In-Space Propulsion Engine Architecture Based on Sublimation of Planetary Resources:

From Exploration Robots to Near-Earth Object Mitigation

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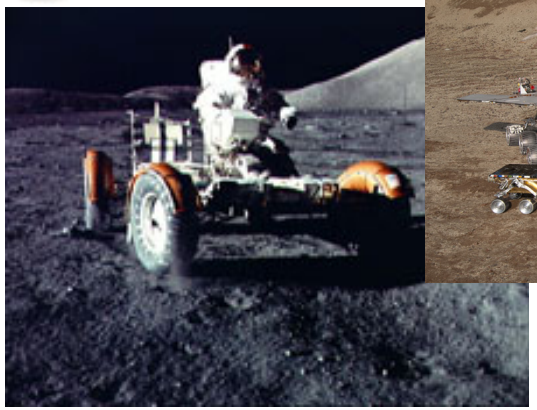
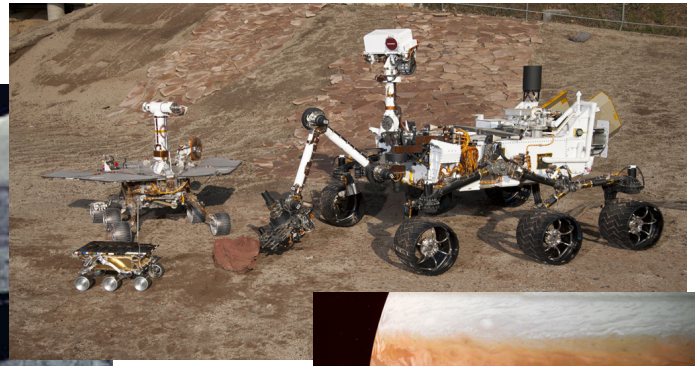
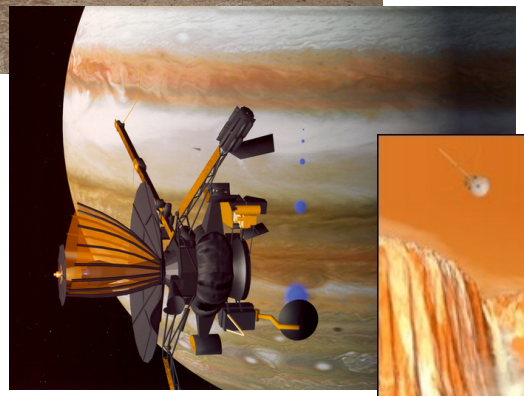
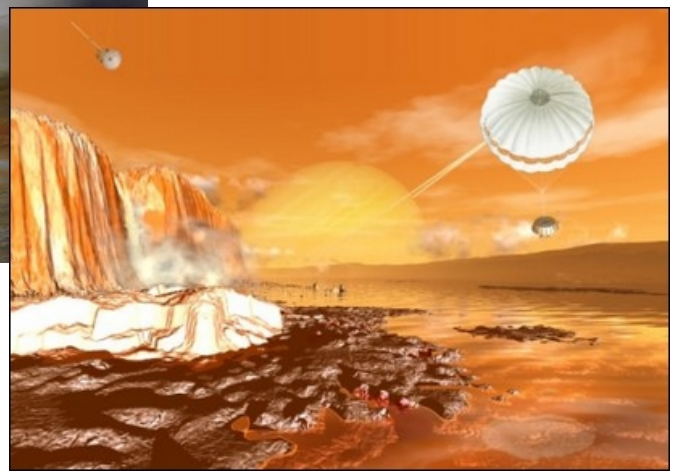
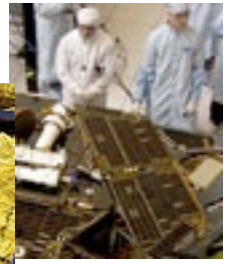
Exploration Spacecraft at work

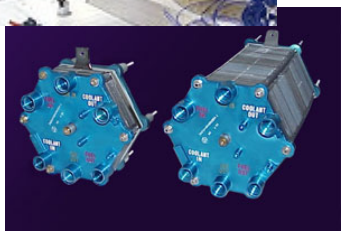












Electrical system

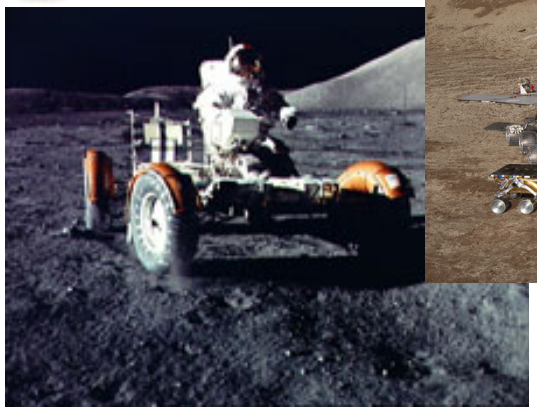
Thermal system

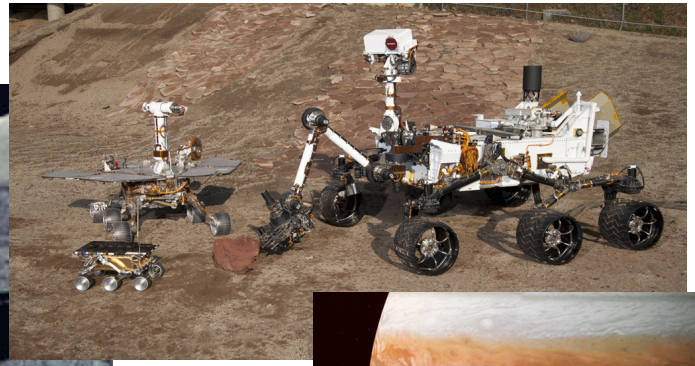
Chemical system

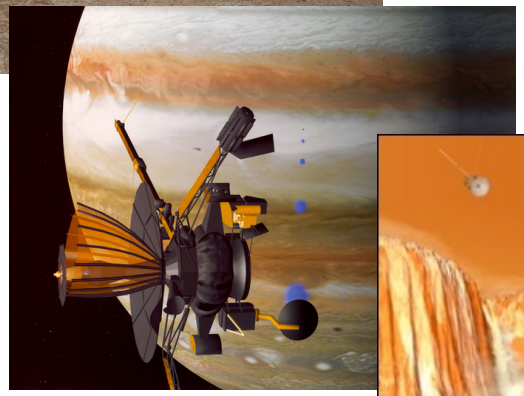
Mechanical system

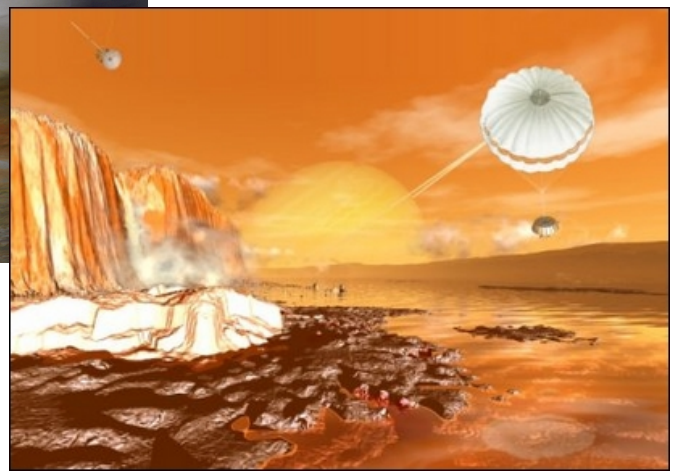
Propulsion system

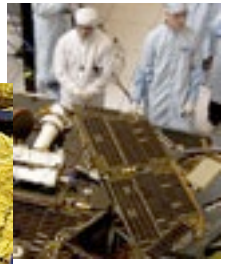
Exploration Spacecraft at work

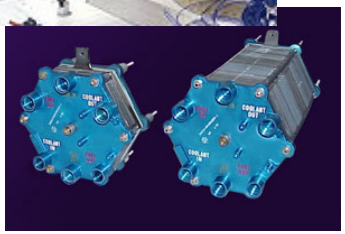












Electrical system

Thermal system

Space resource ??

Chemical system

Mechanical system

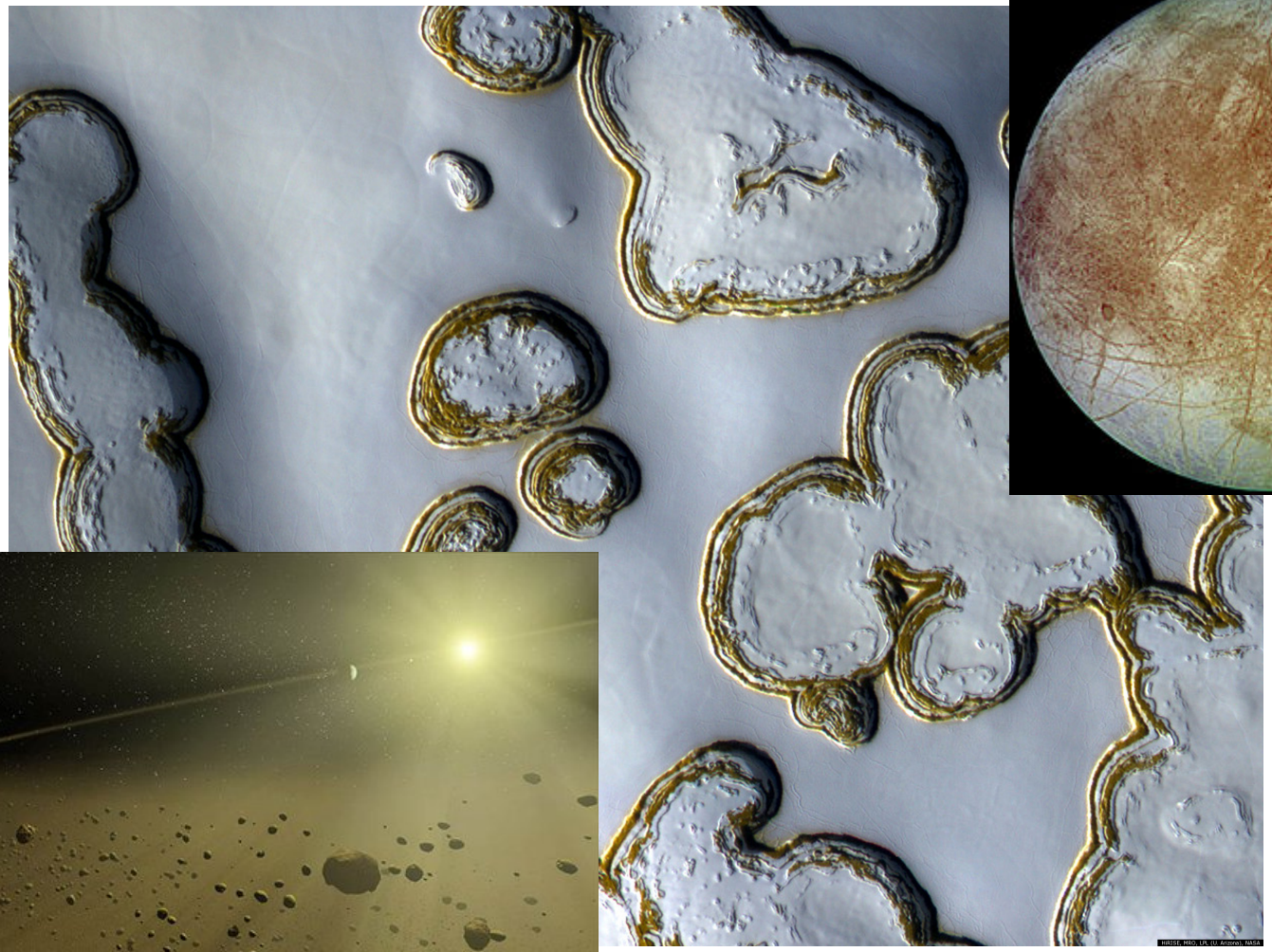
Propulsion system

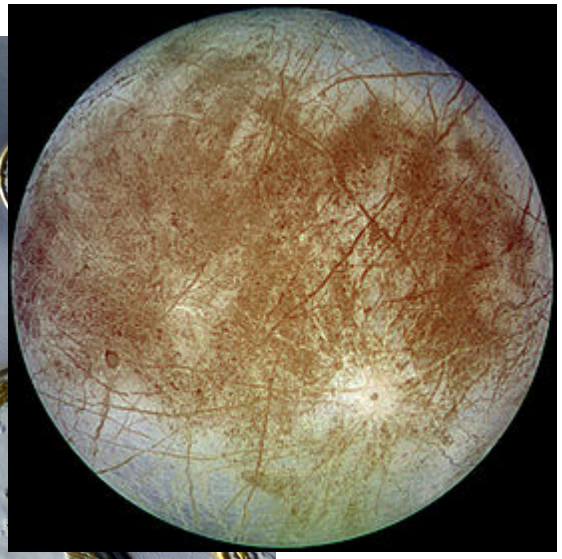
Exploration Spacecraft make little use of space resources

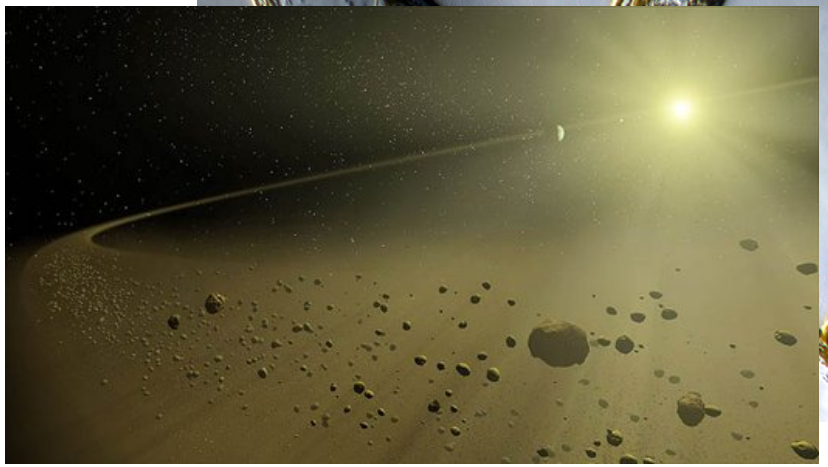
Solar illumination, vacuum, heat sink, solar winds

But same stuff is found in space as on Earth…

Ice … everywhere







NIAC study

State of Knowledge

Volatile and mineral resources available on asteroids, comets, moons and planets in the solar system

Supplemental Mechanical Power for Exploration Systems

Volatile resources ➔ Mechanical power or propulsion to deep space missions?

Identify the right applications : resource, conditions, location, need.

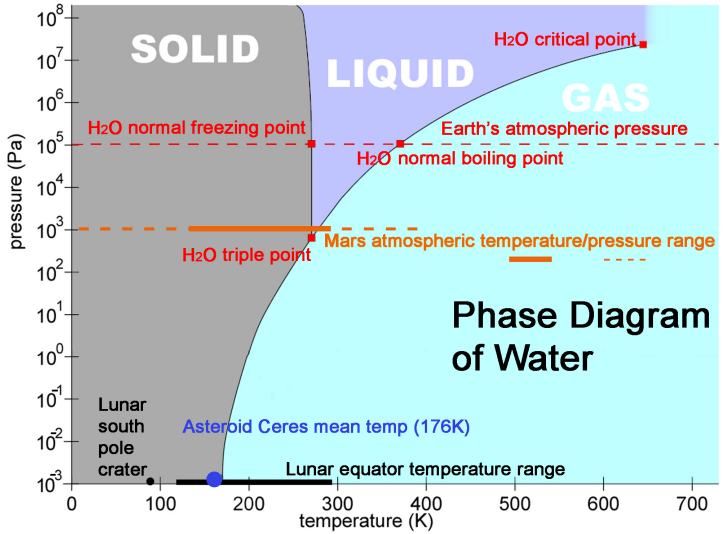
Measure production of gas under conditions and energy input

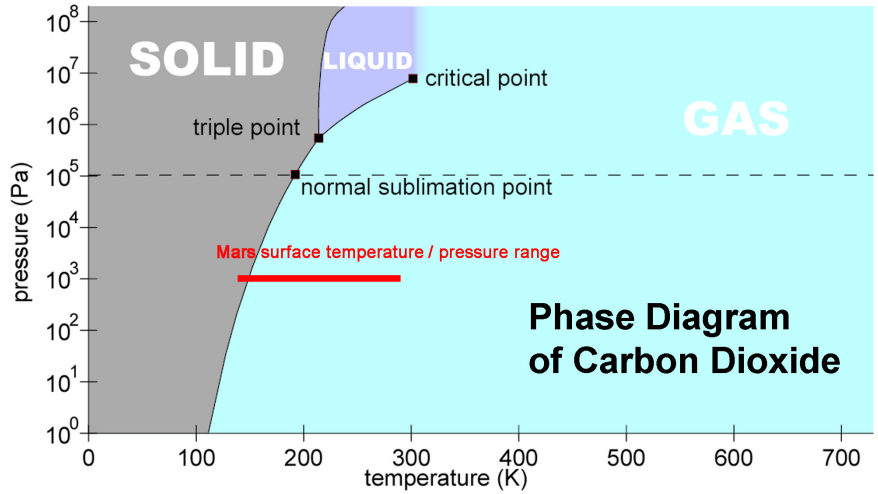
Mitigation of Threat from Near-Earth Objects

Can volatile resources on comets and asteroids be used to deflect them?

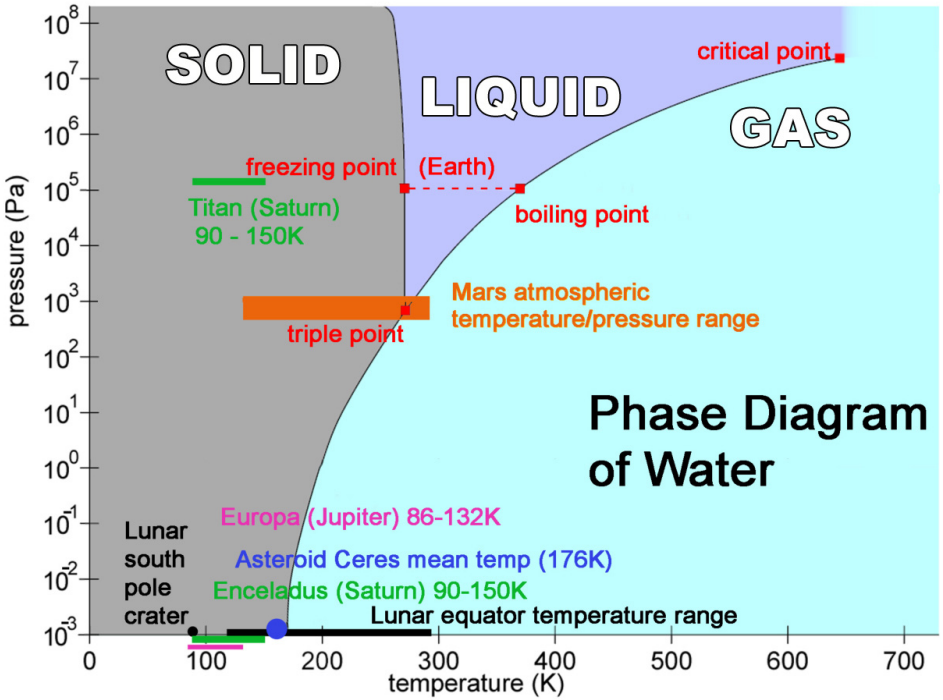
When is it possible?

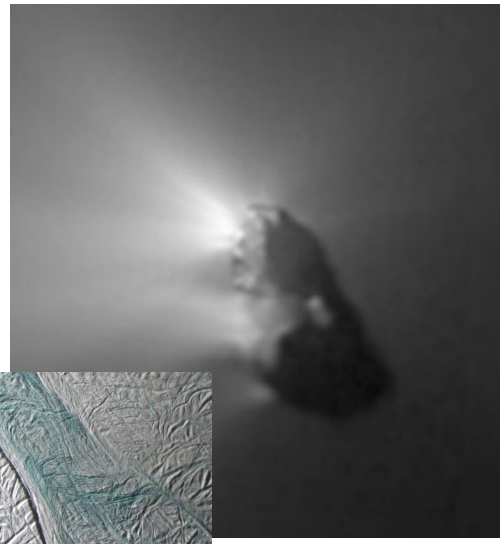
Sublimation



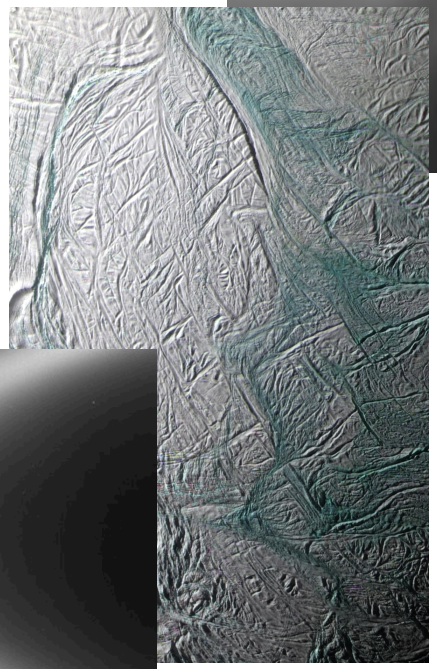


Water Ice conditions in space

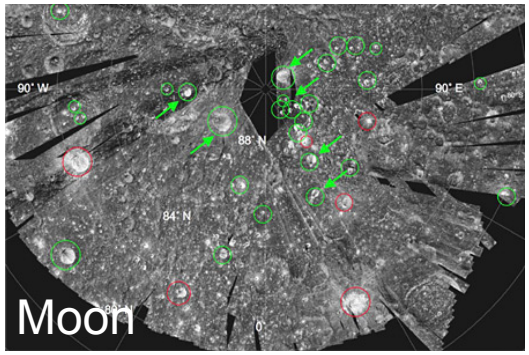




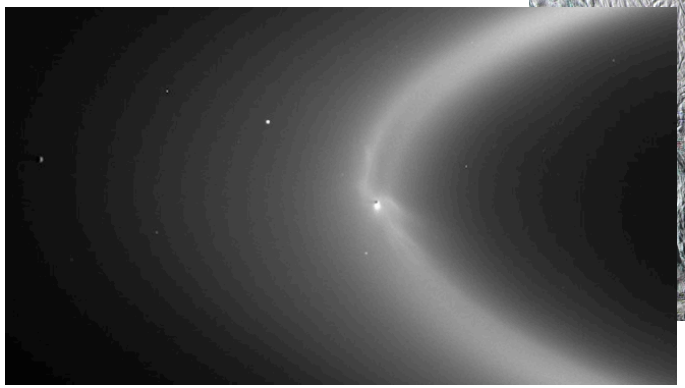
Halley



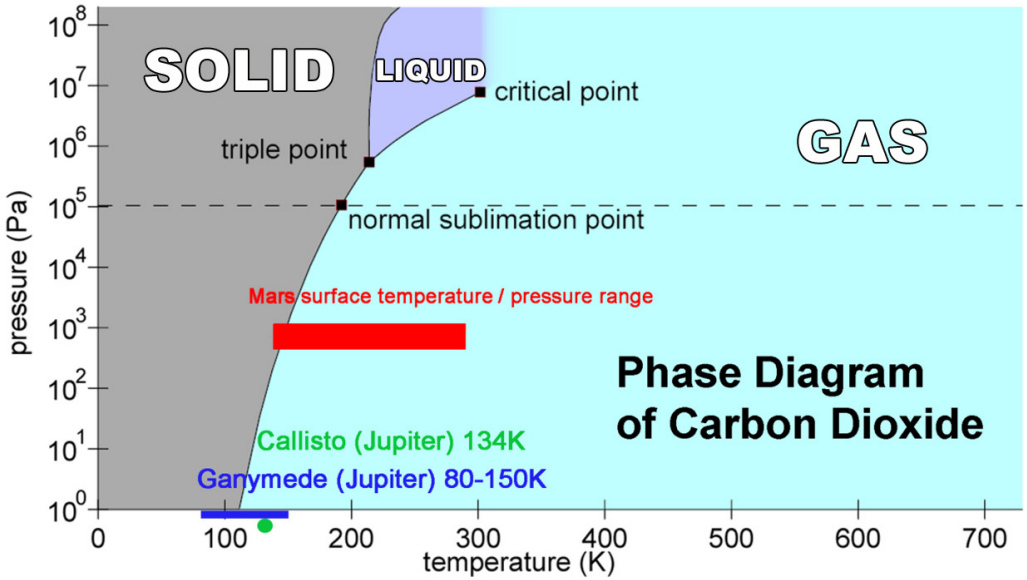
Enceladus

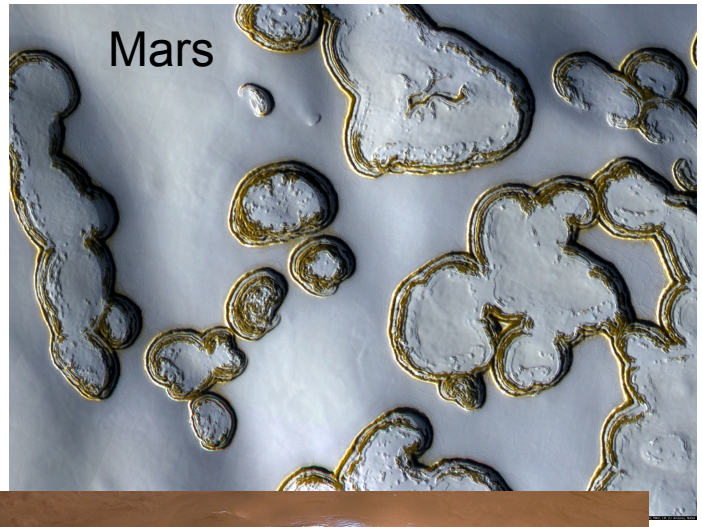


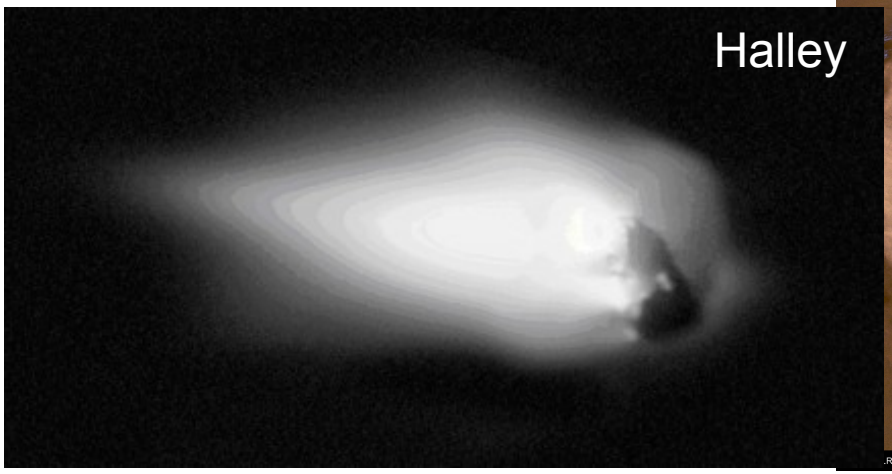
Moon

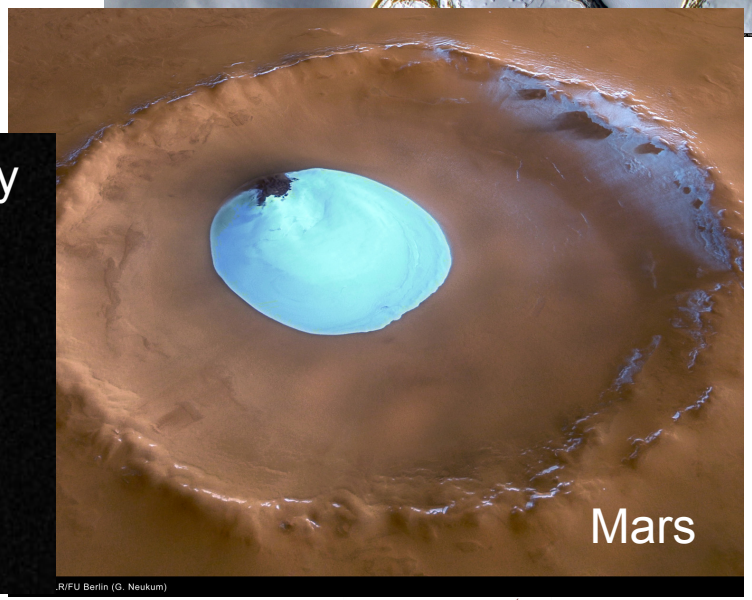


Carbon Dioxide Ice conditions in space









Ice types and conditions in the solar system

Location	Ice Type	Pressure (Torr)	Temperature (K)
Moon	H2O	10^{-14}	40 - 100
Mars	H2O, CO2	4.5	150
Comets	H2O, CO2	10^{-14}	40
Europa	H2O, CH4, CO2	10	100
Titan	H2O, CO2	1,140	150

Applications of sublimation gas in planetary missions

Pneumatic Conveying of Regolith

Soils can be excavated and/or transferred to instrumentation or chemical reactors by gas-driven conveying. 500 grams of CO_2 ice sublimated into gas at 10 psig would convey 5 Kg of regolith in one minute under Martian conditions.

Attitude-control thruster (Mars)

a 3.6N thruster would require 71 Kg of CO_2 per minute.

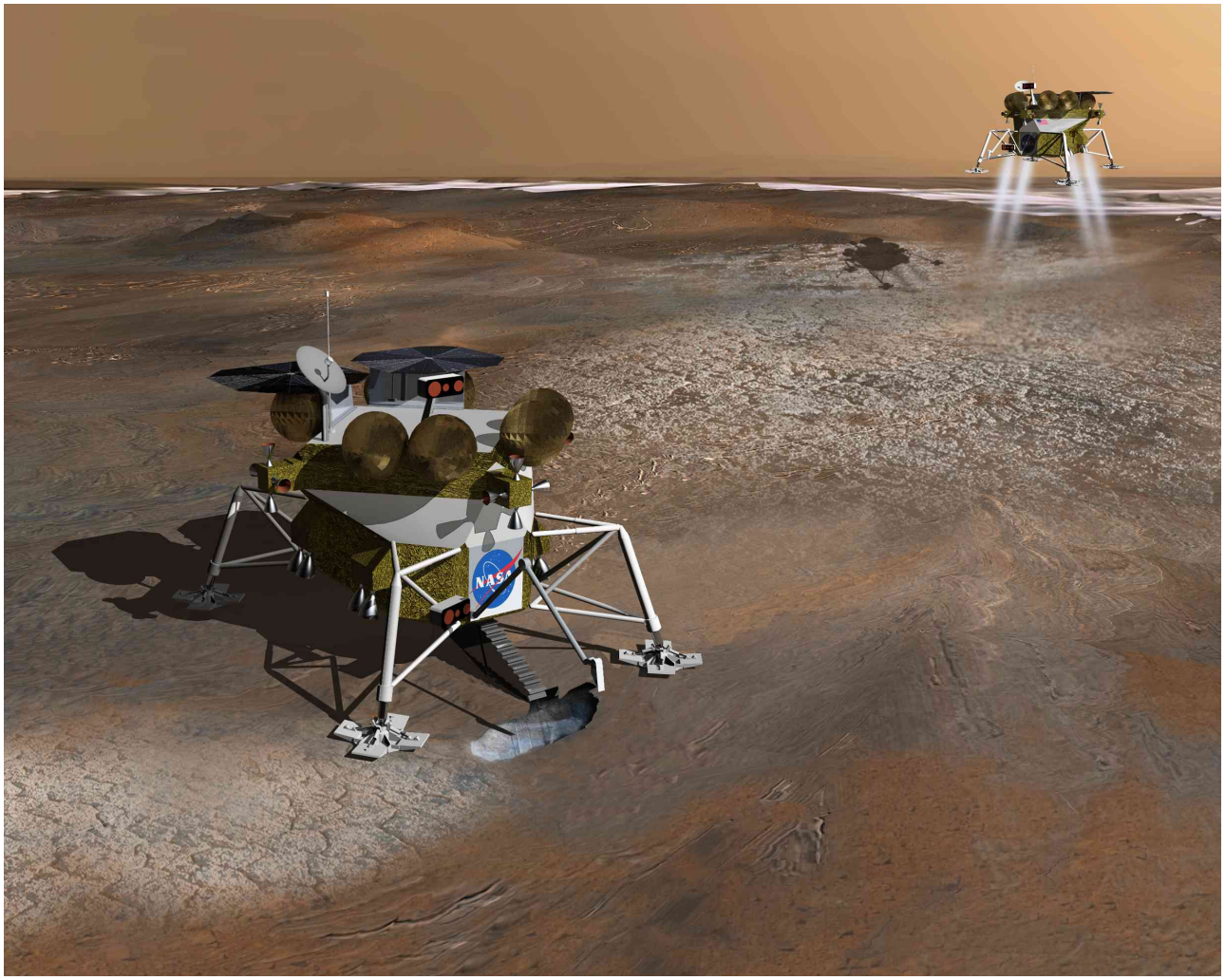
Surface robots mechanical power

Removal of objects, trench digging, gas powered grappling gun, small aircraft assisted launch, tumbleweed propulsion

Near Earth Asteroid deflection

Deflecting a C-type asteroid by providing a ΔV of 1m/s in one day requires ejecting 4×10^{-6}% of its mass at 3m/s during that time. This means 660 Kg of material must be ejected per second for one day to deflect a 400m C-type asteroid.

Exploration Robots Propulsion



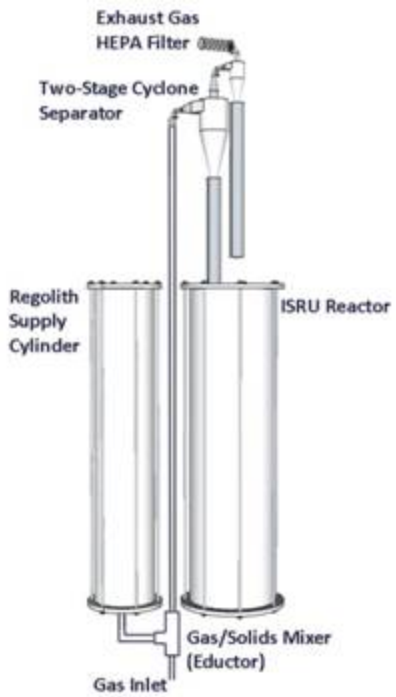
Robotic hoppers acquiring ice from Martian surface to refuel attitude-control thrusters using cold gas propulsion.

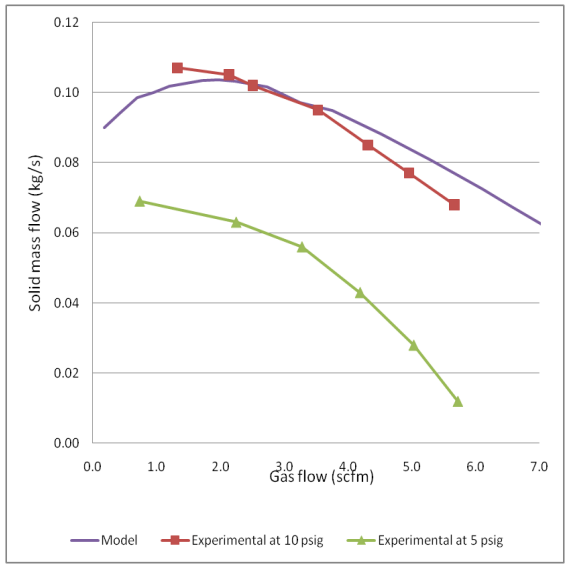
Pneumatic transfer of regolith

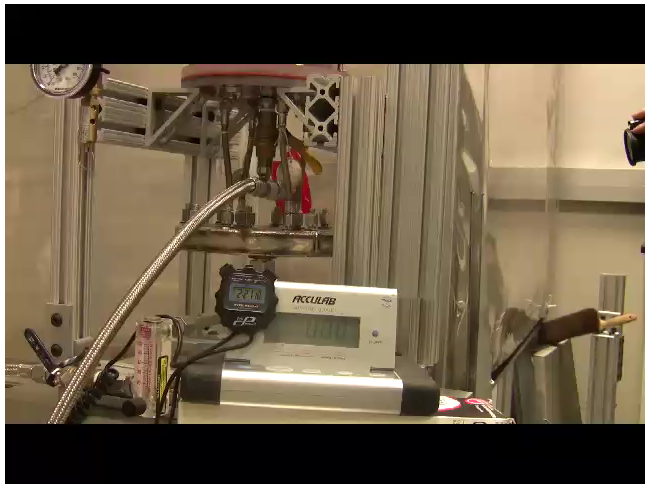
Enthalpy of sublimation of CO_2 under Mars conditions: 590 kJ/kg at 155K

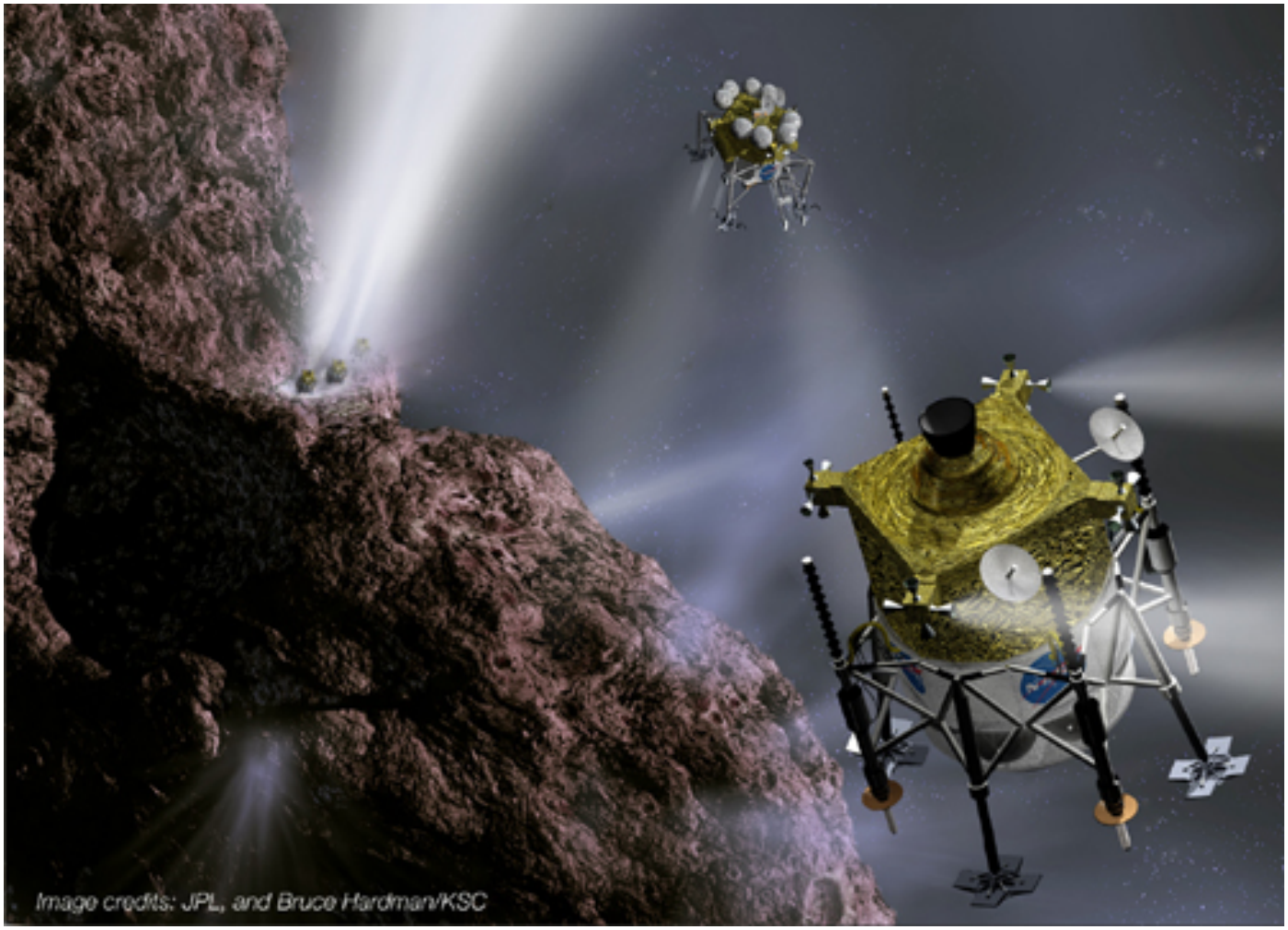
Earth condition transfer (760 Torr): 5-10 psig of air // 100 g/s of regolith

Mars conditions (4.5 Torr): 1-3 psig estimated









Concept for utilizing a comet's frozen resources to provide cold propulsion and deflect it from a potential collision with Earth.

Asteroid & Comet Deflection by In Situ Propulsion

Sustained action over time may become a viable option when:

1. Political or societal pressures delay or eliminate the use of nuclear weapons
2. Disagreement among international partners on the use and availability of weapons
3. Concerns over the fate of the fragmented object.
4. Pre-positioning of propulsive deflectors is feasible ahead of decision times

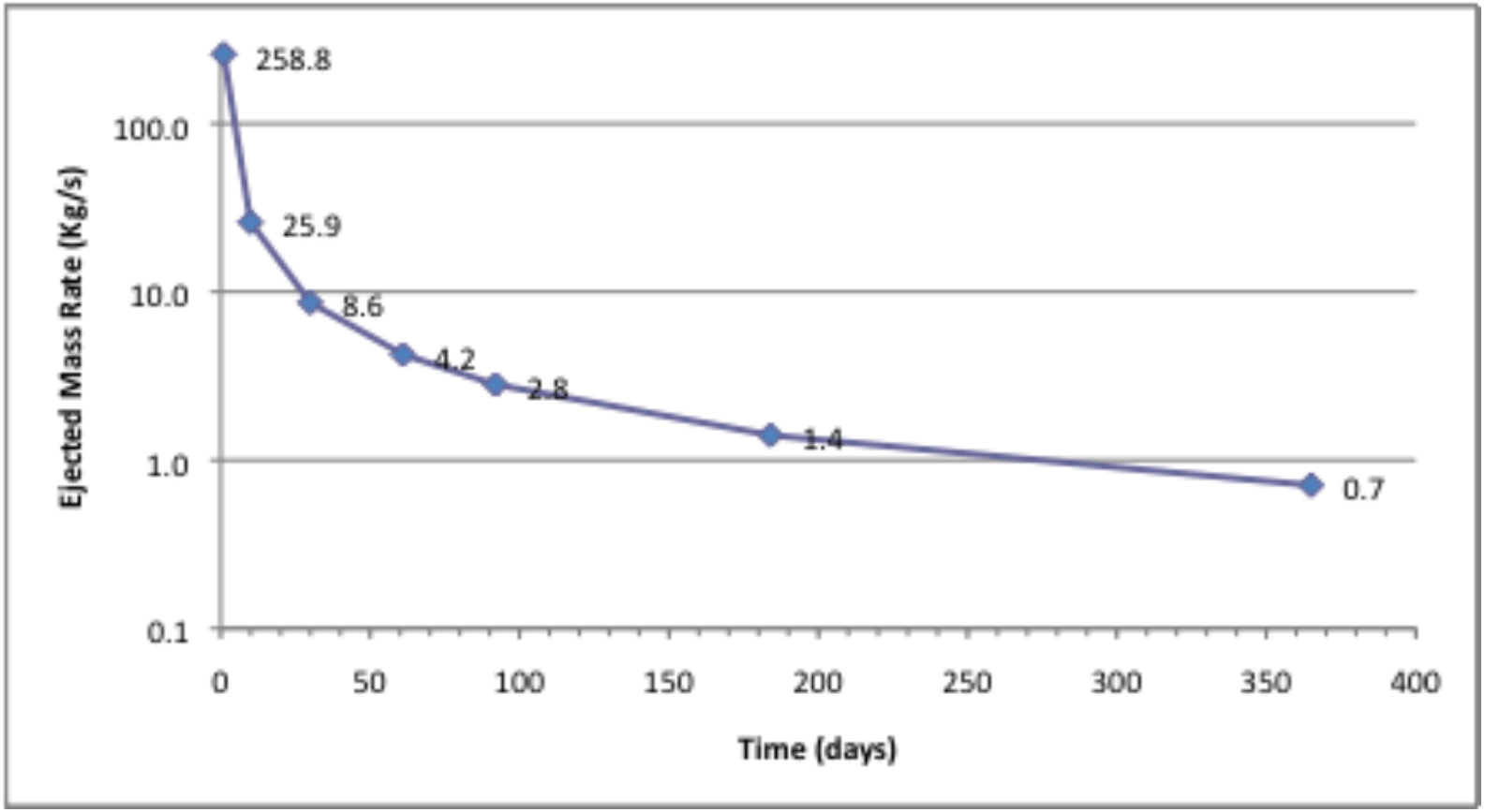
Major challenges

Comets are active producers of gas through sublimation. Can we reasonably impact them by using the same principle?

Unstable environment. Operation for months to a year.

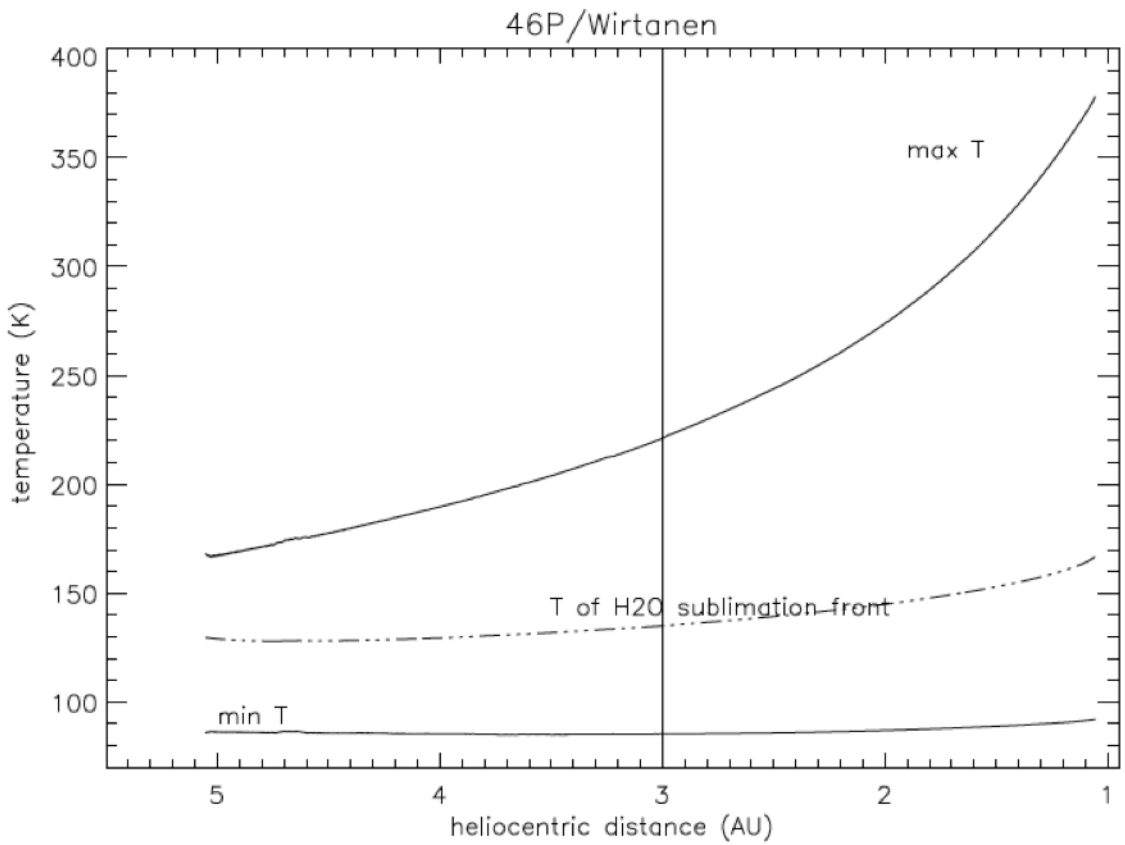
Long mission reliability

In Situ Propulsion for Asteroid & Comet Deflection



Ejected mass flow rate from a comet or asteroid to propel it on a deflected orbit with a ΔV of 1m/s. Example assumes a gas/solid material velocity of 3 m/s, and an object of 400 m in diameter with a density of 2 g/cm^3

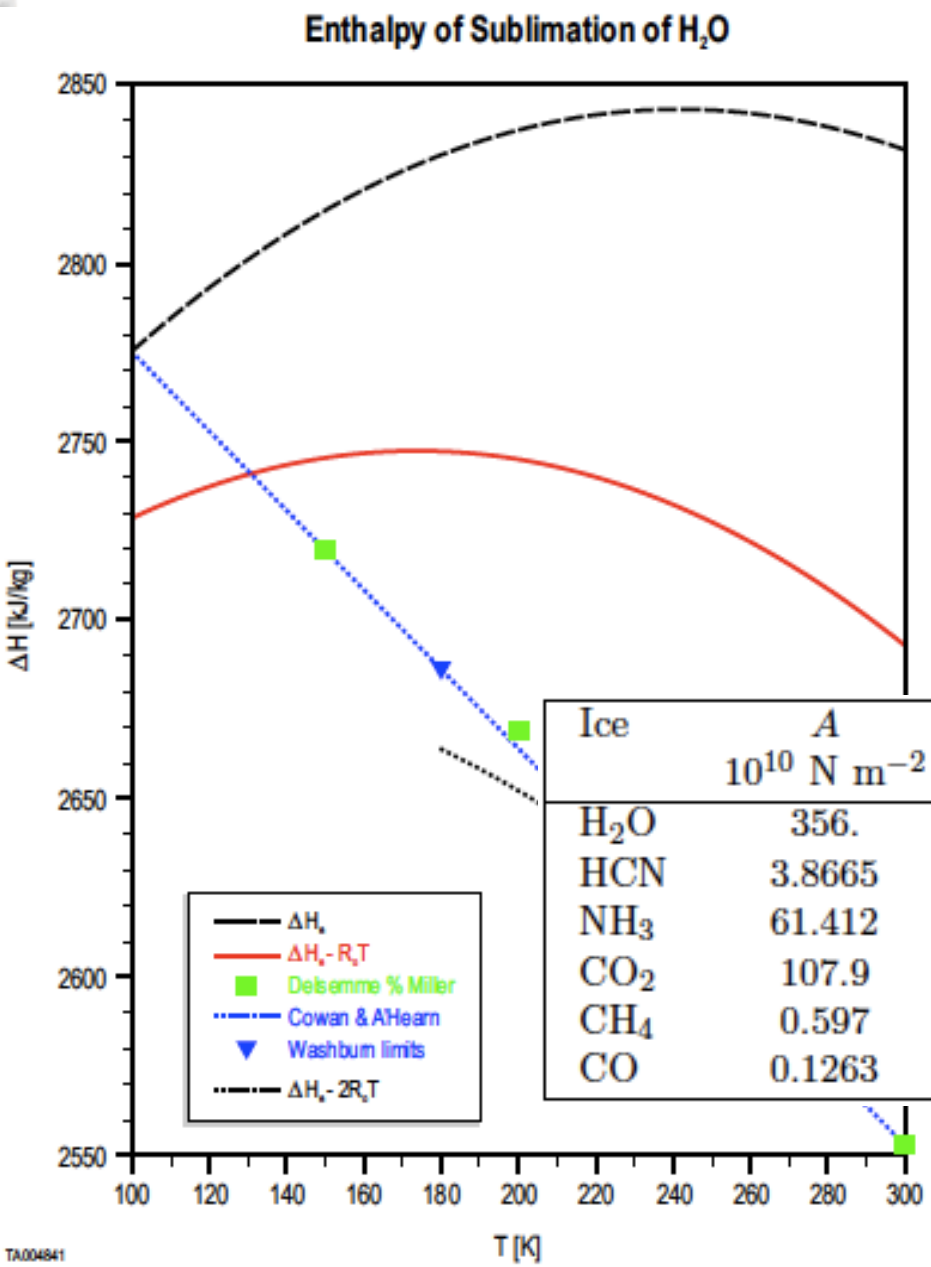
Gas evolution at comets



At perihelion, 0.25 x 10^{27} molecules/s is ejected ~ 416 moles/s

If of water only, 416 moles/s ~ 7.5 kg/s.

W.F. Huebner et al. "Heat and Gas Diffusion in Comet Nuclei", ISSI Report SR-004 (2006)



ΔHs (H_20) ~ 2.75 MJ/kg

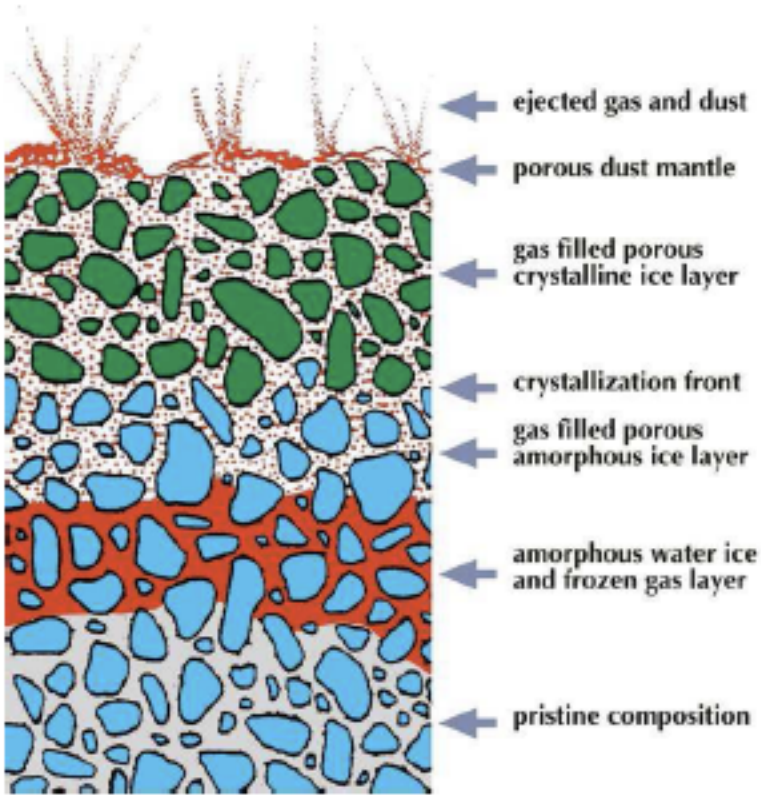
Ice	A 10^{10} N m^{-2}	B K	T_s K	ΔH 10^6 J kg^{-1}	$\dot{r}$ cm/d
H_2O	356.	6141.67	133	2.830	0.8
HCN	3.8665	4024.66	97	1.240	37
NH_3	61.412	3603.60	81	1.760	26
CO_2	107.9	3148.00	70	0.594	78
CH_4	0.597	1190.20	30	0.617	75
CO	0.1263	764.16	20	0.227	200

Heat and Gas Diffusion in Comet Nuclei, ISSI Scientific Report, W.F. Huebner et al.

Comet deflection by water sublimation

1. Controlled Mass ejection by sublimation may be effective at several AU of perihelion
2. Energy required is of the order of 2.7 MJ/kg of ice … i.e. 3 MW power source !

Comet helps: Phase transition of amorphous ice to crystallization is exothermic and triggers sublimation of trapped gases (1.6 kJ/mol)



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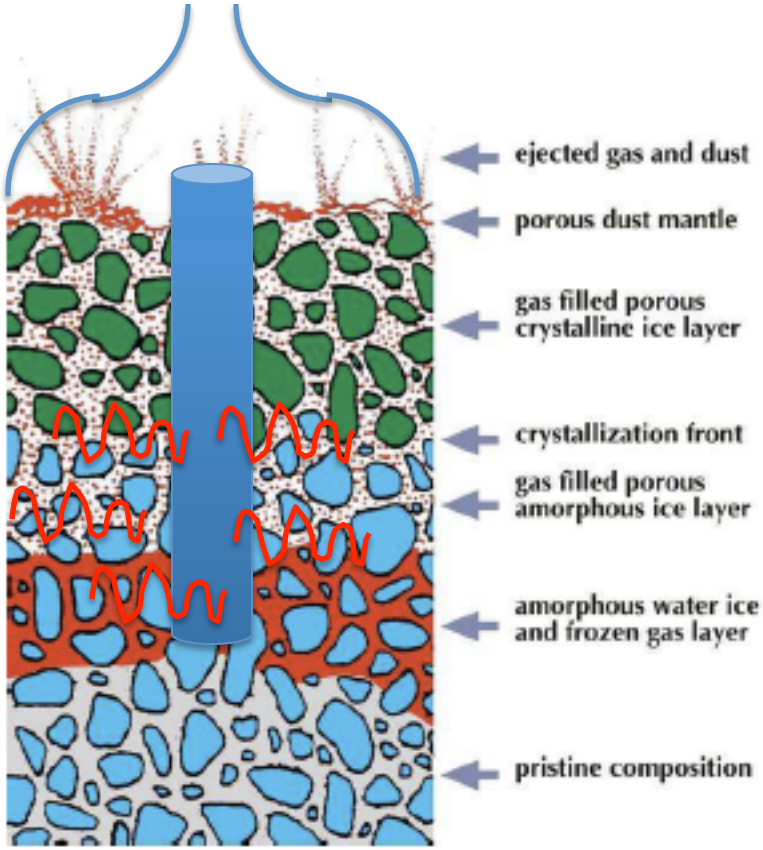
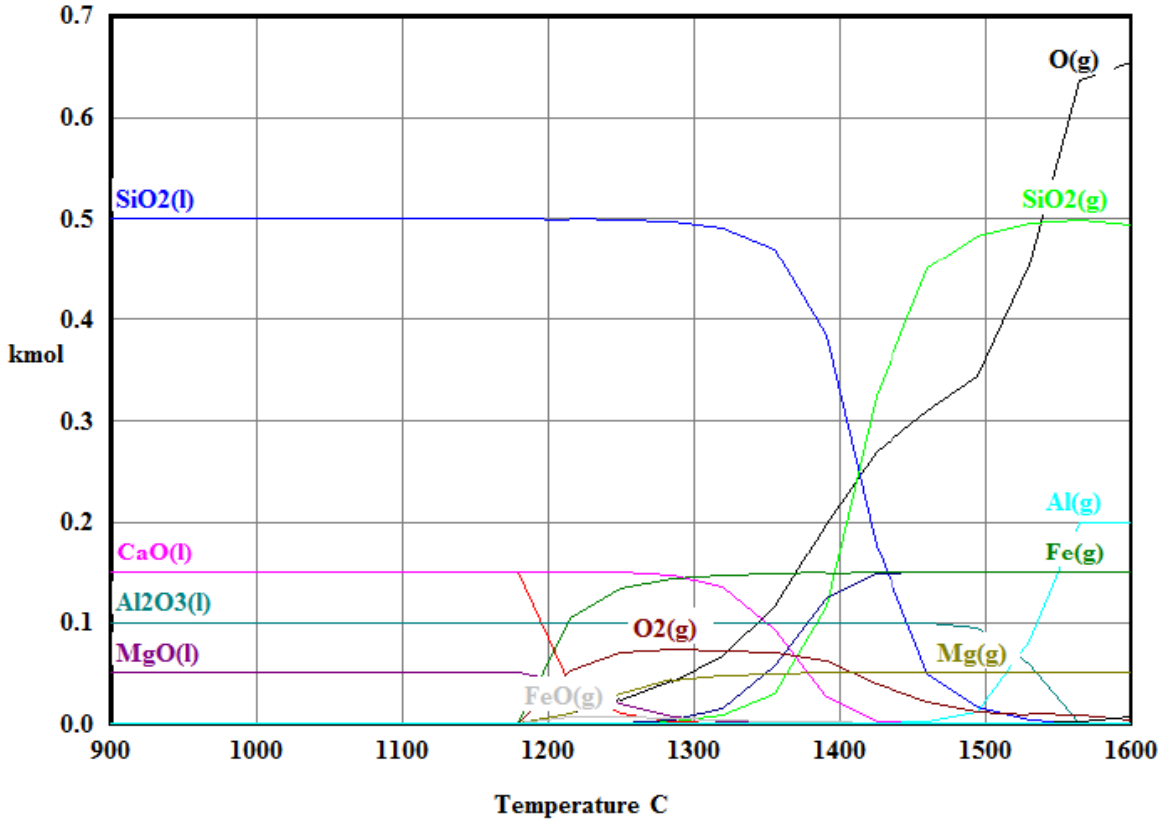
Concept: Trigger phase change by heat piping and propel released gases



Sublimation of silicates from asteroids at pressure 10^{-7} torr



Large energy required: 12 MJ/kg (i.e. 4.7 kWh/kg)

Recombination of species

Summary

Water and Carbon Dioxide ice in our solar system can be sublimated at low pressures.

Exploration Robot applications concepts analysis

Demonstrations of regolith transfer by CO_2 gas and pressurization of extracted gas are underway.

NEO mitigation by in situ propulsion

- Multi-year mission with impact away from perihelion. Not for short warning times.
- Thermal management concepts to lower energy inputs

Slim Fast, Now used by NASA
to save the world from
Overweight Comets!
Image credits: JPL, and Bruce Hardman/KSC

Acknowledgements

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