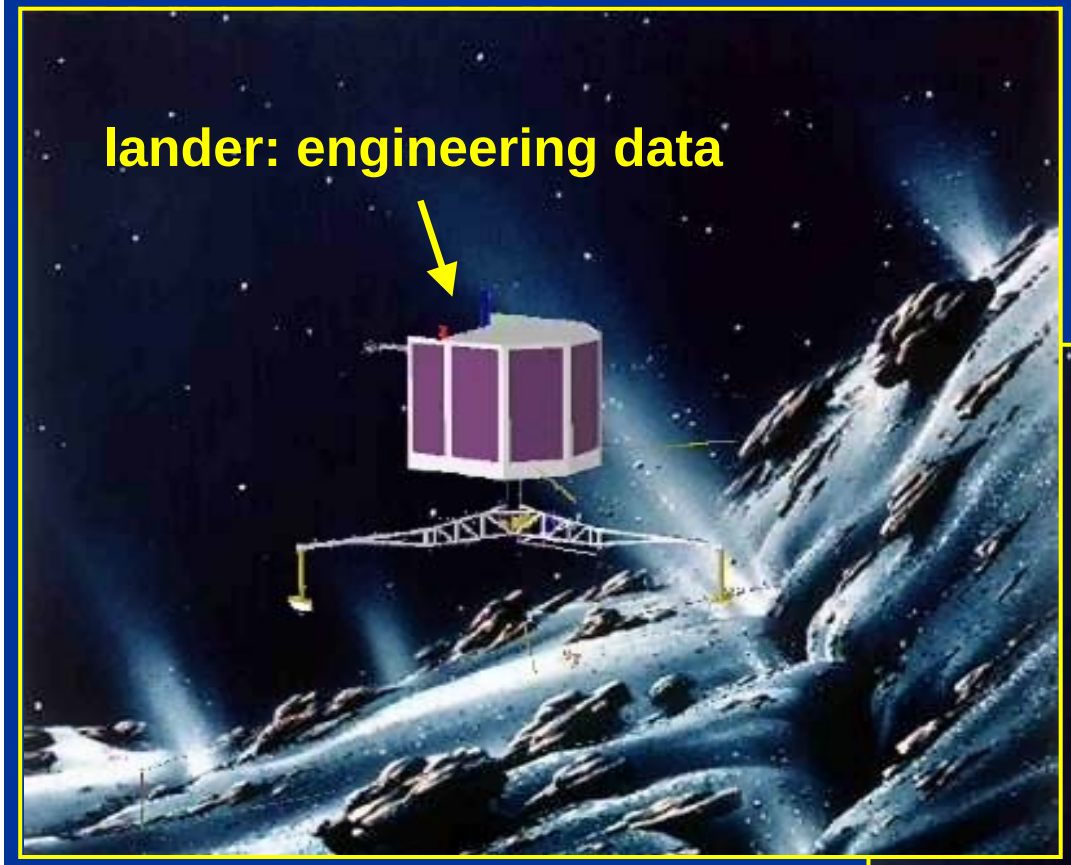


Orbiter maneuver:
Preparation for descent phase
(several days)

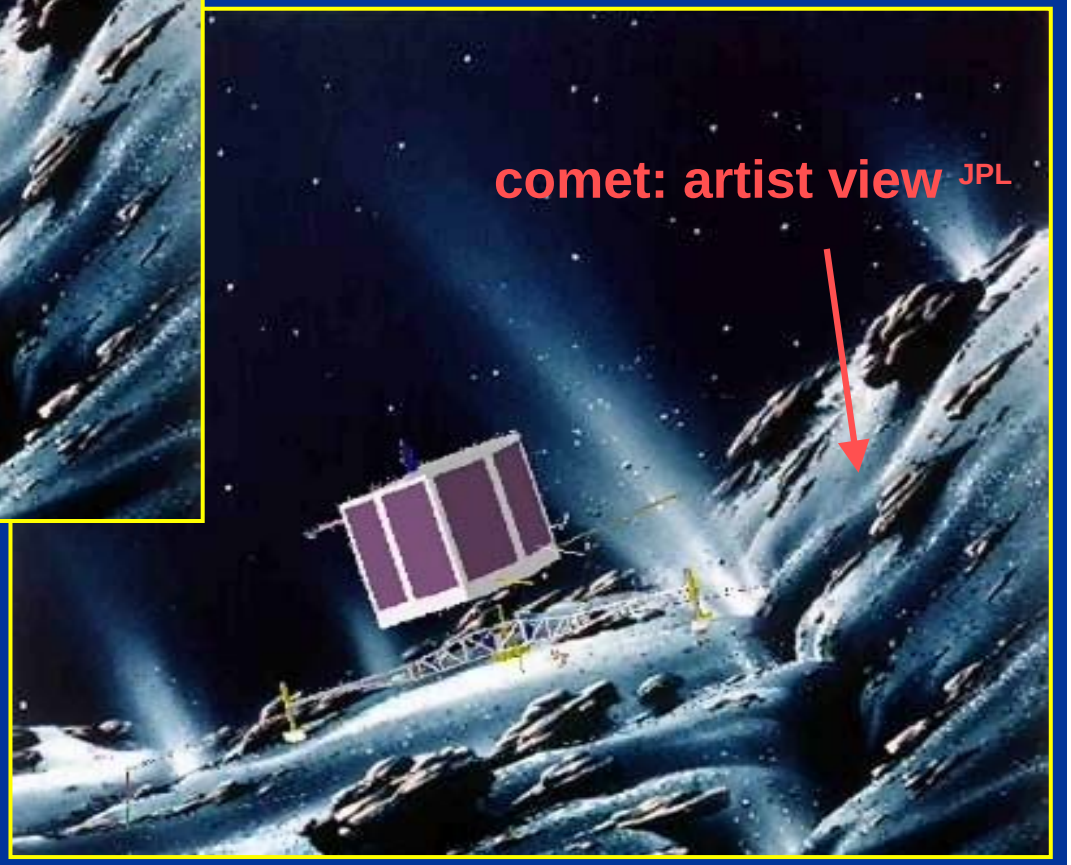


Orbiter, lander and comet:
Separation and descent
(about one hour)

Rosetta Lander: Impact on comet



Lander and comet:
Touch down (sec)



Rosetta lander Philae:

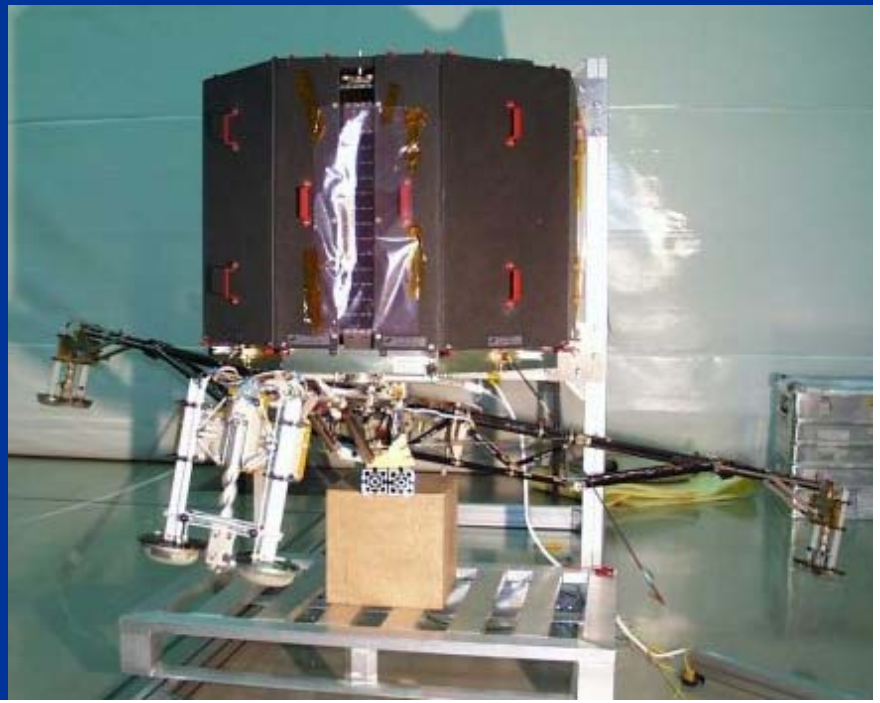
Hardware, simulation and qualification tests concerning the impact on the comet nucleus:

lander flight hardware
concept of inelastic impact on comet surface
simulation model
comet surface
model parameters

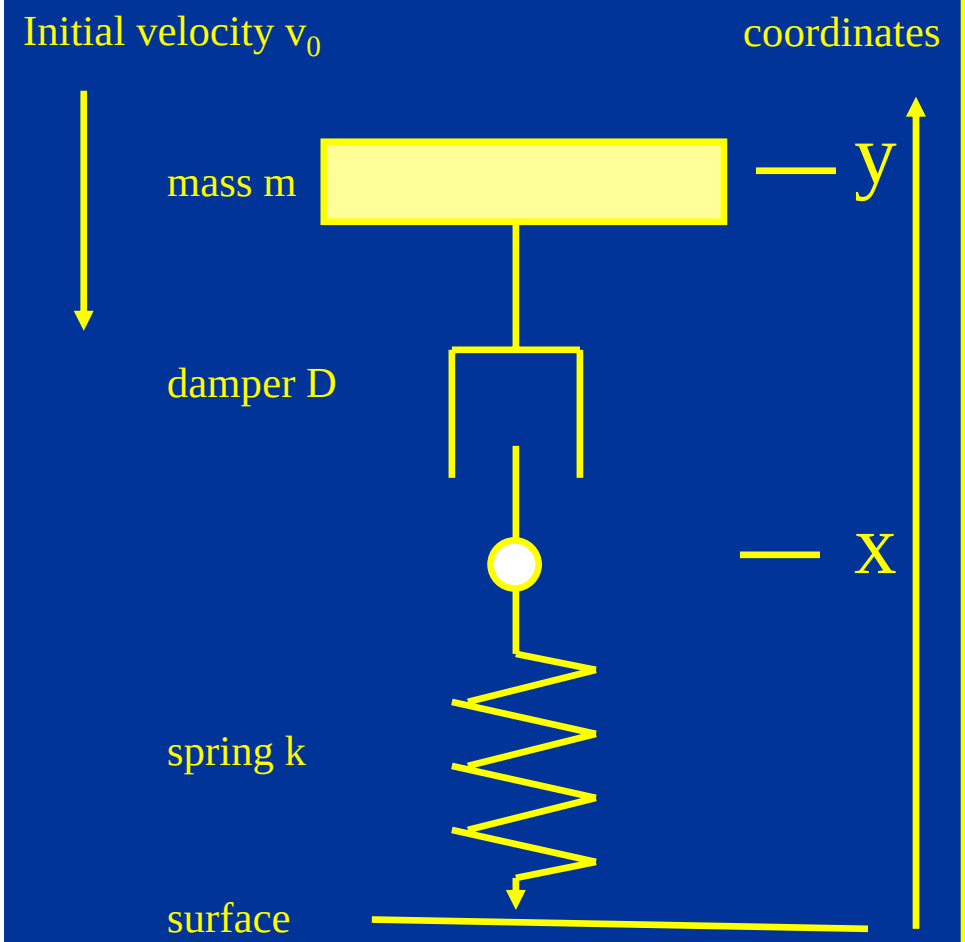
Detail: Lander foot
and icescrew

Lander Philae - flight hardware

Rosetta Orbiter
(Kourou 2003)



Simplified 1-D models for inelastic impact on comet surface



without spring (elasticity k indefinite)
Velocity dependent damp force:

$m\ddot{y} + D\dot{y} = 0$

$v(t) = v_0 \cdot \exp(-D/m.t)$

$s(t) = v_0 \cdot 1/(D/m) \cdot (1-\exp(-D/m \cdot t)$

---

with spring
coordinates: x, y and d = y - x

forces along coordinate axis are equal:

$m\ddot{y} = - D\dot{d}$

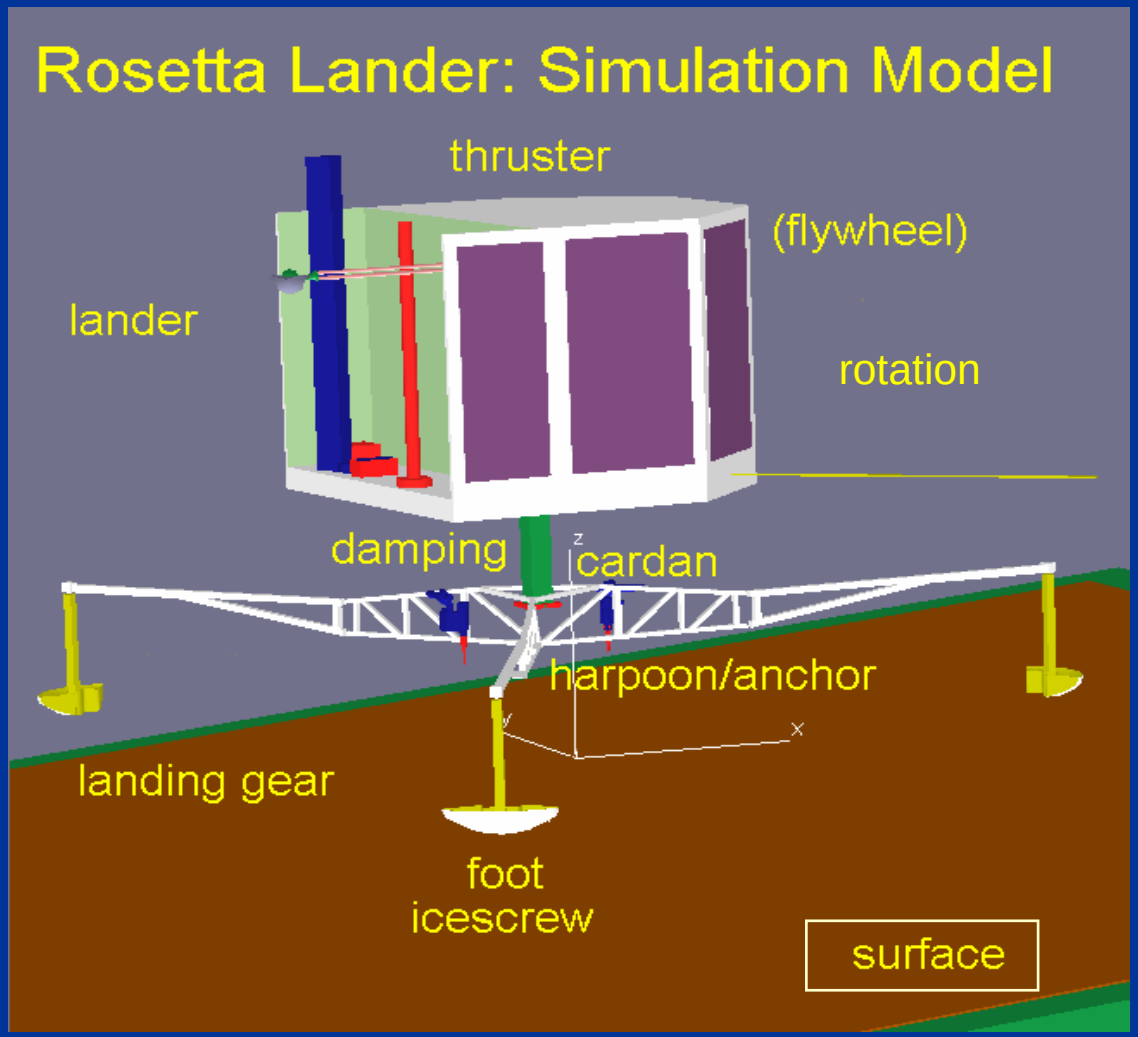
$D\dot{d} = - kx$

condition for inelastic impact
(no rebound)

$\tau_{spring} < \pi/2 \cdot \tau_{damper}$ or

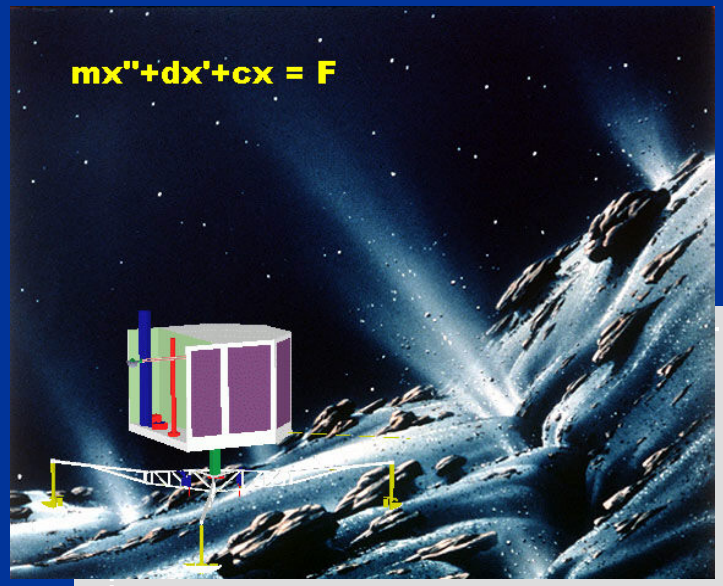
$k > 4\ D^2/m$

Simulation of Rosetta Lander 3-D Dynamics



Rosetta Lander Model Dynamic Parameters:
Source : Lander and Lander documentation (theory and measurement)

Elements of Dynamics: Interaction with the comet surface



Lander

Hold-Down-Thrust

Flywheel

Damping

Elasticity

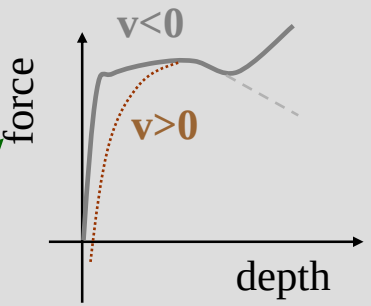
Cardan

Landing Gear

Anchor

Kelvin or Maxwell elements

comet surface: force diagram



?

?

friction

surface $F \sim \mu \cdot F_{normal}$

Selected Landing Site

(not to scale !)

Numerical Simulation:

The numerical simulation makes use of detailed geometry, joints, mass allocation,inertia etc.as defined in Lander CAD design files/documents.

The very basic mechanical / dynamical properties of the lander - comet simulation system are:

Mass (lander)	M = 96 kg
Inertia	I = 5 -6 kg*m^2
mass (landing gear)	m = 9 kg
Momentum of flywheel	L = 5 Nms
Damping tube	d = 800-1200 Ns/m
Cardan joint friction	t = up to 30 Nm
Landing gear rigidity per leg	k = 1.3*10^4 N/m
Impact velocity	v nominal 0.5 m/s < 1 m/s (1.1 to 1.5 m/s)
Rotation of lander	w = 0.4 °/sec*
Angle of attack a	17° *
Angle of impact b	9° (or b*=81°)*
and g	8° *

Gravity	a = 5.10^{-4} m/s^2 (10^{-3} m/s^2)
Comet surface friction	
(assumption: prop. to impact force)	
foot	0.2*
screw	1*
Nominal forces due to foot	
up	up to 2.10^5 N*
down	0 N*
Nominal forces due to ice screw (ice-pic)	
up	F 1200 N *
down	F 1 N*

* examples as used in most presentations
- red labelled: new target comet parameters

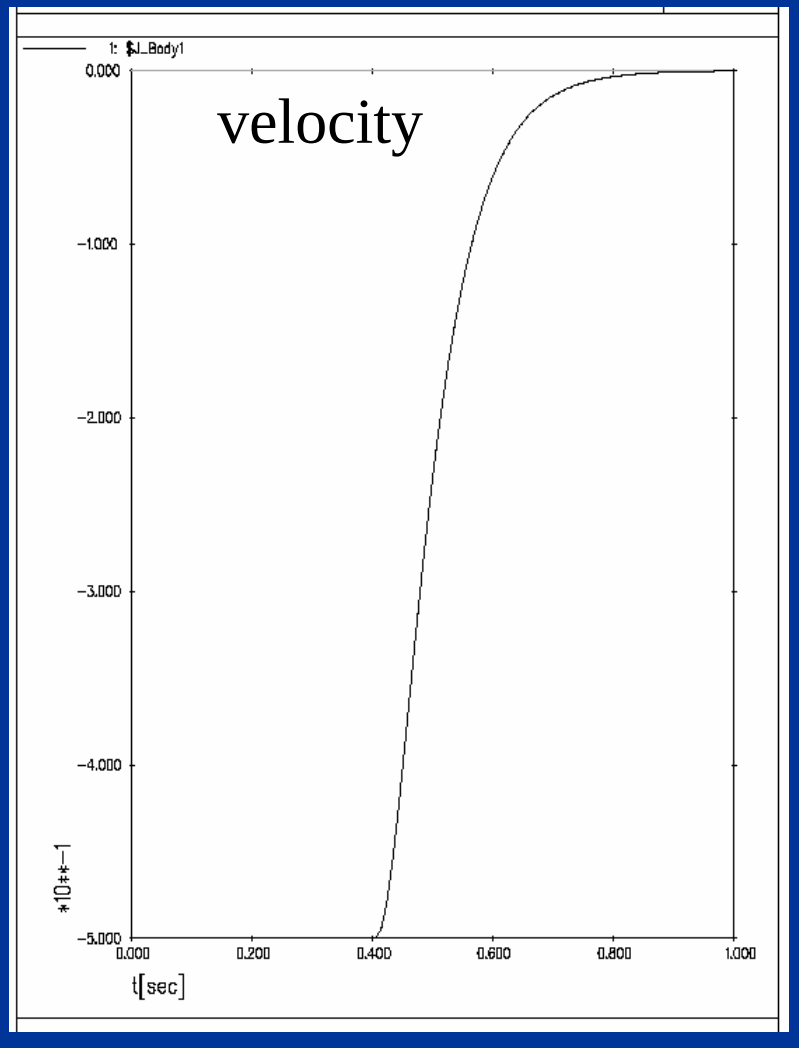
Test Examples

On-ground simulation and laboratory tests in earth gravity environment:

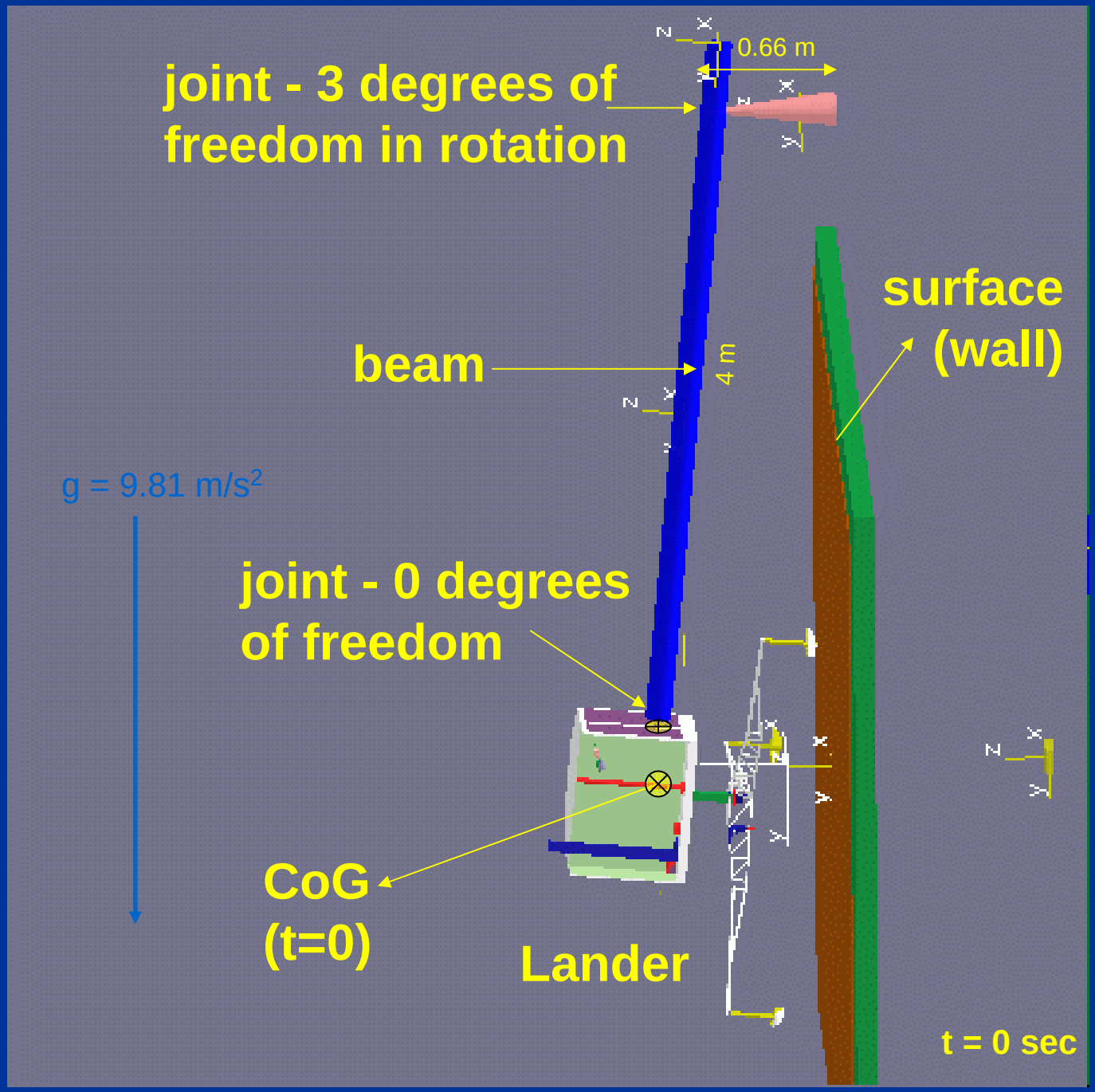
Test of simulation model

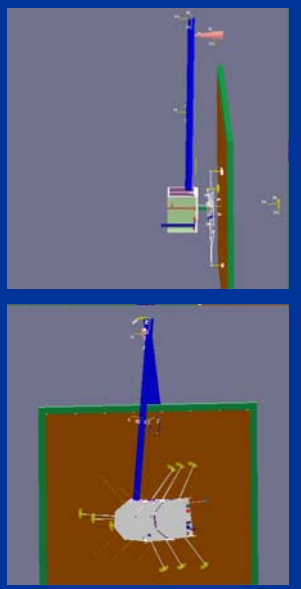
Damping Test (Cart)

Lindau, Jul 2001



Test Configuration

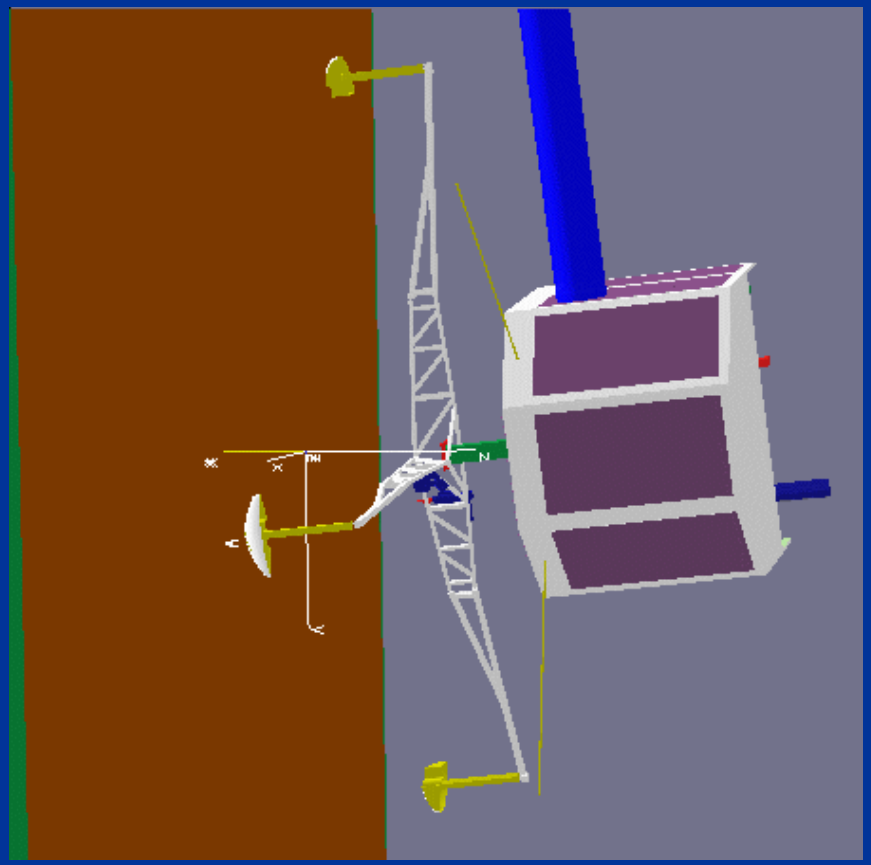


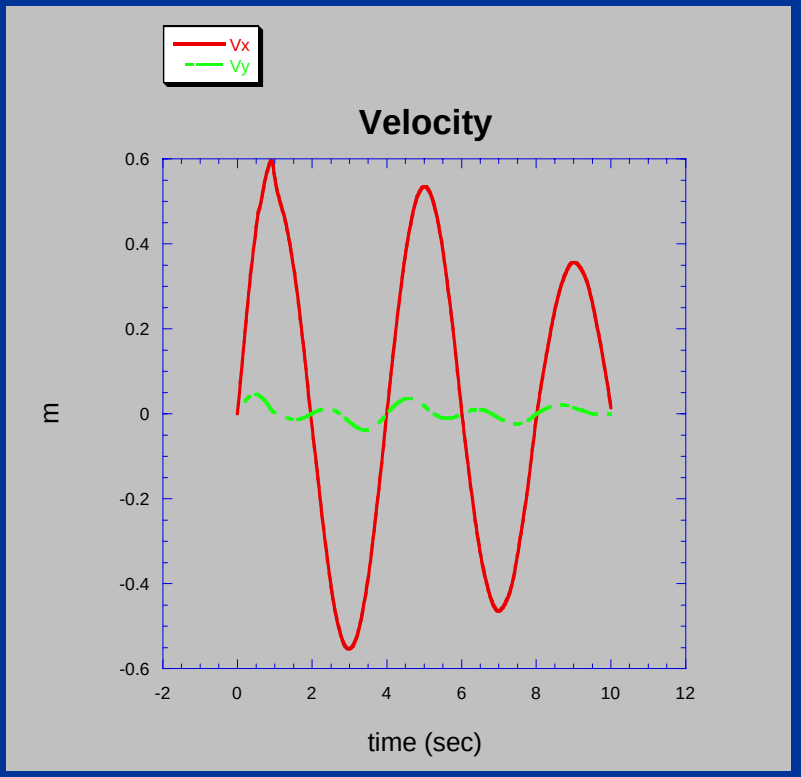


t = ... sec

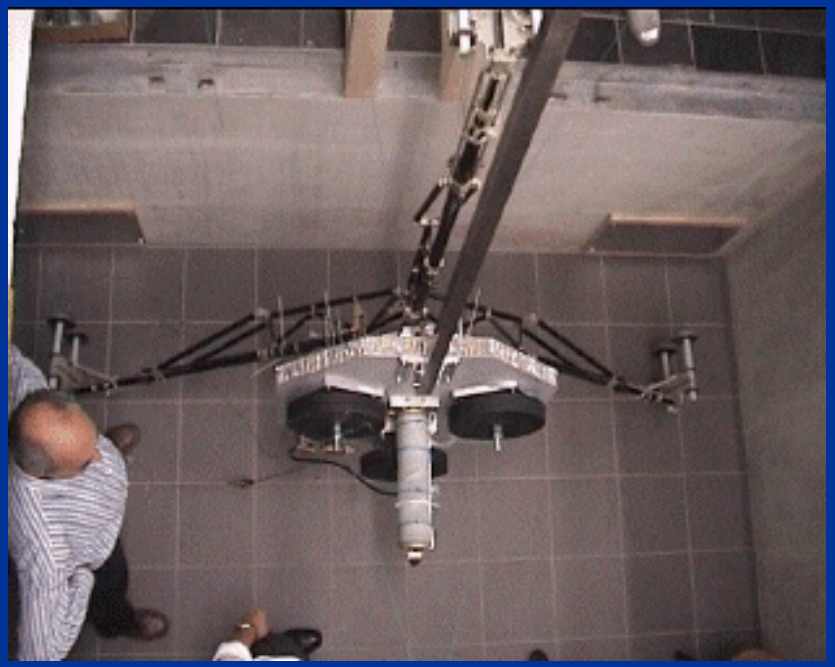
Simulation test with pendulum in earth gravity environment

(friction lander-wall: m=0.1)





Pendulum Test



Aluminium sheet surfaces

Comet analogue material

Lindau, Aug 2001

Simulation of landing scenario for 46P / Wirtanen*

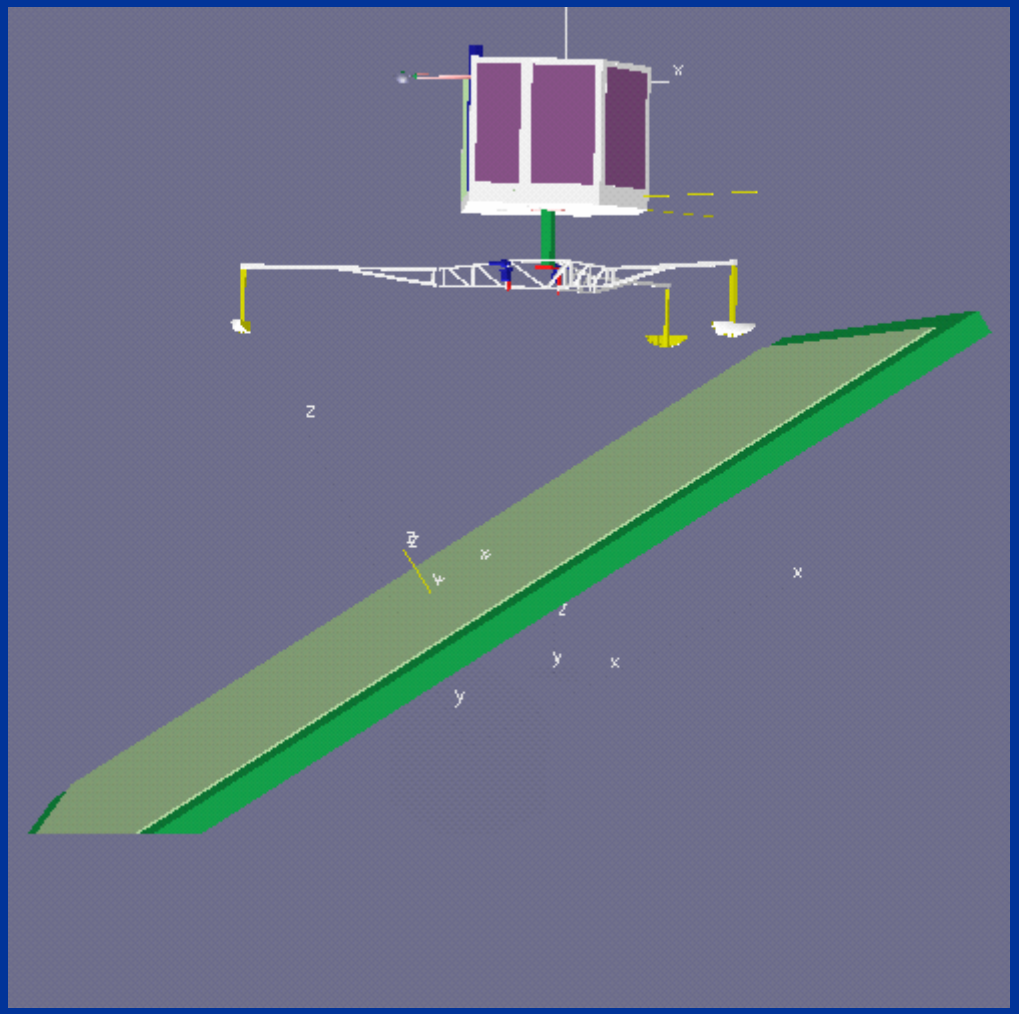
nominal impact velocity:
0.5 m/s, 1 m/s maximum

gravity (comet)
$<5.10^{-4}$ m/s^2

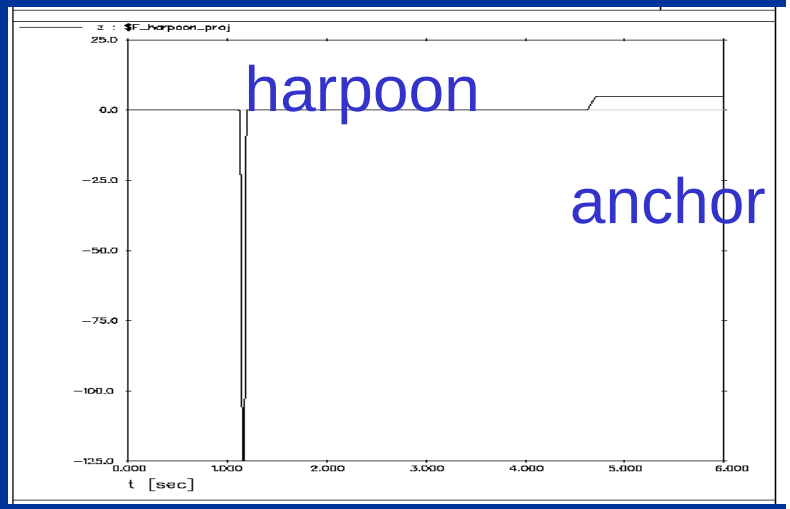
landing concept:
nearly torque free cardanic joint to limit the exchange of angular momentum between lander and comet
(about 18° free tilt angle, cardanic joint
friction torque about 10 Nm, adjustable up to 30 Nm)

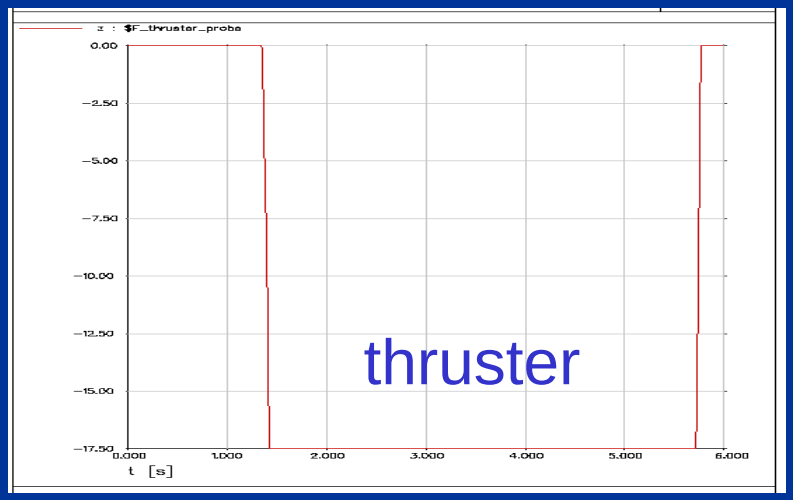
* valid comet mission target up to Jan 2003

Landersimulation I



(slow motion…)



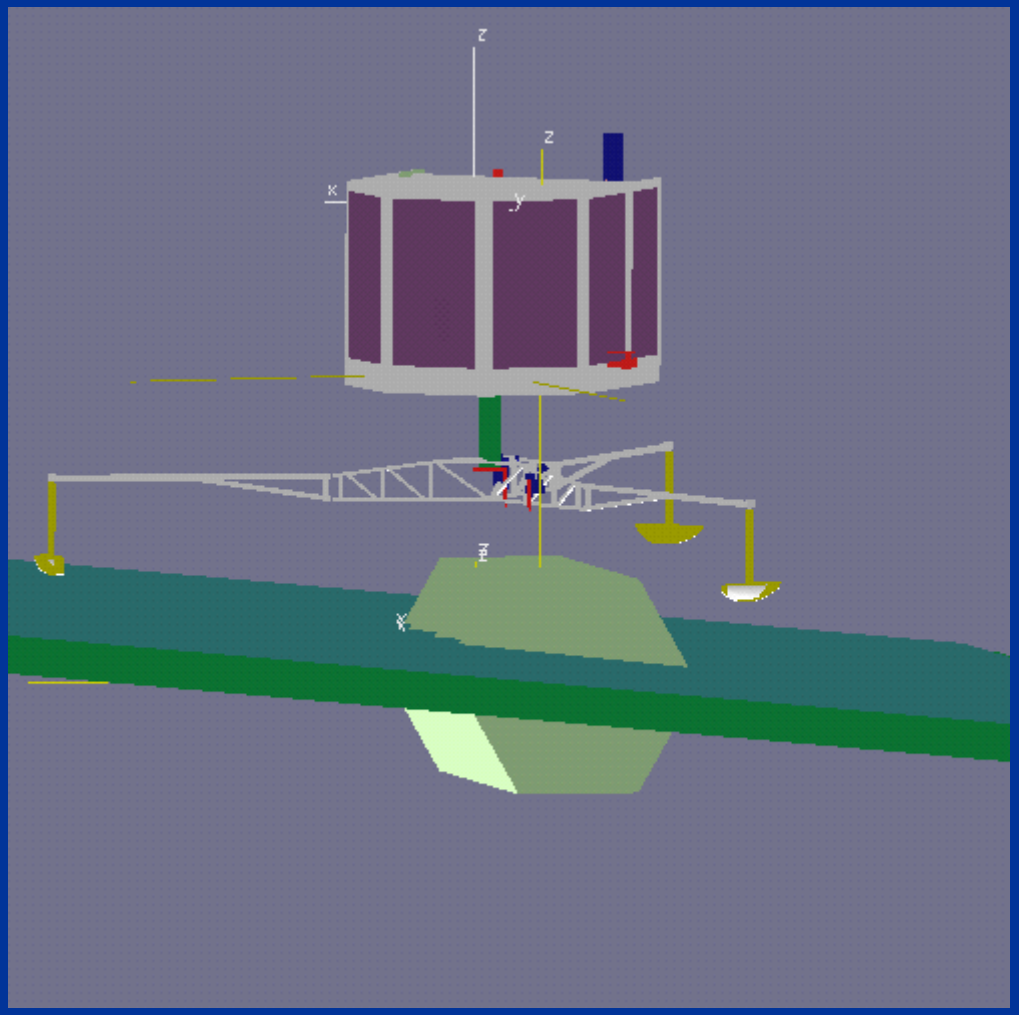


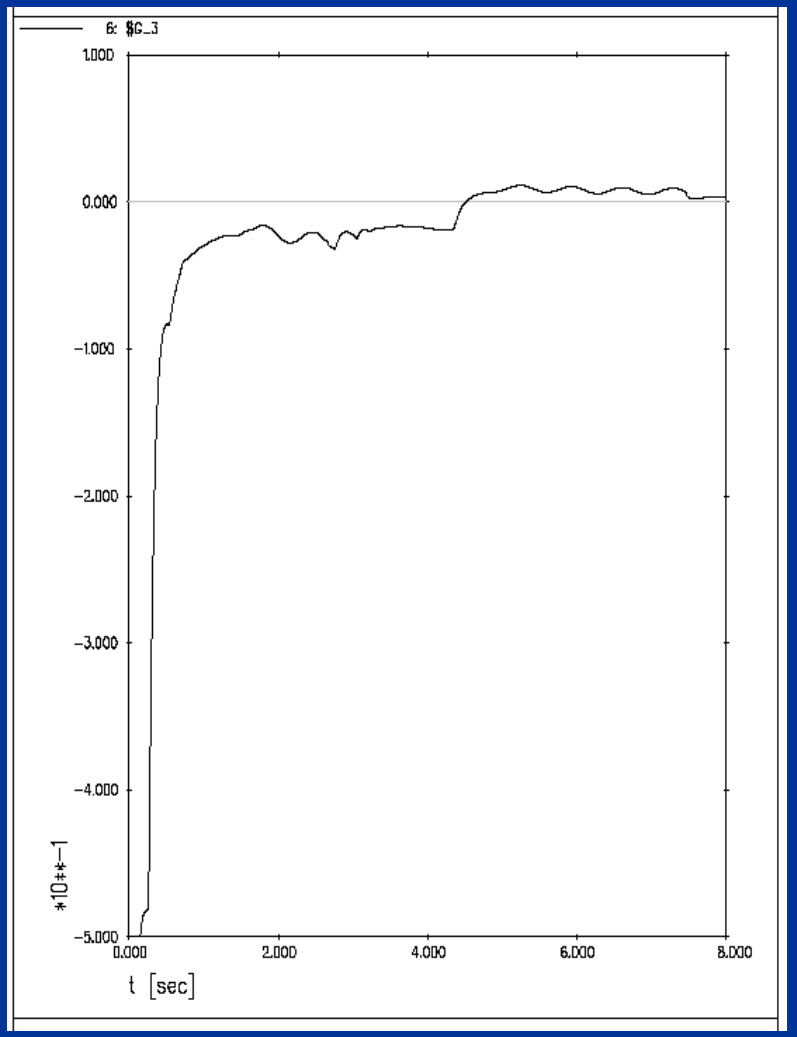
harpoon / anchor forces
and thruster force

Impact velocity : 1 m/s

Landersimulation II

Velocity (v_z, $v_z(t=0)$ = 0.5 m/s)





New comet target: 67P/Churyumov-Gerasimenko

The new target has an observed radius of about 2 km (instead of 800 m as for 46P/Wirtanen) and the gravity is to about 10^{-3} m/s^2 . Therefore the impact velocity of the lander due to the free fall towards the comet is increased significantly.

Challenge:
adaptation of landing scenario towards increase impact velocity (increase from nominal v_{impact} = 0.5 m/s to 1.1…1.5 m/s).
The kinetic energy of the lander is increased by a factor of up to 9.

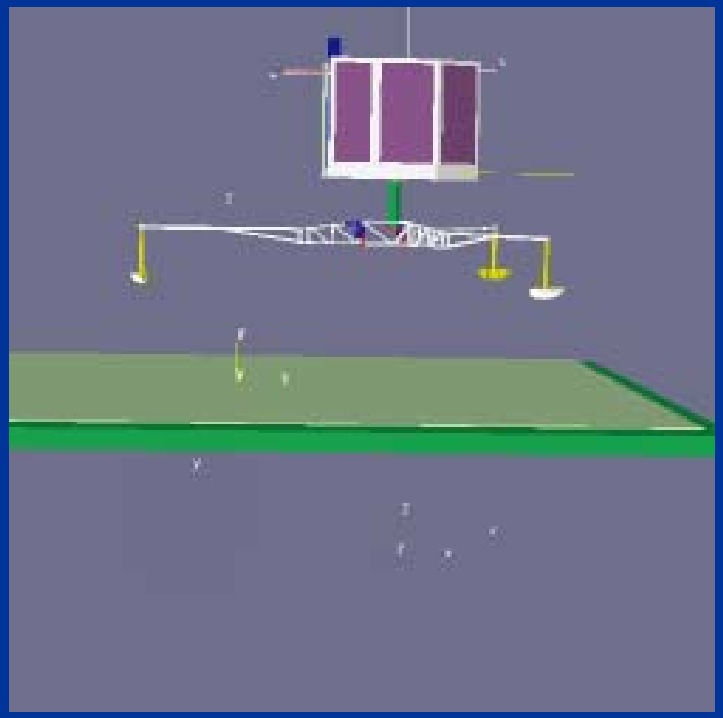
Boundary condition:
Lander is mounted to orbiter, fully tested and qualified.
No major alterations are possible.

Lander attached to orbiter,
Oct 2003

Landersimulation III

V_z=-1.5 m/s, V_x= 0.1 m/s, V_y= 0.1 m/s

"Flat surface"

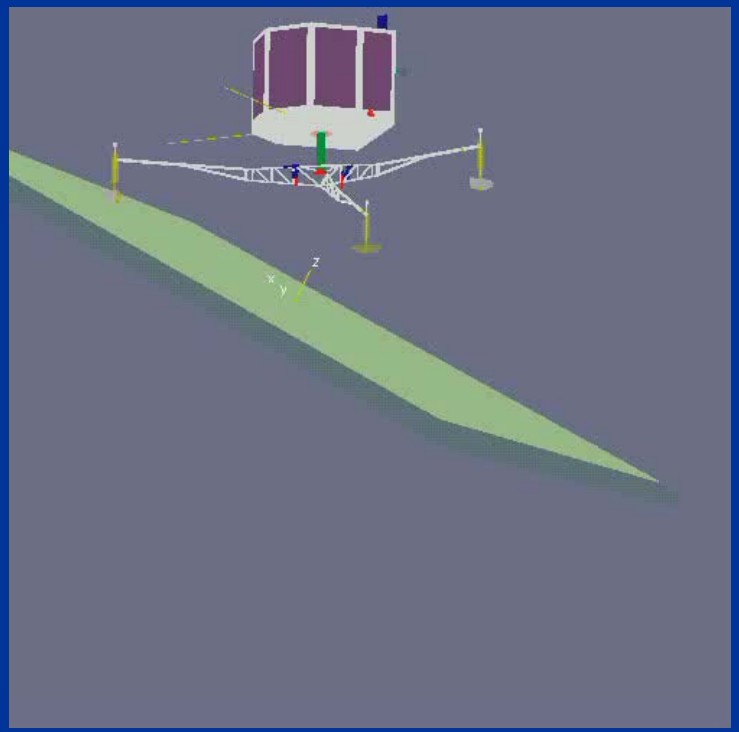


File b001

Landersimulation IV

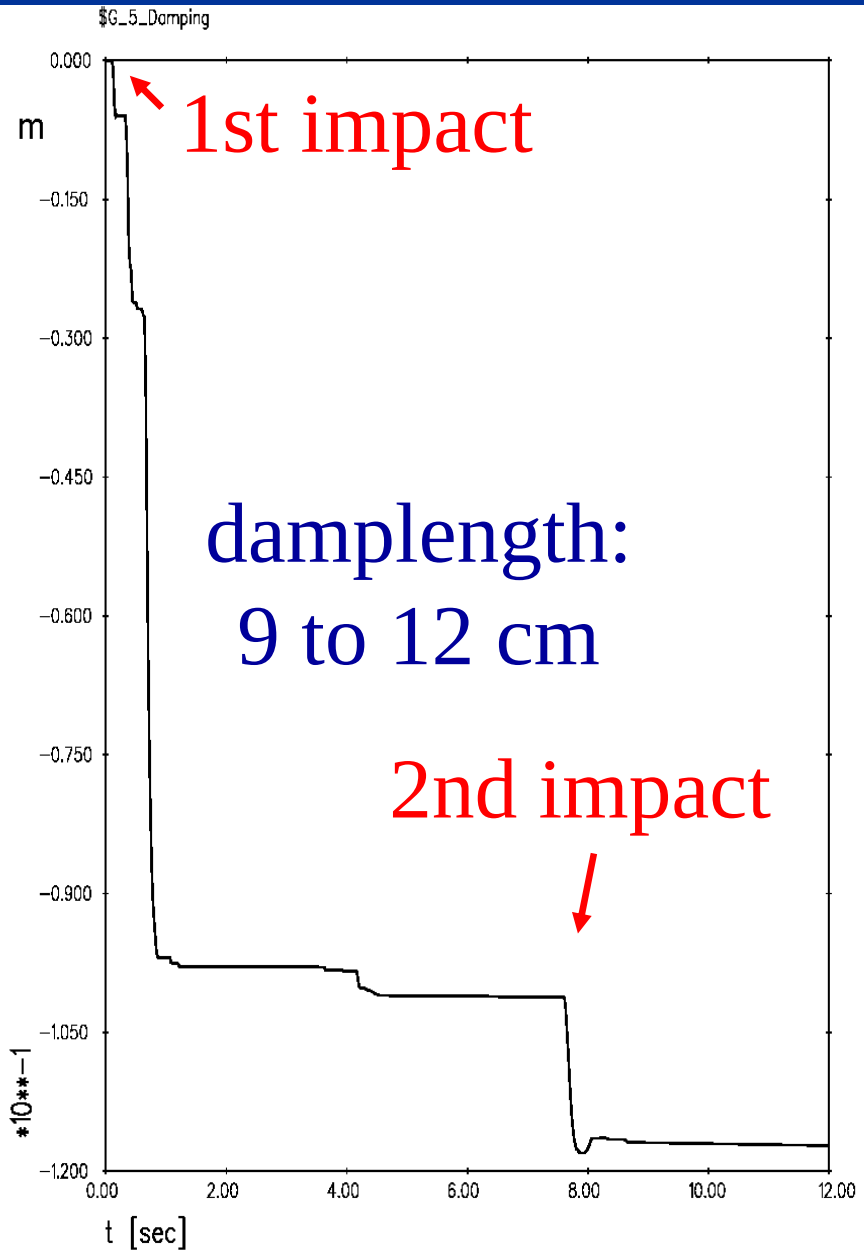
V_z=-1.2 m/s, V_x= 0.1 m/s, V_y= 0.1 m/s

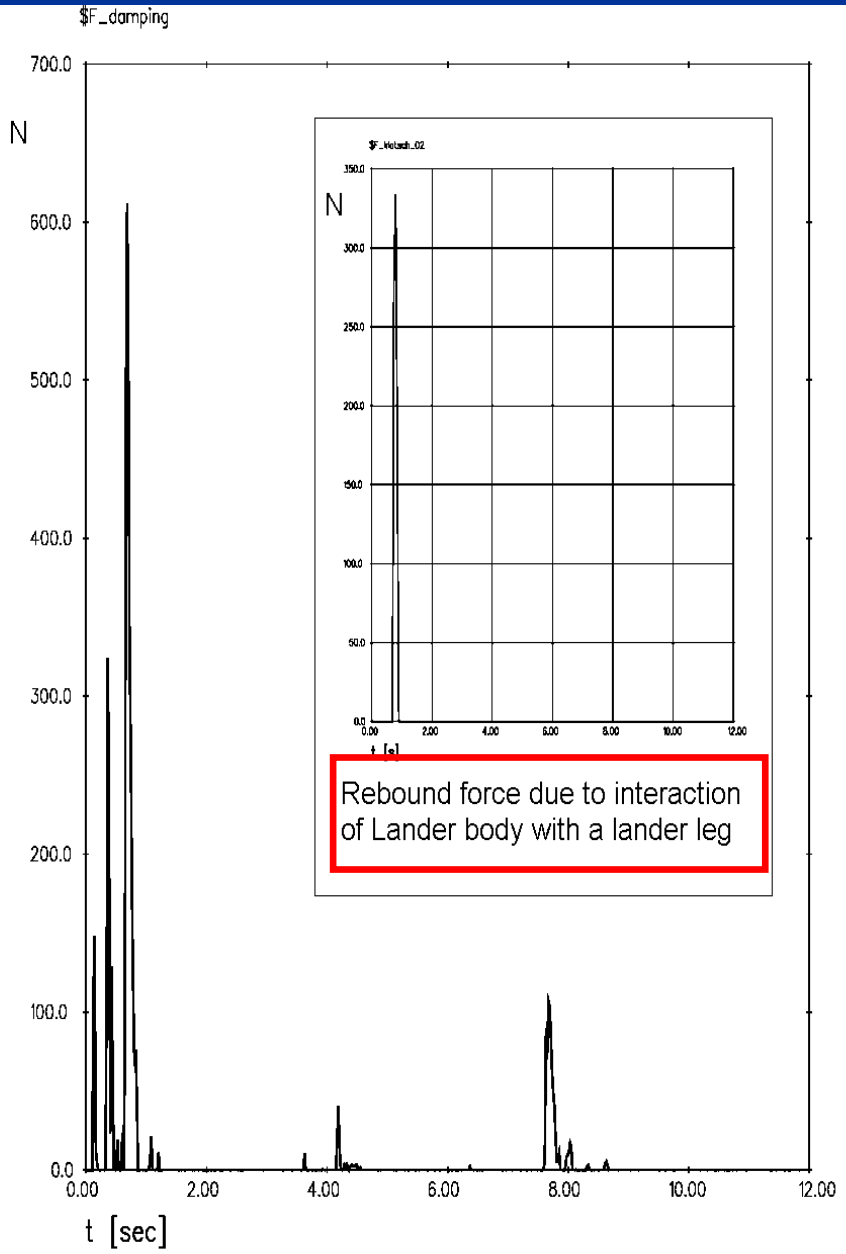
Cardanic joint stiffness: 520 Nm/rad
cardanic joint friction break torque : 30 Nm

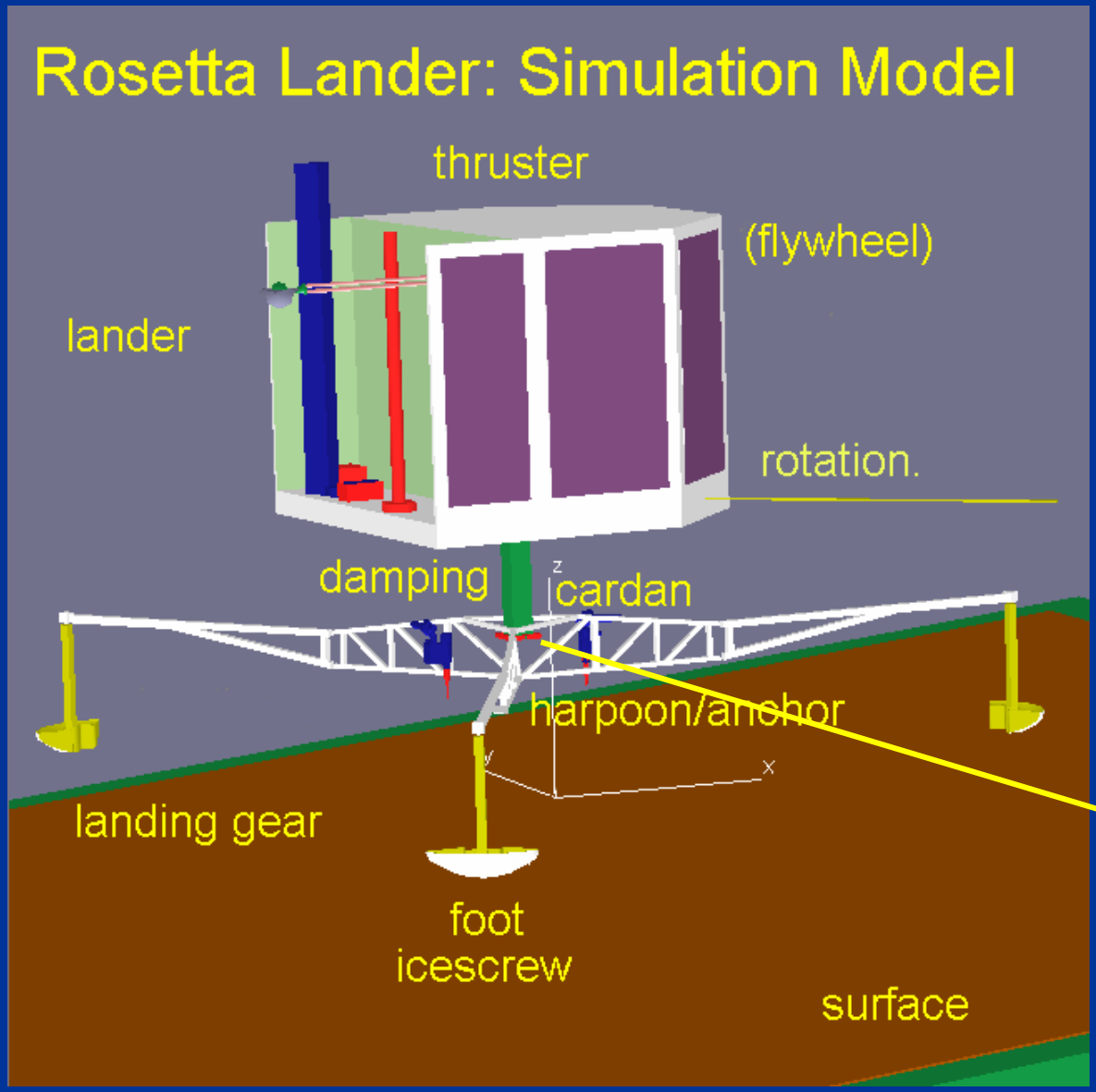


File 011

No cardanic joint tiltlimiter







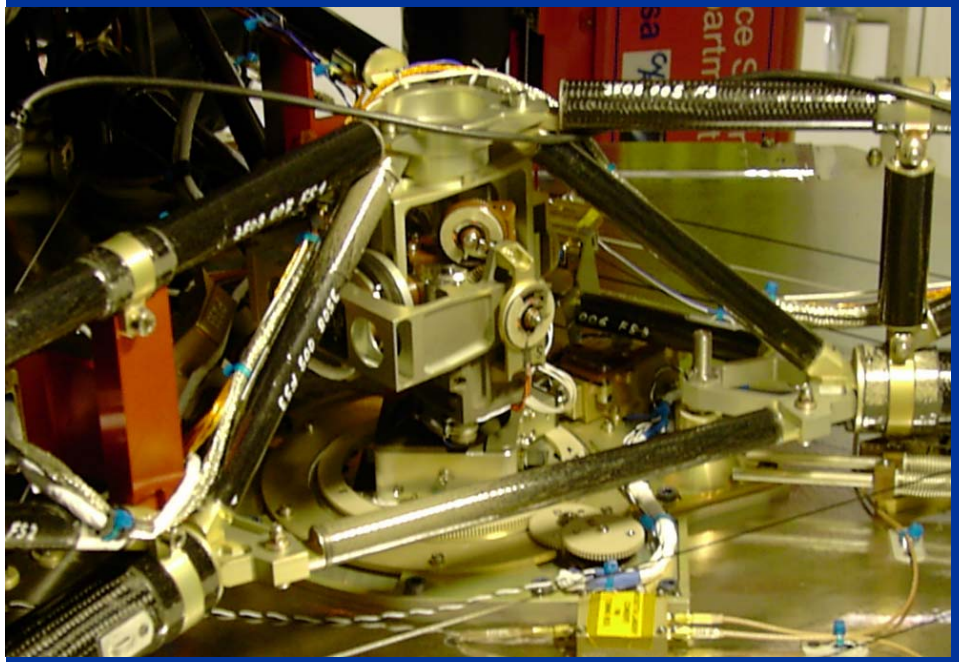
Stiffness cardanic joint (not the friction torque !):
520 Nm/rad measured

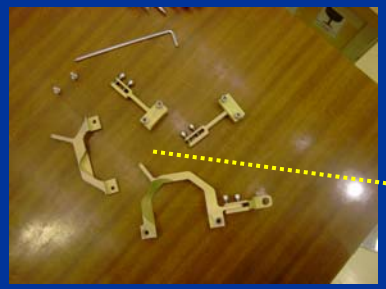
Introduction of a tilt limiter to the cardanic joint:

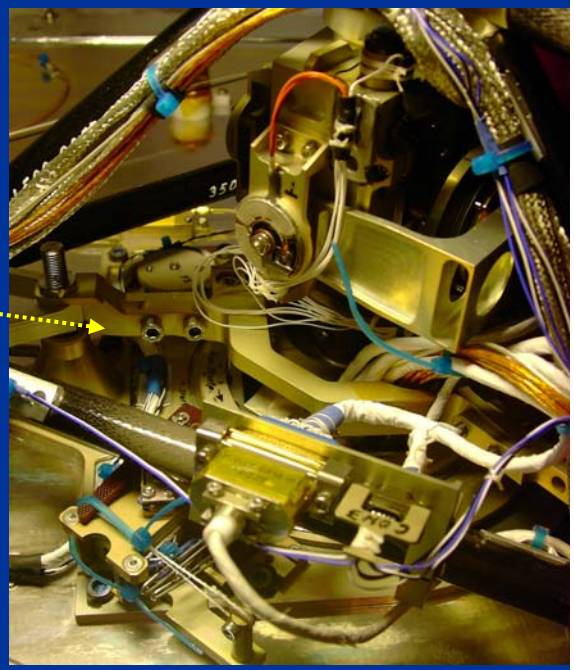
Limitation of free cardanic joint movement to 3°:

Advantage: The lander body can not touch the legs. Possible full use of damping length (about 18 cm) allows to damp impact velocities up to 1.2 - 1.3 m/s (function of slope).

Drawback: The angular momentum exchange with comet must be compensated by thruster and anchor action.







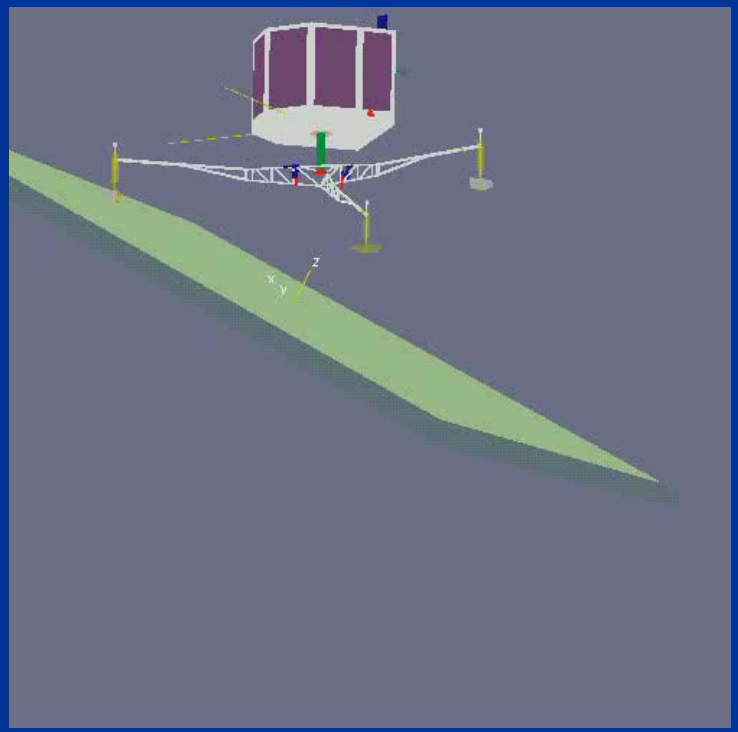
"free" cardanic joint

and with tilt-limiter

Landersimulation V

V_z=-1.2 m/s, V_x= 0.1 m/s, V_y= 0.1 m/s

cardanic joint tilt limiter : 1000 Nm/rad (18°->3°)
cardanic joint friction break torque : 30 Nm



File 010

with cardanic joint tilt-limiter