ICESIP: Internal Combustion Engine Solar Independent Propulsion

for Lunar Polar Exploration Rovers (LPERs)

The very idea is not crazy:

1930's-inspired flathead for Centaur 3rd stage invented by United Launch Alliance (ULA)

Why ICESIP?

#1 Reason:

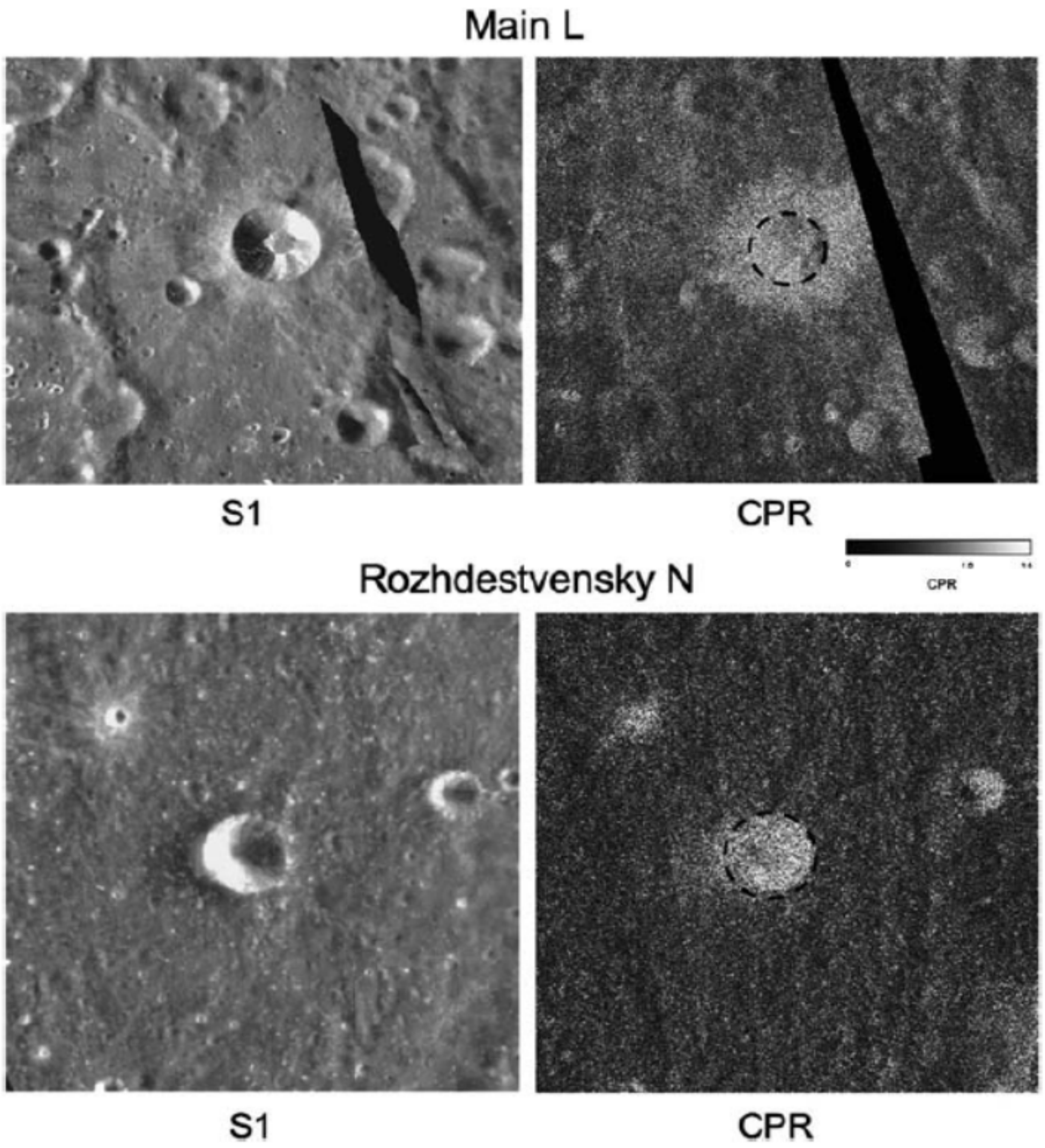
Need for extended operations within permanently shaded regions (PSRs) of Moon

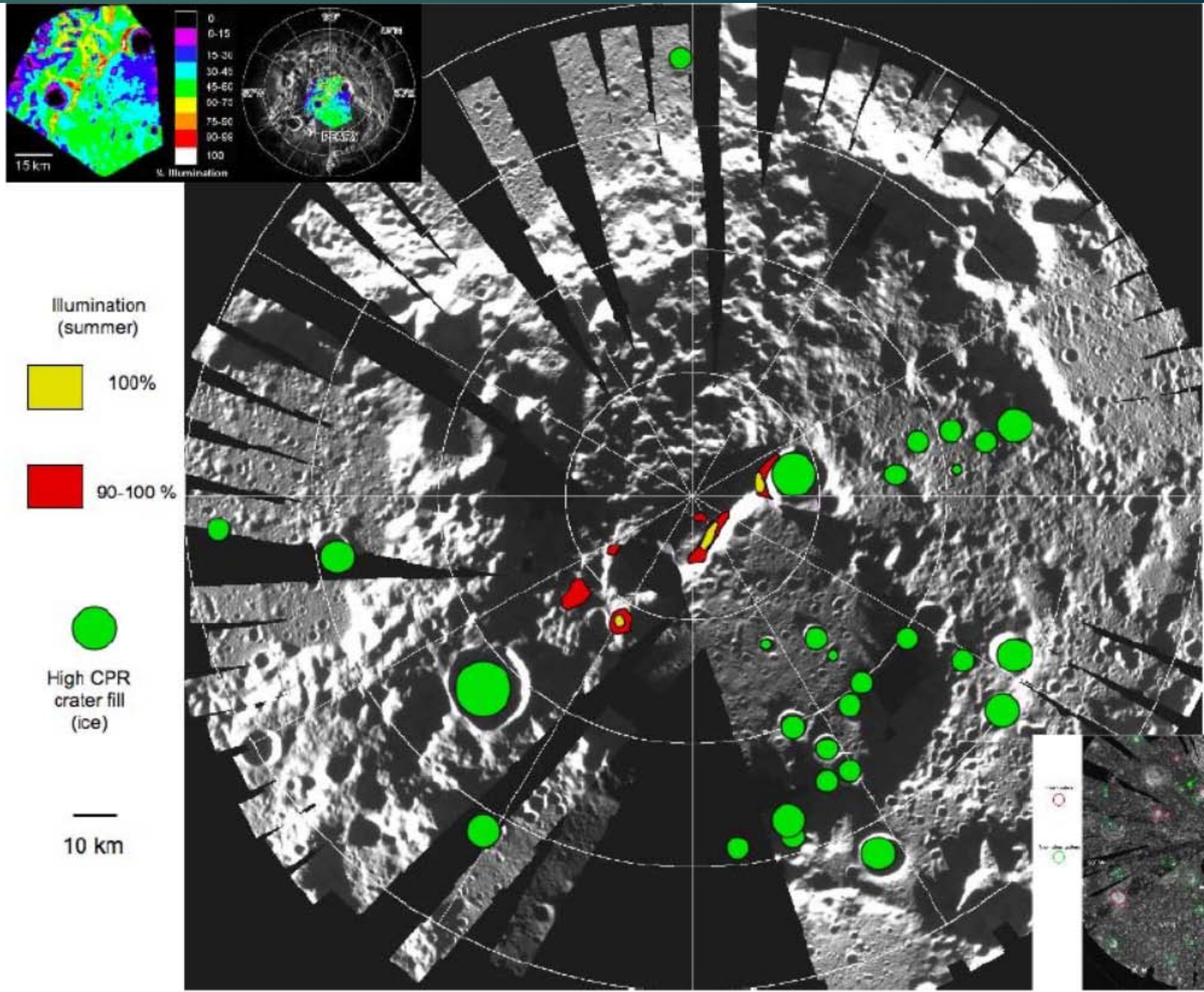
2. Nukes are super-expensive

3. The interesting craters lack solar energy

What are the high value targets (HVTs)?

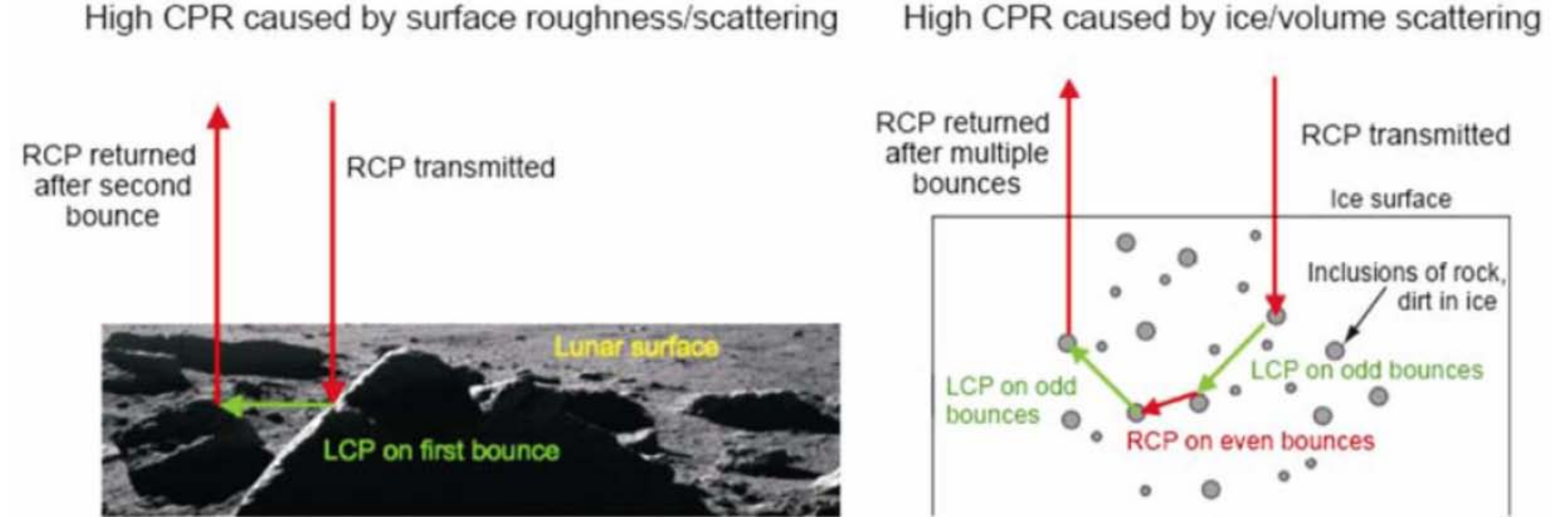
A: the anomalous craters…





Circular Polarization Ratio (CPR)

- ratio of same-sense to opposite sense circular polarization
- thought to mark "relatively pure" H_2O ice

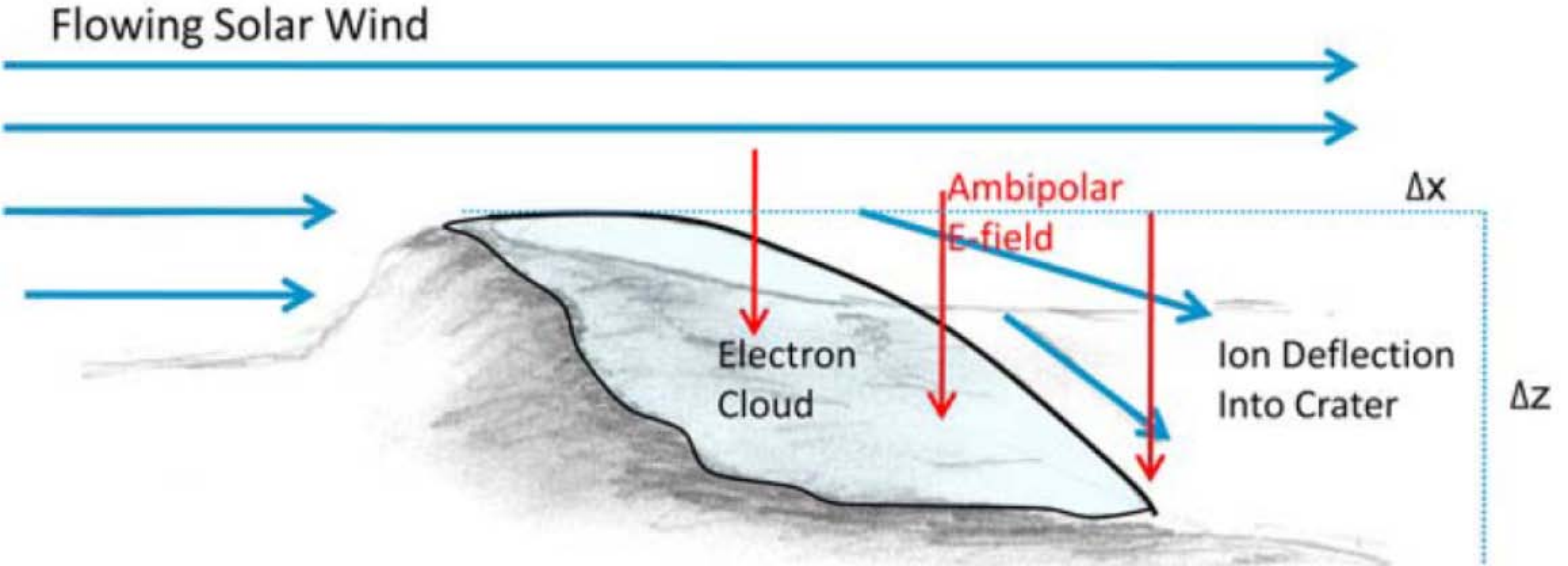


Properties of anomalous craters

1. Extra cold temperatures (~30°K)
2. Would have higher H_2O content
3. Ice of unknown texture or density
4. Small (<20 km) craters within craters
5. Craters tend to be steep sided (~30°)
6. Zones with low electrostatic activity
7. Possibility of electrostatic placer deposits

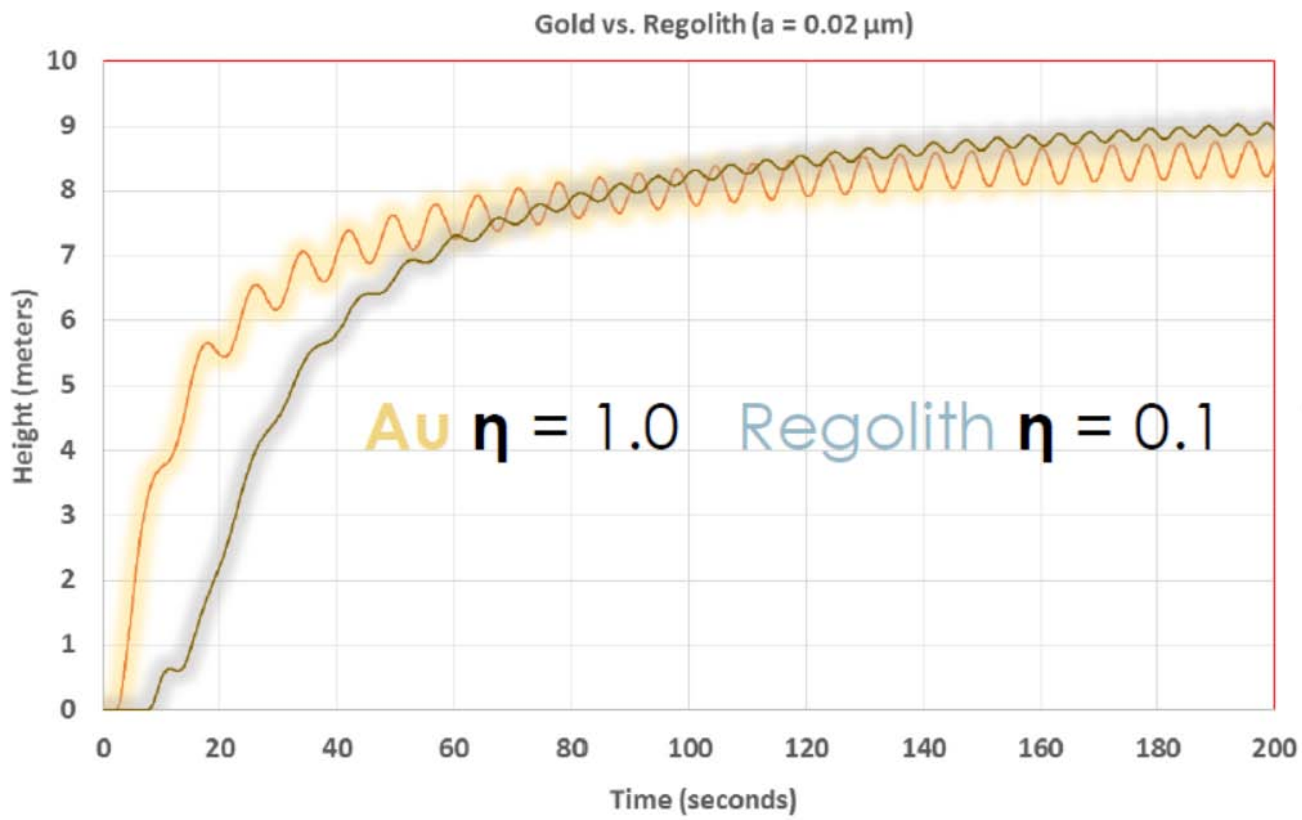
6. Effect of solar wind on lunar ice

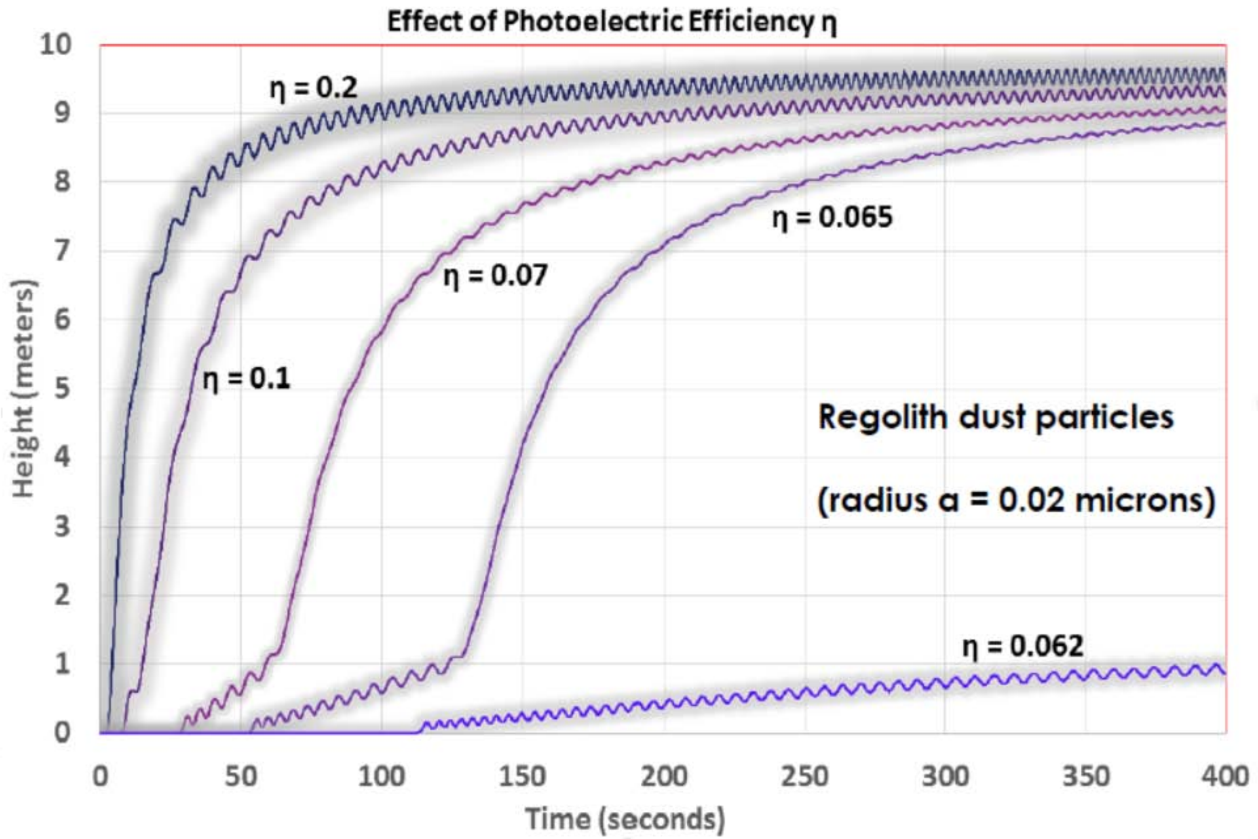
- H^+ ions will cause erosion of lunar ice
- Small craters within craters avoid this effect



Electrostatic placer deposits of gold?

- LCROSS implies ~0.5% Au(5,000 g/t)
- Electrostatic forces favor gold dust transport
- Will accumulate within anomalous craters



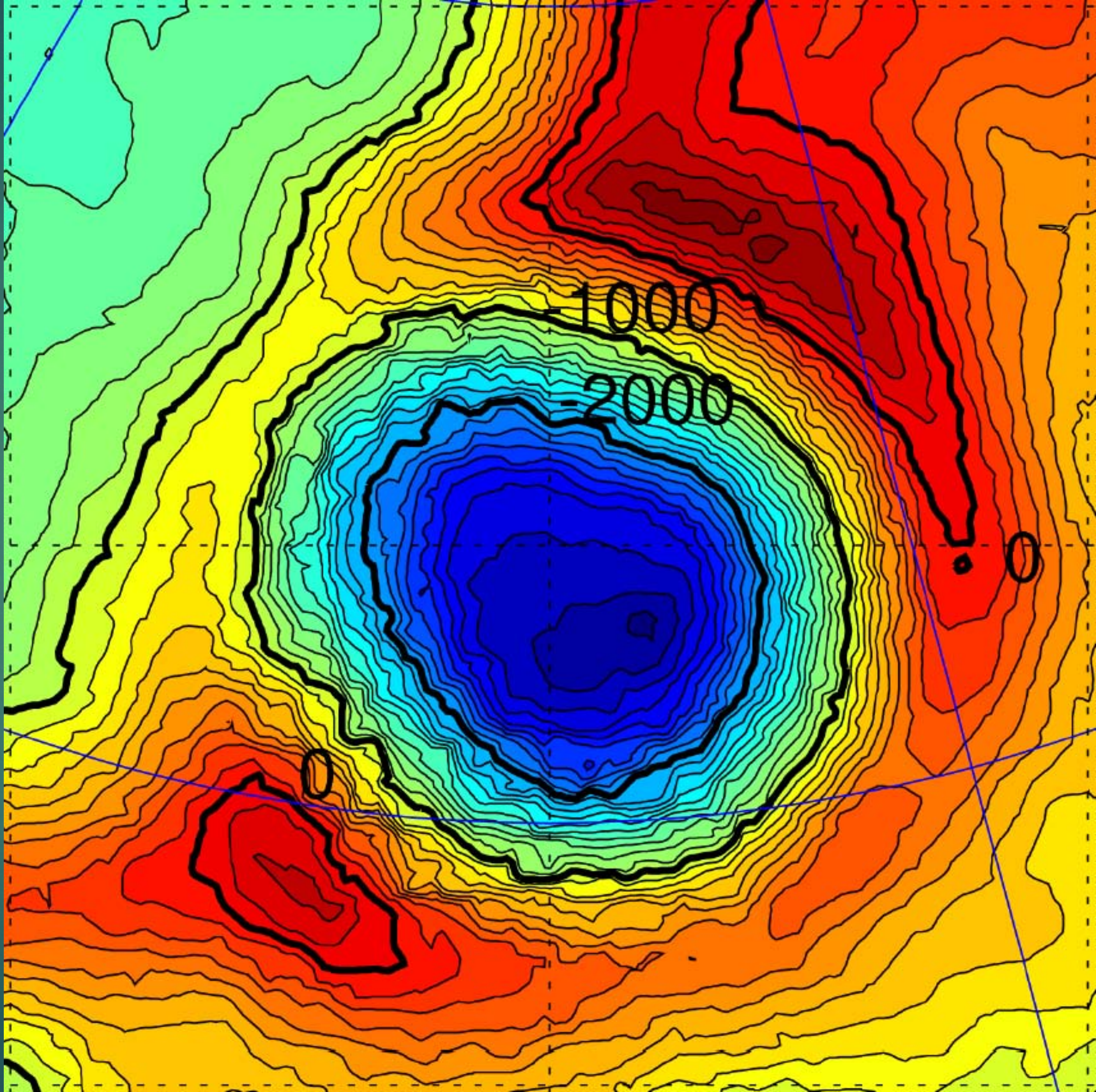


Whipple Crater

30° average slopes

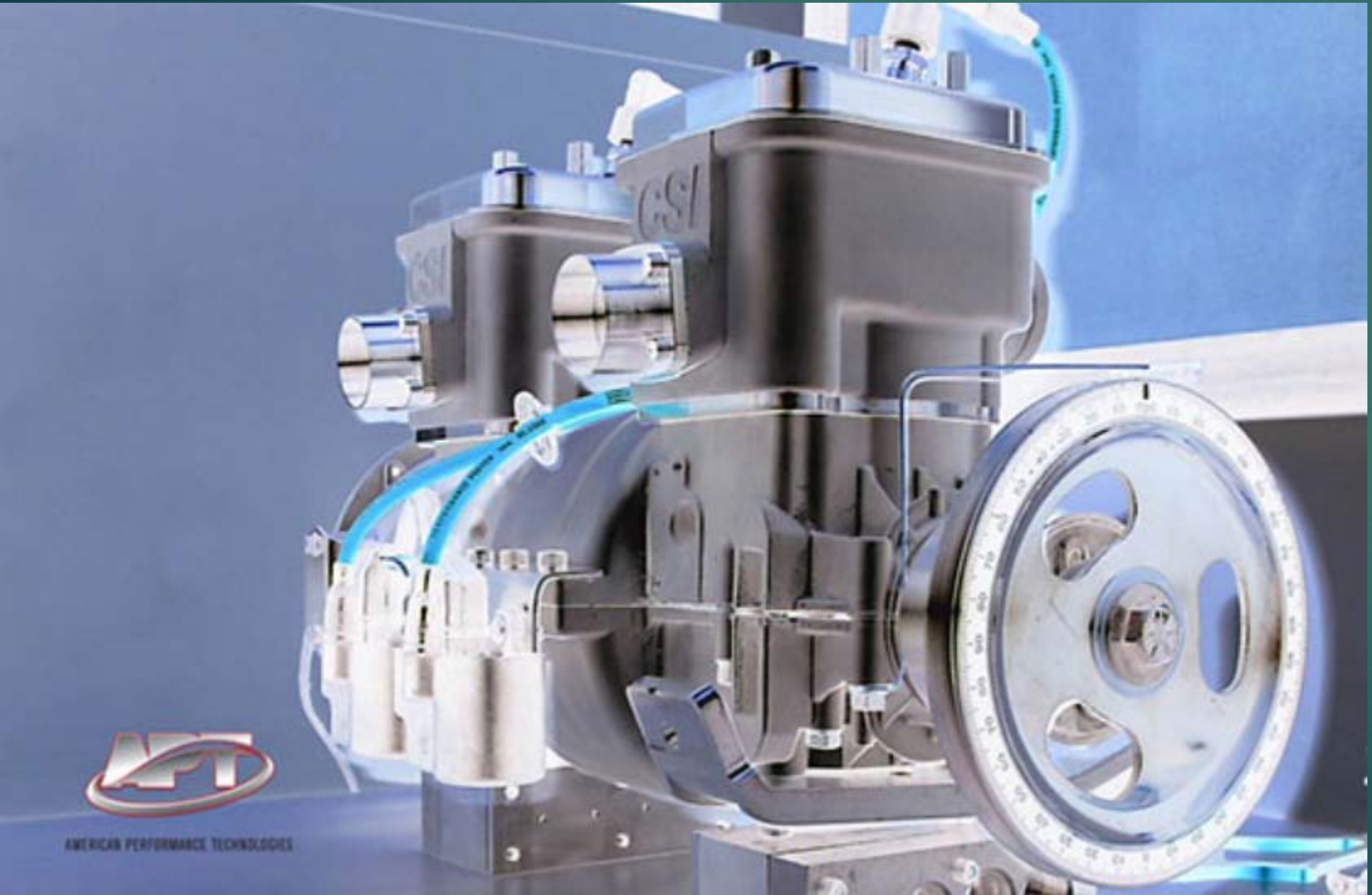
Impossible to explore with RPM

Would have to land in the middle



What we propose: <u>ICESIP</u>

An ICE-electric hybrid powered by the SonicFlow 2-cycle engine:



- Burns no oil
- High power density
- 40% TE
- Fuel economy

ICE-BOTE Trade Study

RPM-style rover:

100 kg total mass

30 kg propulsion mass budget

200 Watt average power
1000 Watt peak power

Battery Only Design

Tesla Roadster	
30	Mass budget kg
5	Margin
25	Mass budget – Margin
25	Total Battery Mass
6.00E+05	Specific Energy (J/kg)
1.50E+07	Total Energy
0.9	Discharge efficency
1.35E+07	Net Energy available for system J
200	Average Power (W = J/s)
67,500	Time s
18.75	Time hr
0.78	Time day

Lithium Ion Battery	
30	Mass budget kg
5	Margin
25	Mass budget - Margin
25	Total Battery Mass
2.00E+06	Specific Energy (J/kg)
5.00E+07	Total Energy
0.9	Discharge efficency
4.50E+07	Net Energy available for system J
200	Average Power (W = J/s)
225,000	Time s
62.50	Time hr
2.60	Time day

LH2/LO2 Design

ICE-hybrid vehicle LH2/LO2	
30	Total Mass budget (kg)
5	Margin
25	Actual mass budget (kg)
0.186	Mass of ICE (kg)
0.223	Mass of generator/starter (kg)
0.409	Total mass ICE + generator kg
500	Battery specific power (W/kg)
1000	Peak Power (W)
2	Battery Mass (kg Li-S)
2.4	Total bat + ICE + generator (kg)
22.6	Mass budget for tankage & propellant
19.805	Mass of Propellant actually burned (kg)
17.604	Mass LO2
2.201	Mass of LH2
12.0%	LH2 boiloff fudge factor
2.465	Total mass LH2
20.069	Total propellant mass (kg)

550.139	moles of O2
1100.278	moles of H2
0.5	molar O2/H2
1,141	Density of LO2 (kg/m^3)
70.85	Density of LH2 (kg/m^3)
0.01543	Volume of O2 (m^3)
0.03479	Volume of H2 (m^3)
50.2	Total Volume (L)
13.3	Total Volume (gal)

LH2/LO2 Design—Tankage

0.1544	Radius of O2 tank (m)
0.2025	Radius of H2 tank (m)
0.2997	Area of O2 tank (m^2)
0.5153	Area of H2 tank (m^2)
	Liquid tank shell densities
0.9027	Inner tank: Al 2024-T81 (bi-grid) stiffened (kg/m^2)
2.1919	Outer tank: DRA 55% (kg/m^2)
3.09465	Total Tank unit weight (kg/m^2)
0.93	mass LO2 tank (kg)
1.59	Mass LH2 tank (kg)
2.52	Total Tankage kg
22.59	Mass of tankage + propellant
22.6	Tankage & Fuel Mass budget
100.002%	(Tankage + Propellant)/ Mass budget

LH2/LO2 Design—Range Extension

285,800	H2/O2 molar Energy (J/mol H2O)
1.59E+07	H2/O2 specific energy (J/kg)
3.14E+08	Total stored energy J
0.4	ICE thermal efficiency
1.26E+08	Rotary energy
0.9	Efficiency of generator
1.13E+08	Energy produced by generator J
0.9	Charge/discharge efficiency
1.02E+08	Energy released by batteries
200	average power
509,424	time s
141.5	time hr
5.90	time days

GH2/GO2 Design—Tankage

16.236	Mass of Propellant (kg)
14.432	Mass O2
1.804	Mass of H2
451.000	moles of O2
902.000	moles of H2
0.5	O2/H2
10,152	Pressure psi
70,000,000	Pressure Pa
0.0157028	Volume of O2 (m^3)
0.0314057	Volume of H2 (m^3)
47.1	Total Volume (L)
12.4	Total Volume (gal)

0.1553	Radius of O2 tank (m)
0.1957	Radius of H2 tank (m)
0.3033	Area of O2 tank (m^2)
0.4814	Area of H2 tank (m^2)
2,700	Density of Al (kg/m^3)
3.00E-03	Thickness of tanks (m)
9.10E-04	Volume of O2 tank shell (m^3)
1.44E-03	Volume of H2 tank shell (m^3)
2.46	mass of O2 tank
3.90	Mass of H2 tank
6.36	Total Tankage kg
16.24	Mass of Propellant (kg)
22.59	Mass of tankage + propellant
22.6	Mass budget
100.002%	Budget – (tankage + Prop)

GH2/GO2 Design—Range Extension

285,800	H2/O2 molar Energy (J/kg)
1.59E+07	H2/O2 specific energy (J/kg)
2.58E+08	Total stored energy J
0.4	ICE thermal efficiency
1.03E+08	Total work done by ICE
0.9	Efficiency of generator
9.28E+07	Energy produced by generator J
0.9	Charge/discharge efficiency
8.35E+07	Energy released by batteries
200	average power
417,622	time s
116.0	time hr
4.83	time days

LCH4/LO2 comparable to GH2/GO2

Other Considerations

- “Waste heat” = useful enthalpy
- 300 Watts available for heating LPER
- Can also be used for instruments like OVEN
- Battery-only designs must produce heat from electricity

- Flex fuel capability
- Residual propellants from the lander can further extend mission time