Towards Ranked Impurity Inventories of Water Resources on the Moon and Mars

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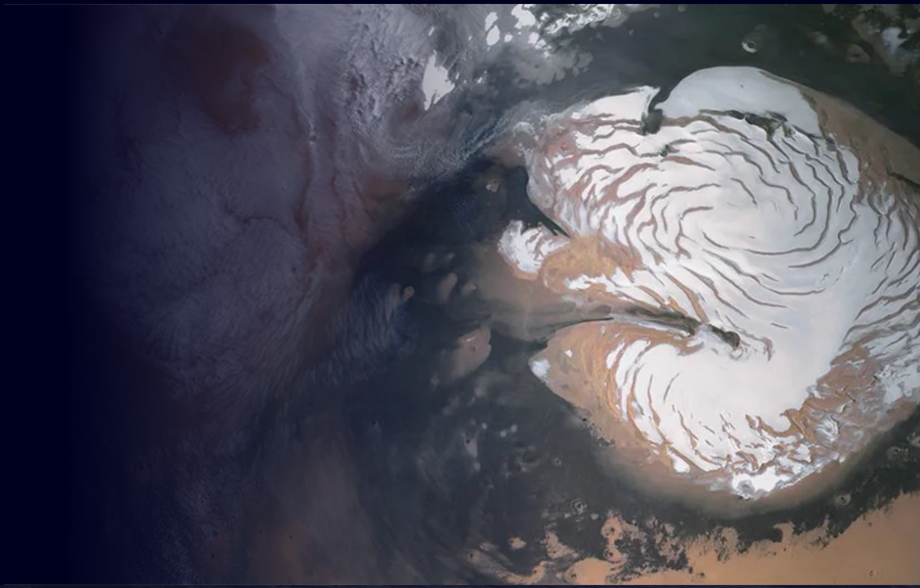

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This work has been performed under a contract with the European Space Agency

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ESRIC-ESA workshops

Baselines for water ISRU on Moon and Mars

Webinars on 26 & 27 February 2024, follow-up at SRW 2024

Physical state

Grades/ concentrations

Impurity types and concentrations

Focussing on the **qualities of water occurrences** rather than on deposit sizes and tonnages:

- How would impurities interact with ISRU technologies and add constraints to purification technologies?
- How would impurity concentrations impact our identification of economically viable resources?

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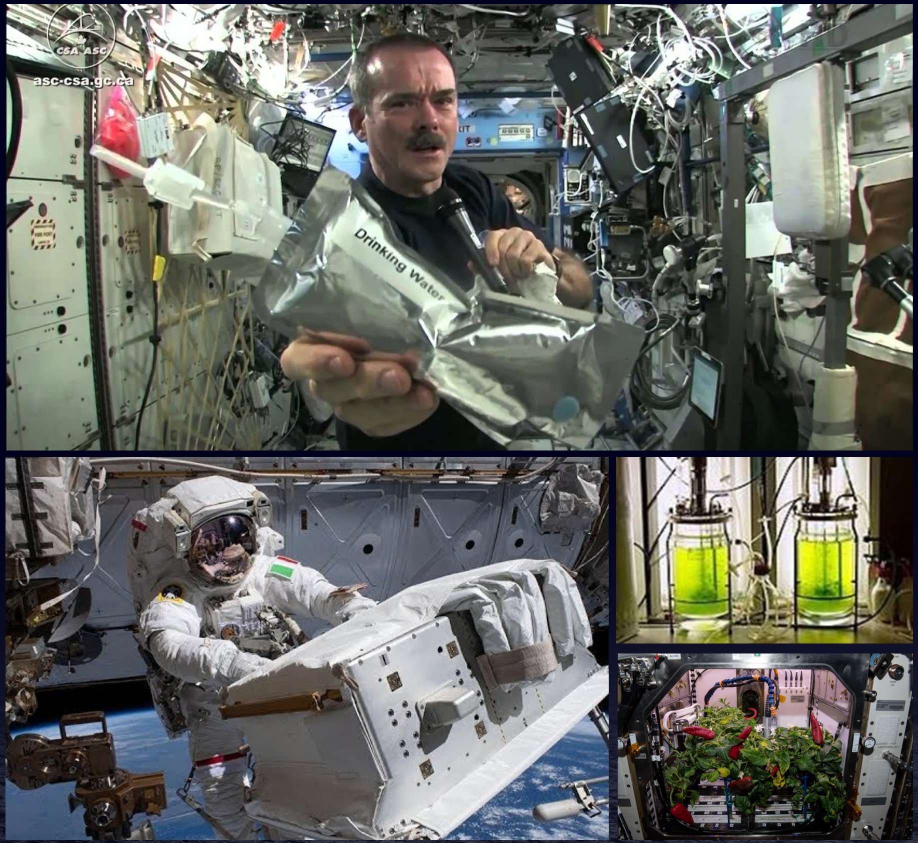
Introduction

Constraints on water purification architectures

Water impurities are downstream risks

ECLSS (e.g., NASA SWEGs)
- Acute or chronic chemotoxicity
- Undesired microbiological nutrition
- Olfactory discomfort (reduced consumption)
- …

Space/ISRU systems
- Material corrosion/degradation
- Loss of performance/reliability
- Undesired reaction products
- …



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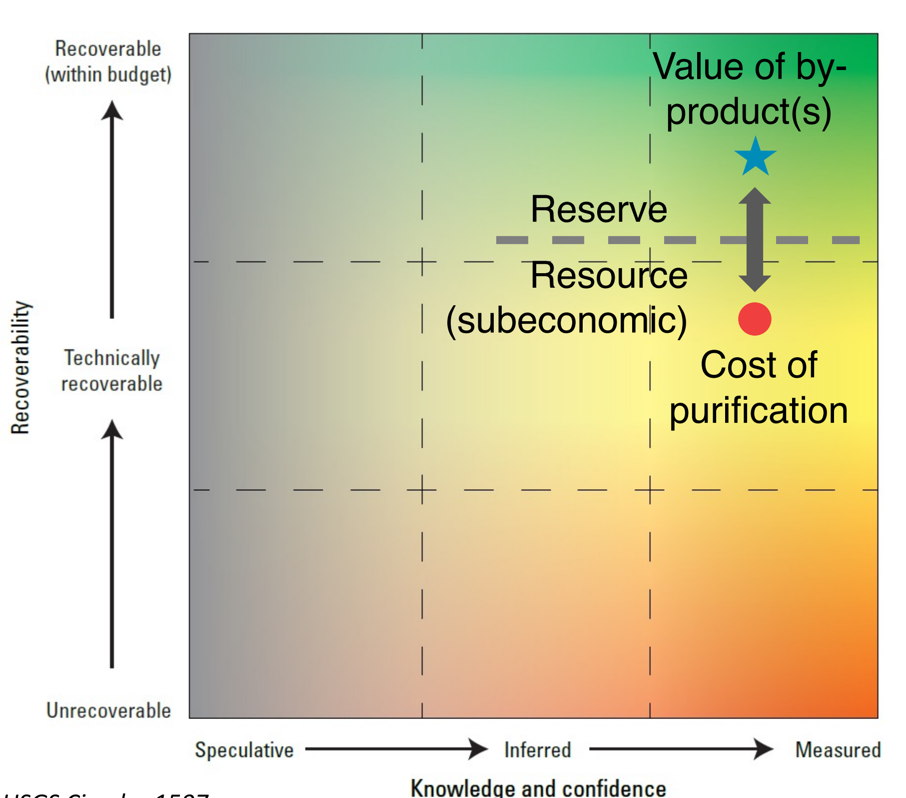
Introduction

Constraints on water purification architectures

Impurities are potential drivers into or out of economic viability

By-product recovery reward

- Geochemically limited elements (e.g., C and N)
- Energetically favourable by-products (e.g., H_2 and O_2)
- Speciality by-products, propellants (e.g., noble gases)
- …



USGS Circular 1507

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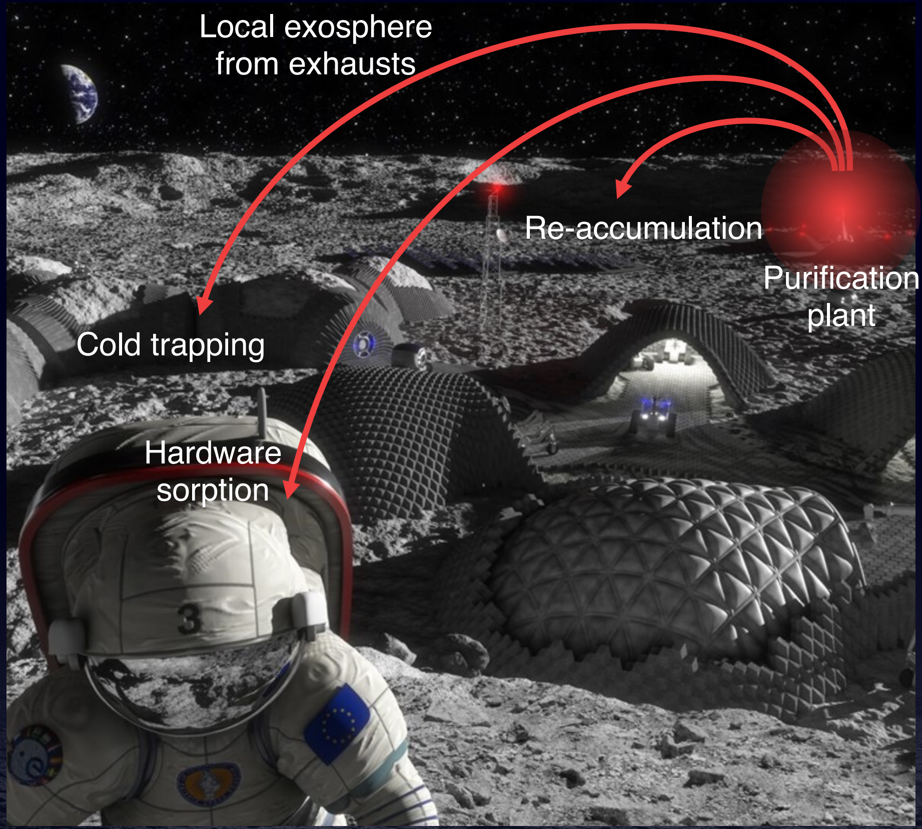
Introduction

Constraints on water purification architectures

Impurity disposal <u>may</u> impact the local infrastructure and environment

Disposal risk

- (Re-)Accumulation in cold traps
- Sorption to infrastructure and EVA hardware
- Planetary protection (e.g., niche for biological forward contamination)



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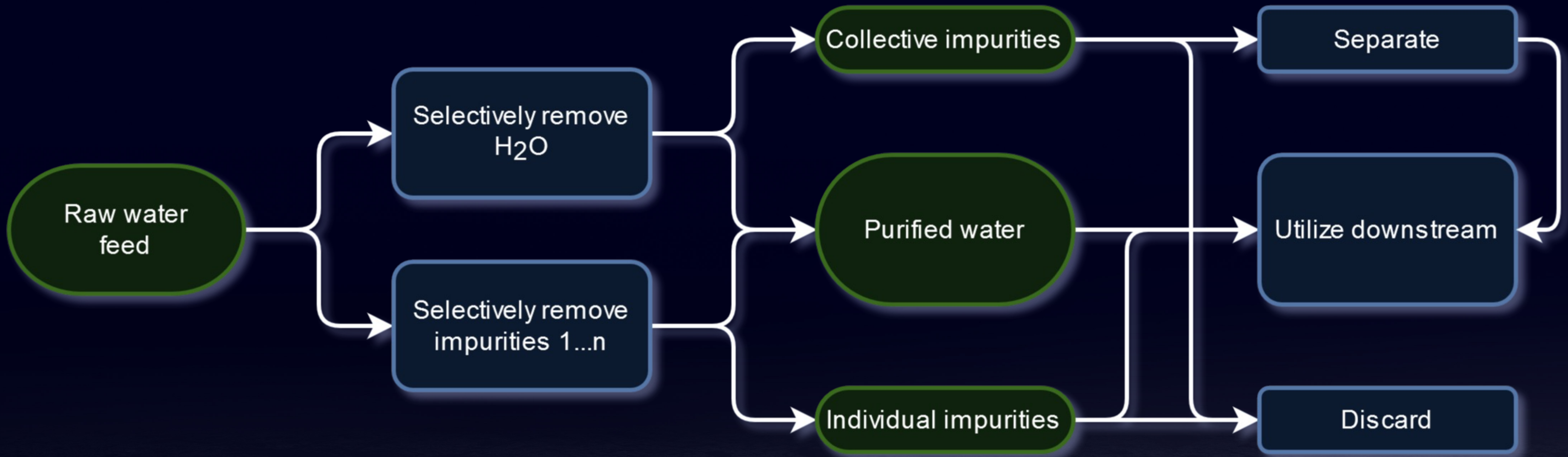
Purification architectures

Selective removal of water or impurities?



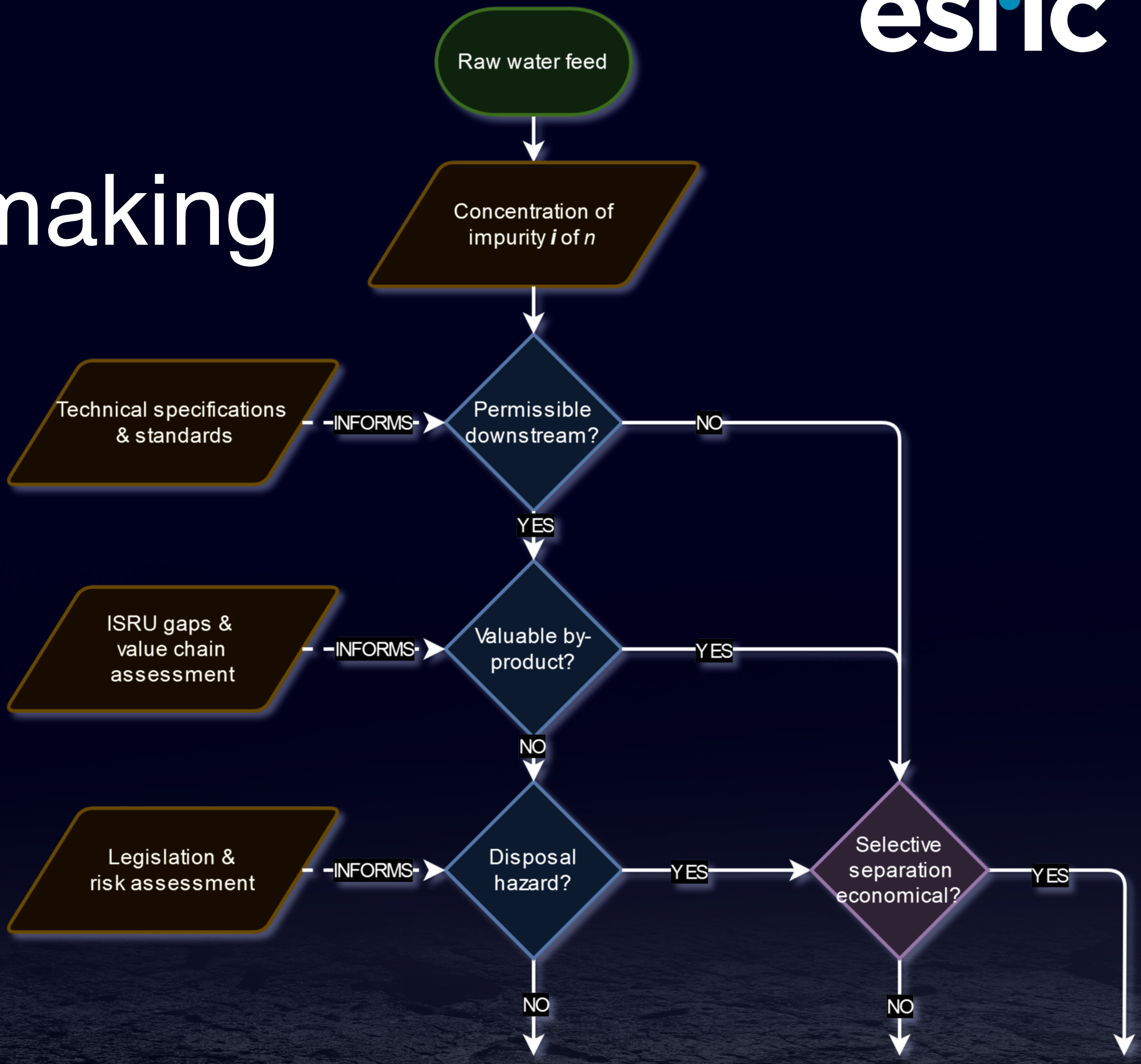
Purification architectures

Architecture decision making

Architecture decisions require iterative assessment of

- Downstream severity
- By-product value
- Disposal risks

► "Ranking" of impurity species and concentrations



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Impurity tables

Pathway	Impurity species	Abundance in the effluent (influent to purification)	Downstream impact severity	Environmental disposal risk	By-product recovery reward
Evaporation, melting, calcination… (gas, liquid)			High: Hazardous		High: Very useful
			Medium: Acceptable		Medium: Niche use
			Low: No problem		Medium: Useless

Mode of **extraction** and **physical state**	Species expected as the result of extraction	Concentrations expected as the result of extraction	Negative drivers	Positive driver
			Incentive for selectively separating an impurity	

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Water occurrences considered

Moon

- Hydrogen in global/ circumpolar regolith
- Water in pyroclastic units
- Ice in permanently shadowed regions

LWIMS (NASA)

Mars

- ~~Water~~ Trace components in the atmosphere
- Ices at ~~polar and~~ mid/low latitudes
- Hydrated lithologies and regolith

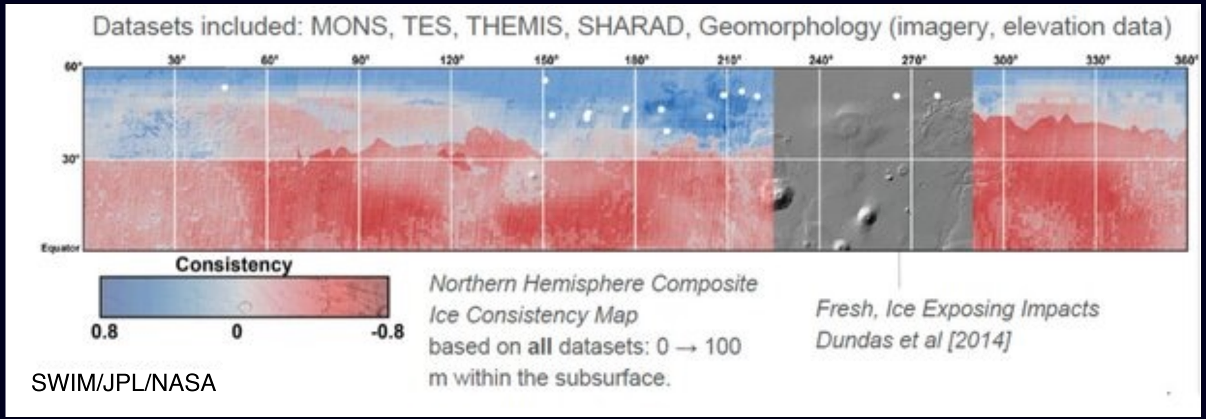
M-WIP (NASA), SWIM, I-MIM (NASA), ARMADILLO (ESA)

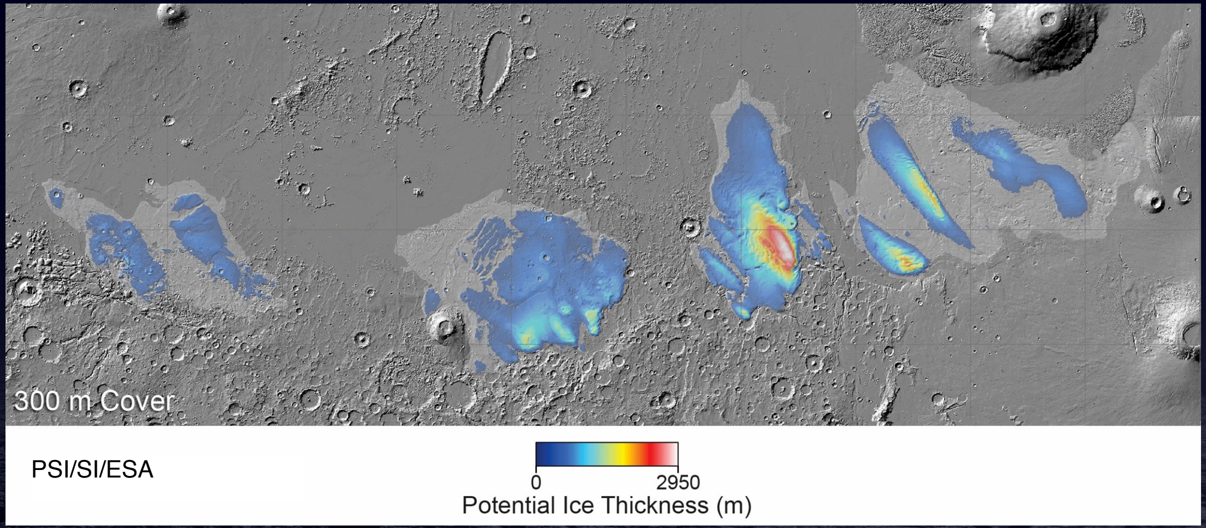
Ices at polar and mid/low latitudes

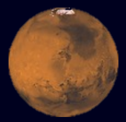
- Polar caps
- Periglacial (>60°)
- Mid-latitude (<60°)
- Low-latitude (Medusae Fossae Fm.)

Impurities delivered by atmospheric chemistry/dust and volcanism

► Is deposition age relevant for prediction?







Ices at polar and mid/low latitudes

Extraction pathway	Impurity species	Estimated abundance in extraction effluent	Downstream severity	Disposal risk	Recovery reward
Evaporated ice	H_2S	? (deposition timing relative to volcanism)	**High**	Medium	Low
	HCl, HF	? (deposition timing relative to volcanism)	**High**	Medium	Low
	H_2O_2	? (deposition timing relative to oxidizing atm. chemistry)	Medium	Low	Medium
	CO_2	<10 mol% (more if atm. carrier gas or clathrates)	Low	Low	Low
Melted ice	ClO_4^-	<16 g/L (30 vol% initial ice)	**High**	Low	**High**
	HCl, HF, H_2S/H_2SO_4	? (deposition timing relative to volcanism)	**High**	Medium	Low
	Dust	5…50 vol%	**High**	Low	Low
	Fe^{2+}, Mn^{2+}	? (probably low, mostly insoluble Fe^{3+})	Medium	Low	Low
	Mg^{2+}, Ca^{2+}, Na^+	<5 g/L	Medium	Low	Medium
	H_2O_2	? (deposition timing relative to oxidizing atm. chemistry)	Medium	Low	Medium
	SO_4^{2-}, Cl^-	<9 g/L	Medium	Low	Low
	CO_2, HCO_3^-	? (if clathrates present)	Low	Low	Low

Mars Phoenix WCL data and a lot of assumptions

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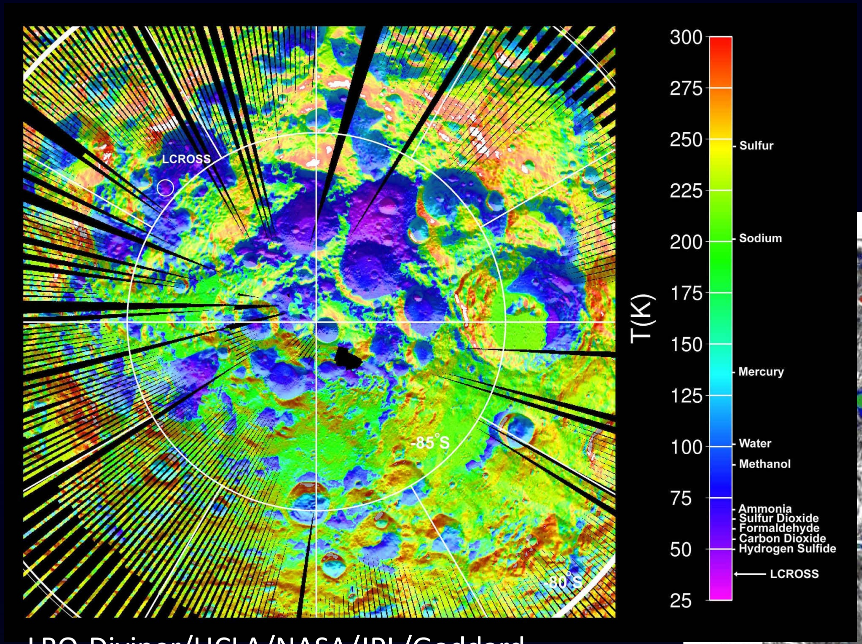
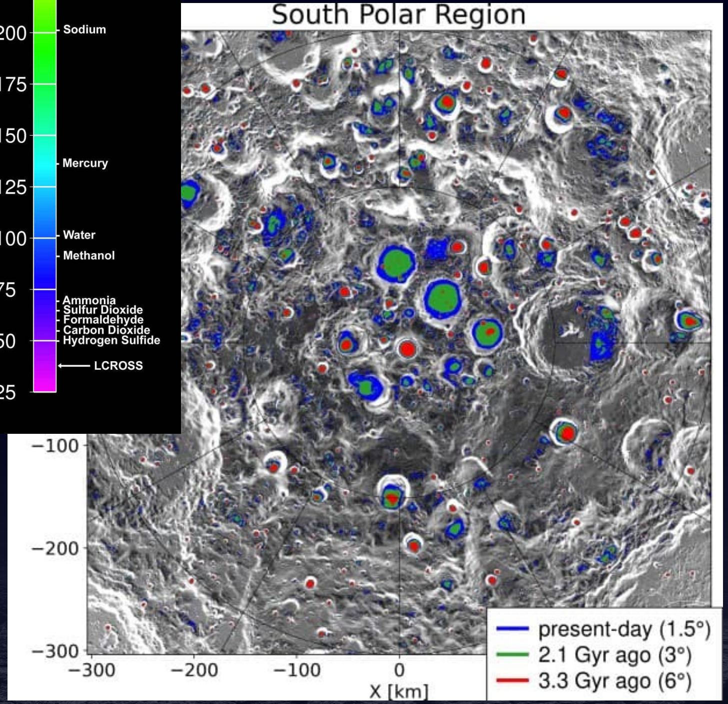
Ice in lunar PSRs

- **Sources**: Cometary/asteroidal impactors vs. volcanic outgassing
- **Delivery**: Modification (impact, photo-/radiolysis, …)
- **Trapping**: Fractionation through T gradients and temporal variations



LRO-Diviner/UCLA/NASA/JPL/Goddard



Schörghofer & Rufu (2023)

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Ice in lunar PSRs

Extraction pathway	Impurity species	Estimated abundance in extraction effluent	Downstream severity	Disposal risk	Recovery reward
Heating and evaporation (low-T gas)	NH_3	0.5…6 mol%	**High**	Medium	**High**
	H_2S	2…16 mol%	**High**	**High**	Medium
	Hg	<0.6 mol% (0.4 wt% in PSR soil)	**High**	**High**	Low?
	HCHO, HCN, COS, CS_2	? (expected in cometary source)	**High**?	**High**?	Low?
	HCl, HF	? (expected in volcanic source)	**High**?	**High**?	Low
	CH_3OH	<8 mol% (high uncertainty)	**High**	Medium	**High**
	SO_2	<3 mol%	**High**	Medium	Low?
	CO_2	<5 mol%	Low	Low	**High**
	CO	<4 mol%	Medium	Low	**High**
	C_2H_4 (CH_4, C_2H_6)	<5 mol%	Medium	Low	**High**
	H_2	<9 mol% (high uncertainty)	Low	Low	**High**

LCROSS data and a lot of assumptions

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Conclusions

Baselines for water ISRU

Impurity types and concentrations

Decisions on purification architectures hinge on:
- Impurity inventories and extractive modifications
- Downstream requirements and environmental risks
- By-product value and economic viability of recovery

More data needed on lunar and Martian ices:
- Fundamental scientific understanding of water cycles
- Predictive genetic modelling of deposits for ISRU architectures