

RESOURCE CONSIDERATIONS FOR ENABLING SUSTAINABLE TRANS EARTH HABITATION

SRR/PTMSS Workshop
Tech Session 4

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June 2016

NASA/TM-98-206538



**Resource Utilization and Site Selection
for a Self-Sufficient Martian Outpost**

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April 1998



The Why's of it All



1. My interest & goal – to get humans living off Earth, permanently and sustainably and as soon as possible (Barker, 2015).
2. Today, Red Flags and multi-faceted perspective Food for Thought!
3. Ongoing question - Science vs. Settlement (Exploration)?
 - Are humans going to go explore the solar system or are we going to move into the solar system?
 - Exploring is great when you have limited, intermittent funding;
 - Settlements are nearly impossible in such a mode – especially when you need to optimize the creation of “things” needed by humans (Sustainability vs. Resupply).
4. The single most Important resource for permanent settlement is **WATER**
 - Once Proven, you can optimize locations by collocating with other resources, engineering and research requirements



Who Can Sustain Funding and Why?



Space is very difficult and therefore costly:

Problems and examples (in the news) to keep in mind:

- 1) Commercial Launch Market (which was and may still be the only launch/space market that might be called lucrative):
 - “Europe’s Ariane 5 rocket has a flawless record since 2002 and regularly racks up **50%** or more of the global commercial launch market. Despite this, the Arianespace launch consortium has been **unable to earn a dime without** \$100 million in annual **subsidies** from the *European Space Agency*.”
 - U.S. Air Force — the world’s biggest, best-funded space agency — concluded that neither Boeing and Lockheed Martin would remain viable with separate launcher operations despite providing exclusive access to the U.S. government market and decided to merge rocket the programs to form United Launch Alliance.
- 2) “*XCOR Aerospace*, a company best known for attempting to build a reusable suborbital spaceplane, has laid off a significant fraction of its workforce to focus its resources instead on development of a rocket engine.”
- 3) “*Planetary Resources*, which last week announced a \$21.1 million investment round, was founded as an asteroid mining company but has recently turned its focus toward an *Earth observation program* known as Ceres.”



International Space Station (ISS)



Where are we now?

- 15 years of continuous habitation
- 100,000 *Low-Earth Orbits*
- LEO is at ~360 km & ~25,800 miles/orbit
 - Or a total of 2.58 million miles;
 - Or about 5500 trips to the moon and back;
 - But no where near Mars. A close'ish opposition of ~55 million miles means we have only gone ~4.6% that distance.

All parts/resources/consumables are brought from Earth





Mining for Smart Phones – A Perspective



Class project for Geology and Environmental Science:

Do you know what it takes to make your Cell Phone?

- Funding conflict & violence, forced labor, pollution & e-waste, ecosystem destruction and animal extinction...

ELEMENTS OF A SMARTPHONE

ELEMENTS COLOUR KEY: ● ALKALI METAL ● ALKALINE EARTH METAL ● TRANSITION METAL ● GROUP 13 ● GROUP 14 ● GROUP 15 ● GROUP 16 ● HALOGEN ● LANTHANIDE

SCREEN



Indium tin oxide is a mixture of indium oxide and tin oxide, used in a transparent film in the screen that conducts electricity. This allows the screen to function as a touch screen.



The glass used on the majority of smartphones is an aluminosilicate glass, composed of a mix of alumina (Al₂O₃) and silica (SiO₂). This glass also contains potassium ions, which help to strengthen it.



A variety of Rare Earth Element compounds are used in small quantities to produce the colours in the smartphone's screen. Some compounds are also used to reduce UV light penetration into the phone.

ELECTRONICS



Copper is used for wiring in the phone, whilst copper, gold and silver are the major metals from which microelectrical components are fashioned. Tantalum is the major component of micro-capacitors.



Nickel is used in the microphone as well as for other electrical connections. Alloys including the elements praseodymium, gadolinium and neodymium are used in the magnets in the speaker and microphone. Neodymium, terbium and dysprosium are used in the vibration unit.



Pure silicon is used to manufacture the chip in the phone. It is oxidised to produce non-conducting regions, then other elements are added in order to allow the chip to conduct electricity.



Tin & lead are used to solder electronics in the phone. Newer lead-free solders use a mix of tin, copper and silver.

BATTERY



The majority of phones use lithium ion batteries, which are composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Some batteries use other metals, such as manganese, in place of cobalt. The battery's casing is made of aluminium.

CASING



Magnesium compounds are alloyed to make some phone cases, whilst many are made of plastics. Plastics will also include flame retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.

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Is your cellphone made with conflict minerals mined in the Congo?





Mining in Alternate G-environments



What kind of mining?

- Most likely type of mining to begin with will be surface mining (strip or open-pit mining)

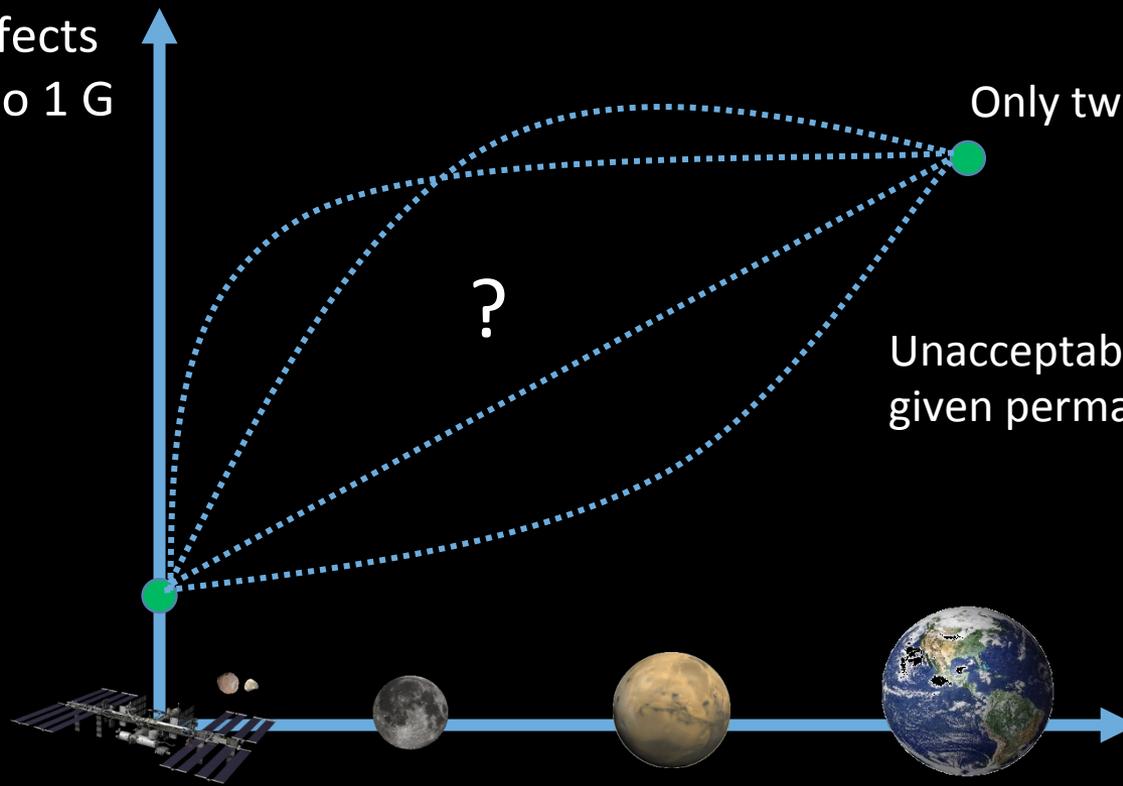


But If Plans Include Humans...



Partial G Environment Understanding
(Research Still Needed for Long Duration Health Exposure)

Health Effects
Relative to 1 G



Only two significant data sets.

Unacceptable knowledge gaps
given permanent settlements

Gravity Environment



Mining in Alternate G-environments

From Theory to Practice



So, mining is a good working theory, but not much has changed since we first began flying in space; Yet, people keep selling the idea without having “proven” anything.

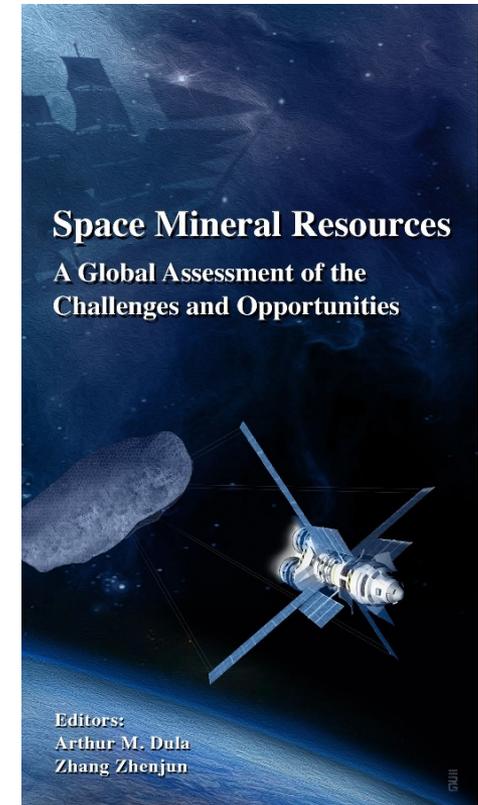
In the news:

“Asteroid Mining **May Be** a Reality by 2025”



"The Luxembourg Government forges ahead with the SpaceResources.lu initiative by presenting an overall strategy to be implemented progressively for the exploration and commercial utilization of resources from Near Earth Objects (NEOs), such as asteroids."

July 2015 - “Improving the world we know today **will be possible** by leveraging the phenomenal resources available in our solar system” and “Humanity, in general, **will benefit** from mining space mineral resources...”



International Academy of Astronautics





Mining in Alternate G-environments



There is a lot of pretty, interesting and inspiring imagery and ideas out there. But is this helpful or not?



What if Luxomberg's small "prospector-x" finds nothing of value?
Do they run out of money?

(<https://deepspaceindustries.com/prospector-x/>)

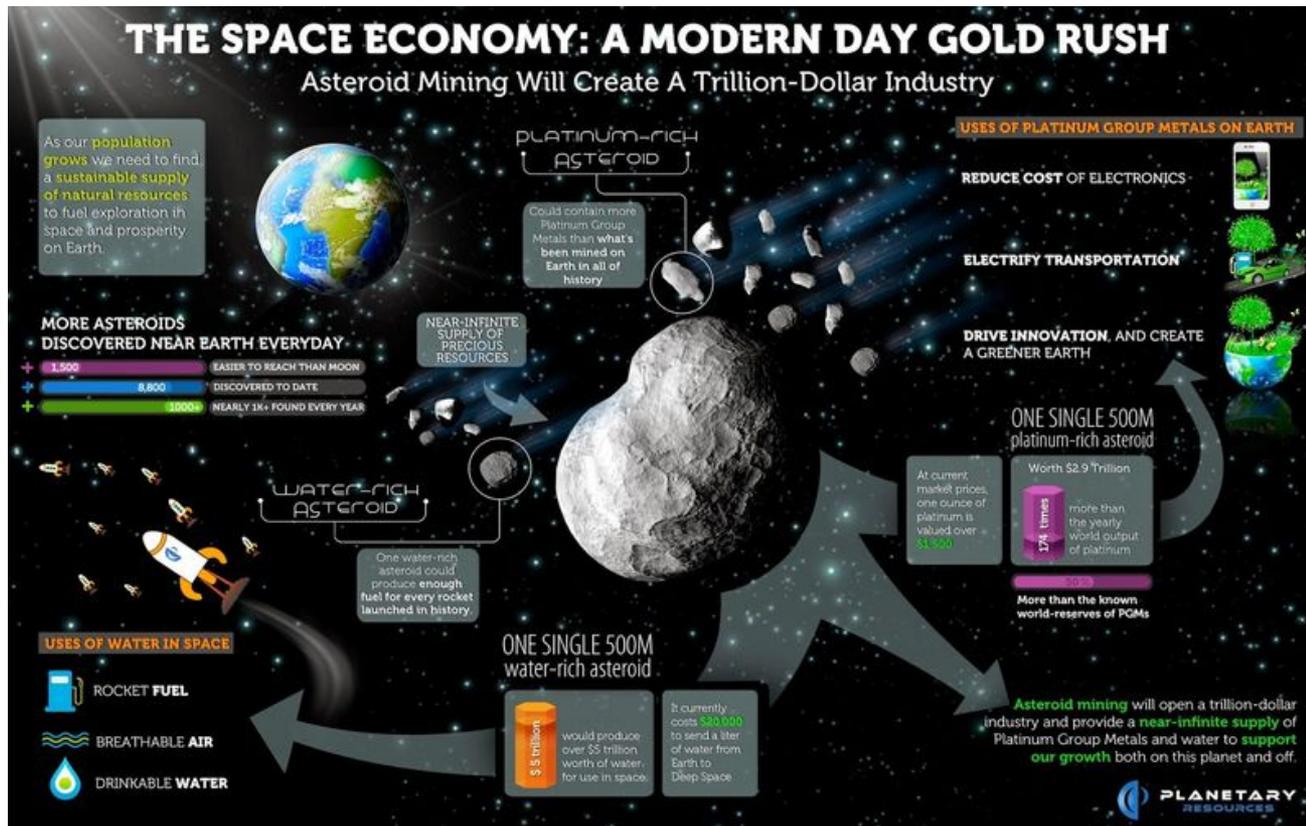


Mining in Alternate G-environments



Flashy material may falsely exhort and entice the public, and public officials, without comprehensively explaining the complex and difficult details.

Additionally, the ongoing sales pitch seems to muddy the water and distract (NASA) from a single, attainable and internally cooperative goal.





How do we get to the point of actually mining?

Mining Definitions and Process



On Earth:

North American Palladium, Ltd.

- 1) Field mapping of geologic structures, rock types identification, etc. by geologists.
- 2) Soil & near surface sampling over wide areas of interest.
- 3) *Geophysical exploration if funding available; methods include: aeromagnetic surveys, electromagnetic surveys, hyperspectral imaging, reflection seismology...
- 4) Narrowing of areas of interest and more sampling (soil, trench and chip sampling).
- 5) Initiate Drilling (methods depend on type of deposit).
- 6) Geostatistical analysis/modeling of drill density results to balance cost of more drilling...drilled to a level of confidence:
(Inferred, Indicated, Measured, Probable and Proven)
- 7) Cost estimates (equipment fleets, development/pre-stripping, infrastructure, manpower, consumables, power, ventilation, etc.) are iteratively made to determine and based on cut-off grade (the minimum grade, ounces per ton, a company will mine a material as “ore” and direct it to the mill).
- 8) Mining (near-surface: surface to only a few hundred meters – open-pit).

On Earth, a deposit is not considered an “ore” body unless it can be extracted at a profit.



How do we get to the point of actually mining?

Mining Definitions and Process



Space (Off Earth):

1. Geophysical remote sensing from satellites with large foot prints (very little subsurface material knowledge – GPR/GRS).
2. Surface sampling or geochemical analysis (rovers) over very small, easily accessible regions.
3. Results to date: Almost every potential resources off Earth are only known to the lowest levels of confidence (Inferred)
4. Now What (as time ticks away)? – We don't really have the luxury of the iterative nature of terrestrial the prospecting processes.
 - a. Develop a highly focused orbital/aerial reconnaissance program for narrowing resources
 - b. Pick best landing site to sustain humans
 - c. Begin “Near-near surface” Mining



Resource Questions - Fact or Fiction



- **What resources are available now?**
- **What resources are attainable now?**
- **What resources are usable now?**
- **What resources are most needed and why?**
- **What resources most drive mission, vehicle and infrastructure design?**



Fusion (Actual vs Fantasy Resource)

- Helium 3 – No present use: we've had tokamak reactors and stellarators (deuterium-tritium plasma) – since 1951
 - magnetic and inertial confinement
 - So far has proven to have insurmountable scientific and engineering challenges
 - Cost and complexity of the devices involved increased to the point where international co-operation was the only way forward
 - No pragmatic results (i.e., more energy out than used) from previous work or facilities, and several projects started and canceled due to cost or funding cuts
 - International Thermonuclear Experimental Reactor (ITER) - France, 2020's
 - Chinese Fusion Engineering Test Reactor (CFETR)- China, 2030's
- Therefore, we could be 20 years or 100 years away; no one knows or similar to "humans to Mars" it's perpetually 20-30 years from now.
- So please stop selling this to the public!

<https://www.iaea.org/newscenter/news/energy-future-status-nuclear-fusion-research-and-role-iaea>

<http://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-fusion-power.aspx>



Prospecting in Space -So, what do we really know?



The majority information regarding the surfaces of other bodies comes from remote sensing – observations of just the very thin surface of these worlds.

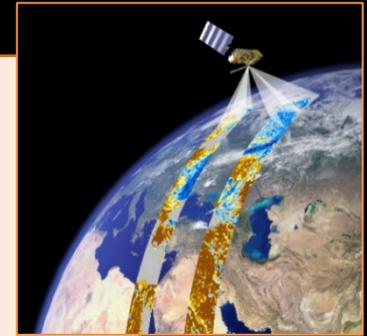
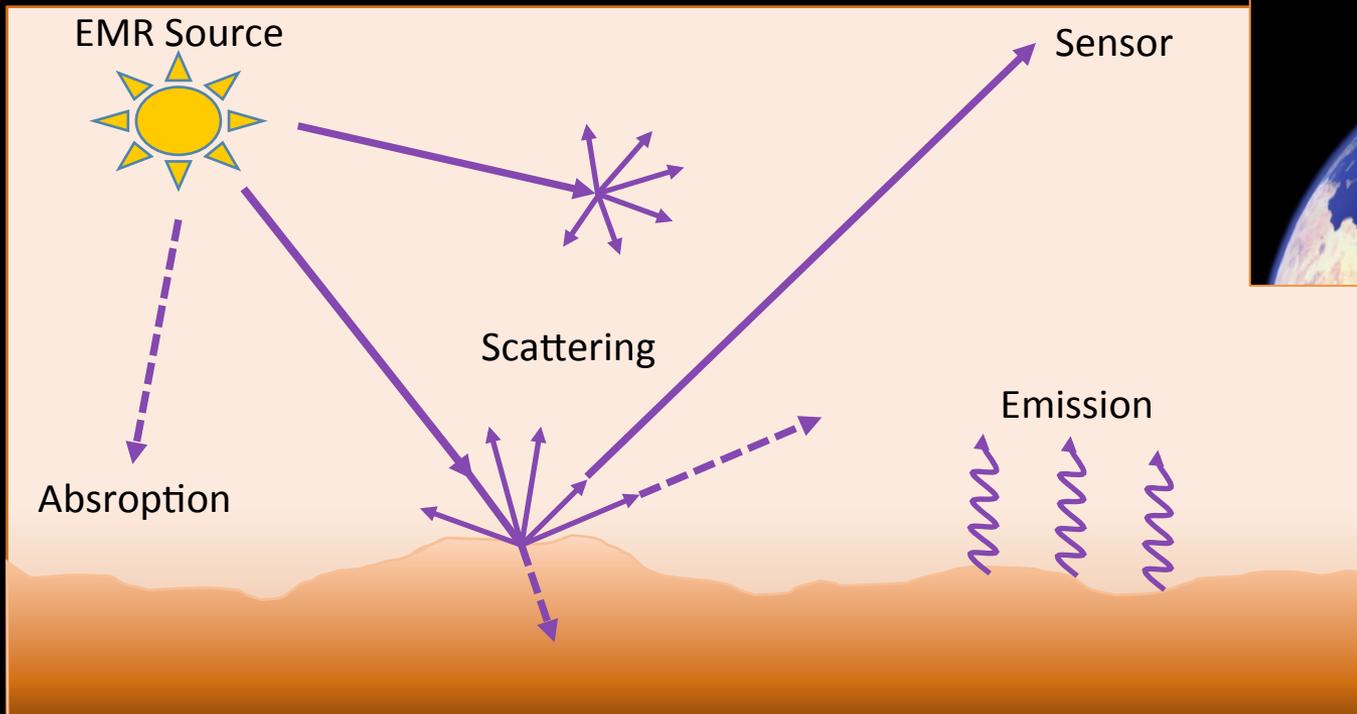
- The first landform studies to use of aerial remote sensing occurred in the 1930s
- Terrestrial satellite remote sensing techniques have historically been used for mineral exploration (i.e., starting in 1972 with Landsat 1) through only two applications:
 1. geological mapping including faults and fractures that localize ore deposits;
 2. to recognize hydrothermally altered rocks by their spectral signatures. Resulting in a narrowing of the data allowing for near immediate comparison or acquisition of new data through ground truth expeditions
- #2 cannot occur in off Earth because of cost, mass and time.



Prospecting in Space -So, what do we really know?



This is not a remote sensing course, but the fundamental point is that we know very little about the spacial location of surface materials, only the very surface of any object for most EM types and this is the most speculative level of information possible.



- * Gamma Ray Spectroscopy goes a little deeper for some things and fortunately **water** is one of them.
- * Ground Penetrating Radar works a little better for some things and fortunately **ice** is one of them.



Prospecting in Space -So, what do we really know?



Minerals and Elements

Fairly Well Known:

- Moon – anorthosite, basalt and Mg-suite & KREEP rocks (ground truth – **Measured?**)
- Mars – andesite, hematite, olivine, magnetite, sulfur, etc. (West and Clark, 2010; **Inferred**)

Speculative:

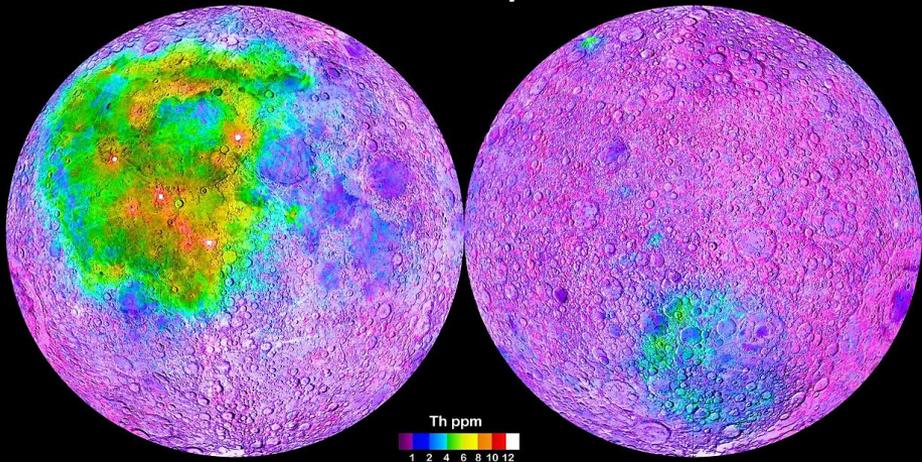
- Mars – nitrogen (Mancinelli and Banin, 2003), goethite (Fish, 1966), etc. (**Inferred**)

We have lots (terabytes) of near surface information (**Indicated**)



PDS: The Planetary Data System

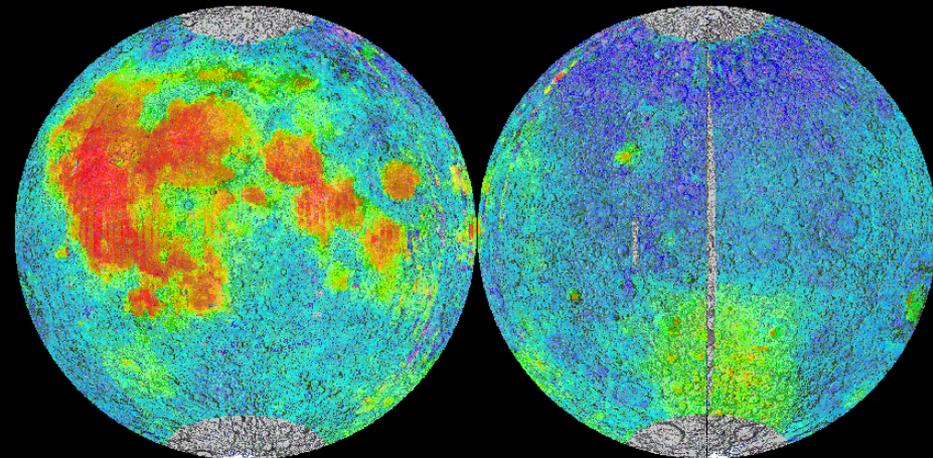
Lunar Prospector



Th ppm
1 2 4 6 8 10 12

Clementine Iron Map of the Moon

Equal Area Projection



Near side

0 2 4 6 8 10 12 14
Fe (wt.%)

Far Side



Prospecting in Space - So, what do we really know?



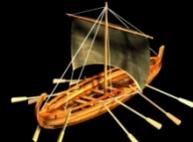
Probably greater than an **Indicated** level of confidence

'Homestake' Vein
Apparently **Gypsum**

Other gypsum indications occur in the dune sands
of Olympia Undae (but high latitude $\wedge 70$ N)

NASA's Mars Exploration Rover
Opportunity. The vein is about the width
of a thumb and about 18 in (45 cm) long.

http://science.nasa.gov/science-news/science-at-nasa/2011/08dec_slamdunk/



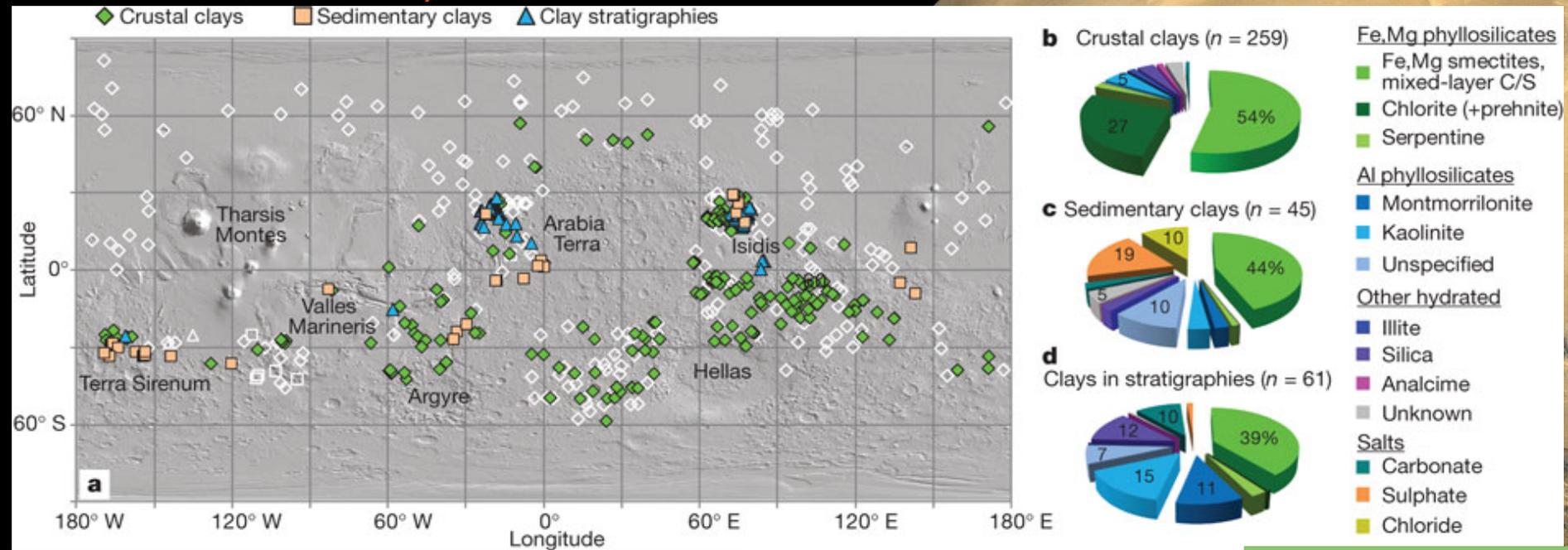
Prospecting in Space - So, what do we really know?



We have lots of research pinpointing a variety of surface lithology's, mineralogy's and elemental abundances

- But to what depth?
- But to what accuracy (foot prints usually on kilometer scales)

Subsurface water and clay mineral formation...





Prospecting in Space - So, what do we really know?



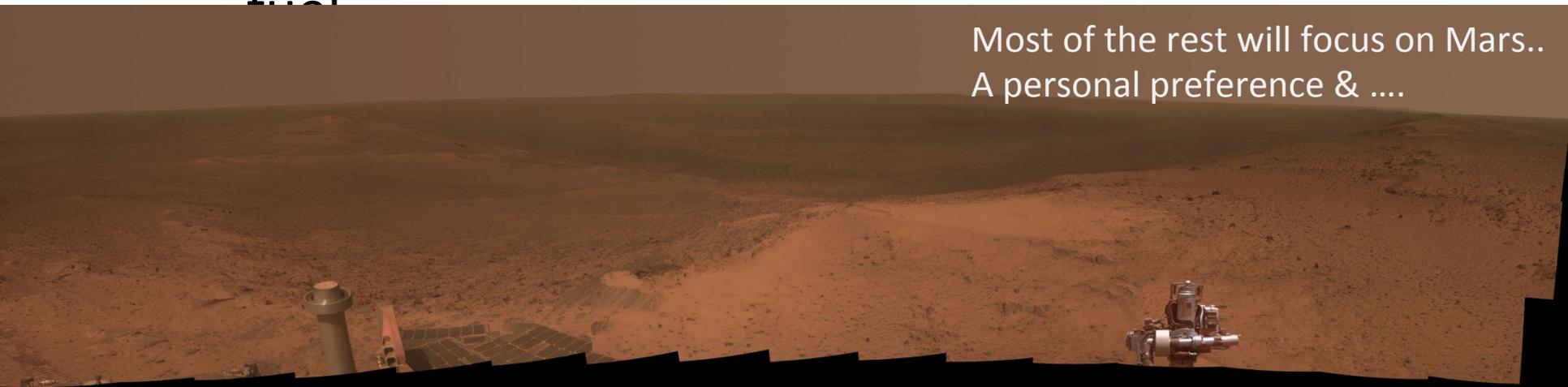
Until widespread “proven” ore-like deposits are identified, much larger mining and processing infrastructure will not be constructed off-Earth. So, for now, the most important resources are those needed to economically transport and sustain life off-Earth.

The only **Probable, Measured, Indicated and Inferred** extraterrestrial resource to date

#1 **Water** (remains to be **Proven**)

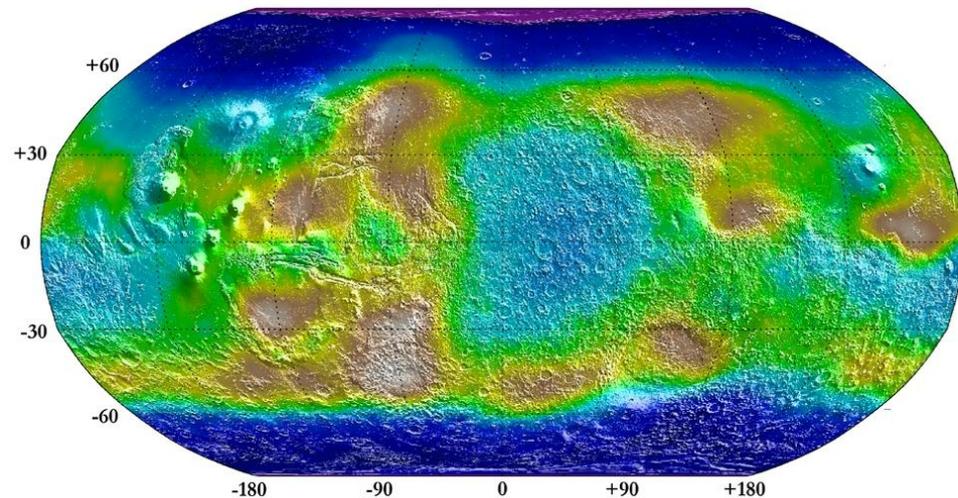
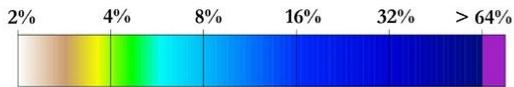
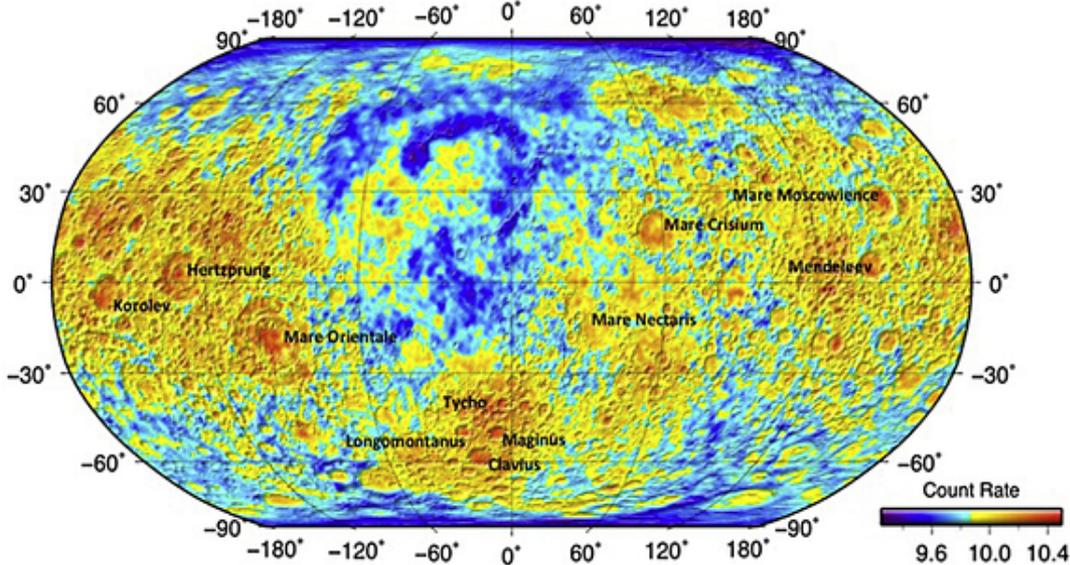
➤ water, hydrogen, oxygen, atmosphere,
fuel

Most of the rest will focus on Mars..
A personal preference & ...





Moon and Mars Signs of Water



Lunar Water:

- Lunar Reconnaissance Orbiter (LRO) spacecraft
- Launched in 2009

Instrument:

- ✓ Lunar Exploration Neutron Detector (LEND)
- ✓ Epithermal neutron counting rate variations suggest variability in water content among craters

Mars Water:

- Mars Odyssey spacecraft
- Launched in 2001

Instrument:

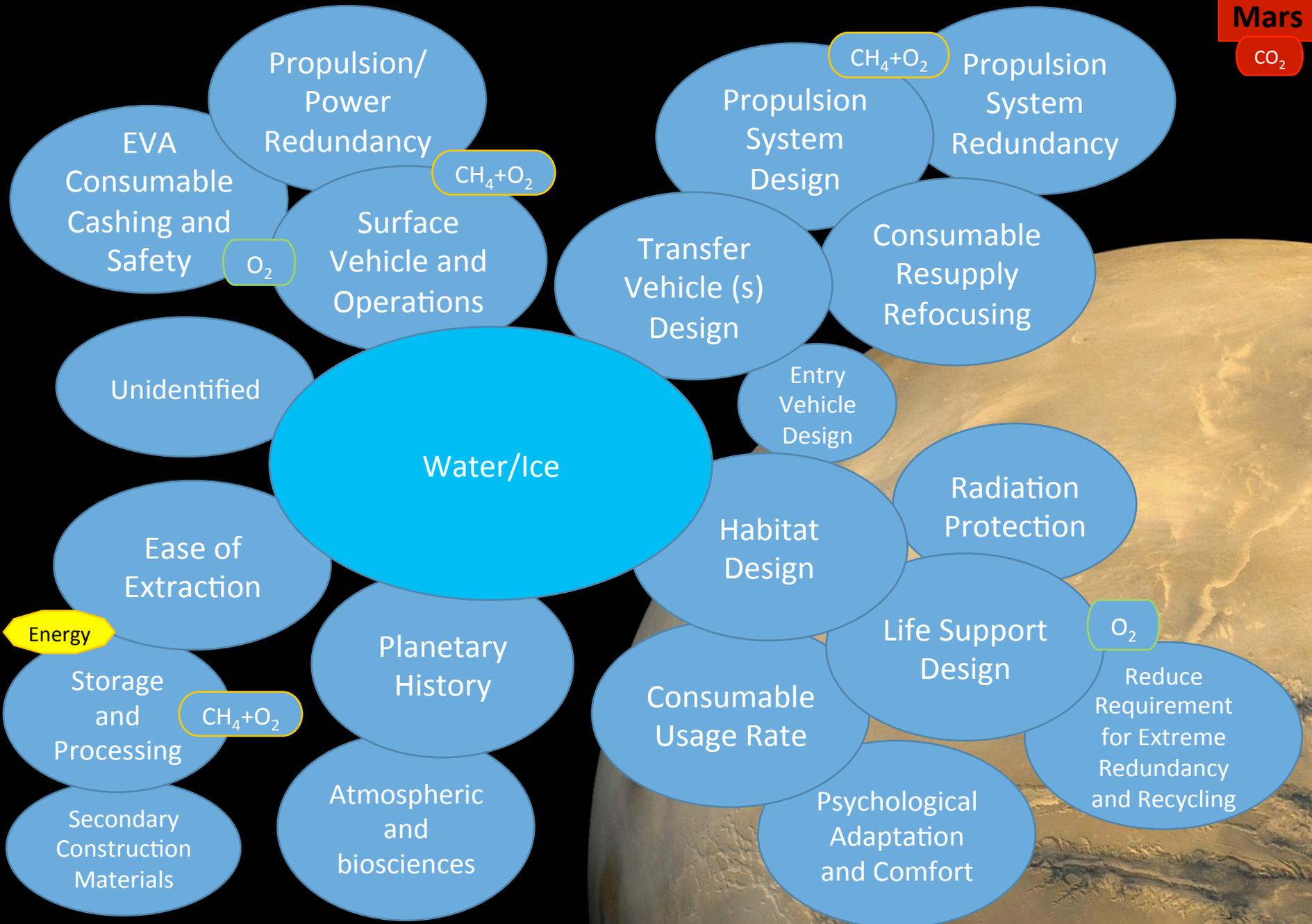
- ✓ Gamma-Ray Spectrometer (GRS)
- ✓ Estimated lower limit of the water content derived from energetic neutrons in the top meter of regolith

SHARAD - Mars Reconnaissance Orbiter

Pick Your Most Important and Easily Extracted Resource and Use it as the Driver for Where to go.

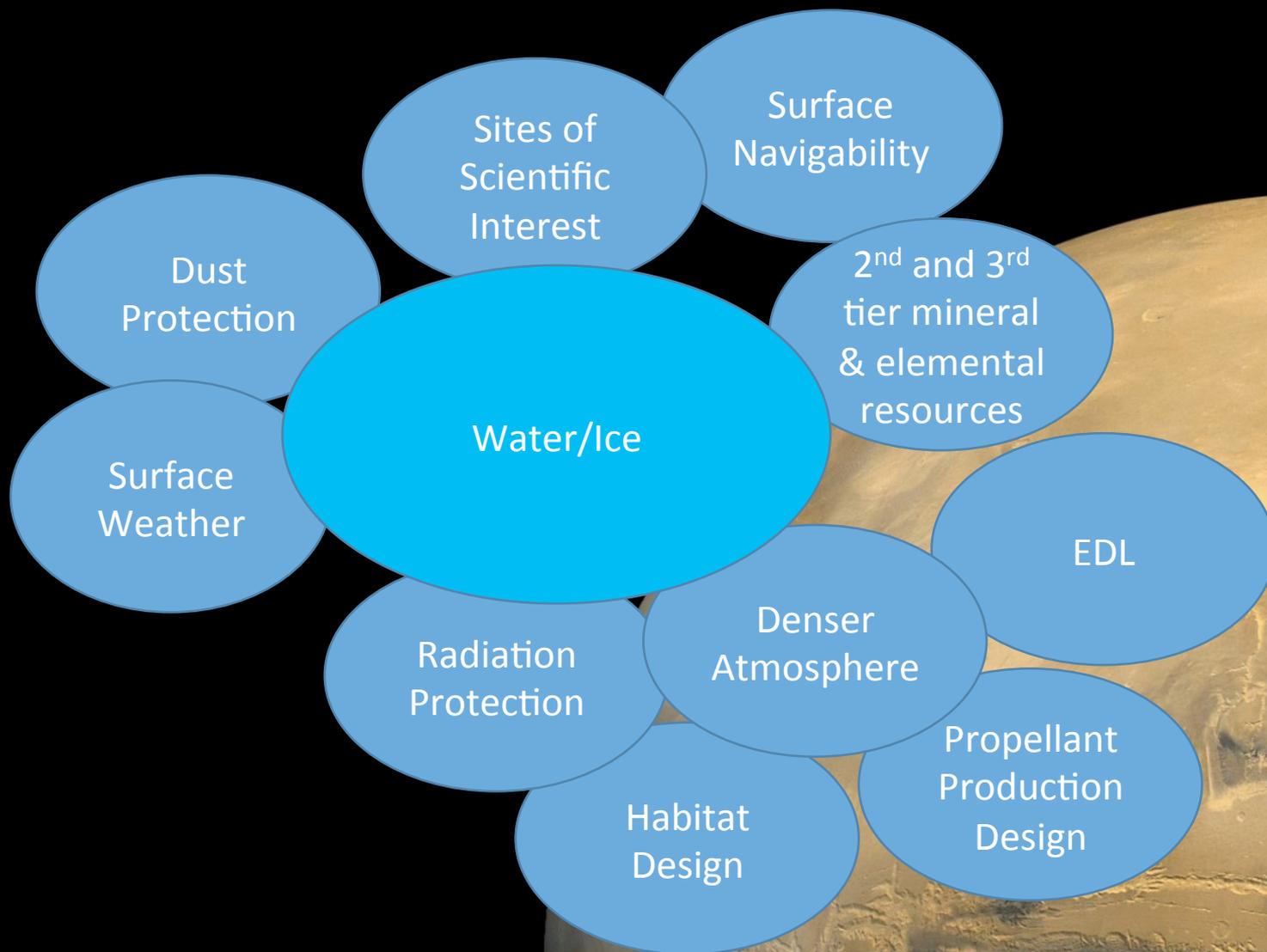
Mars

CO₂



Assuming Most Important and Easily Extracted Resource is Widely Available.
Next – Collocate with as many other design, safety and sustainability enhancing factors as possible.

Mars



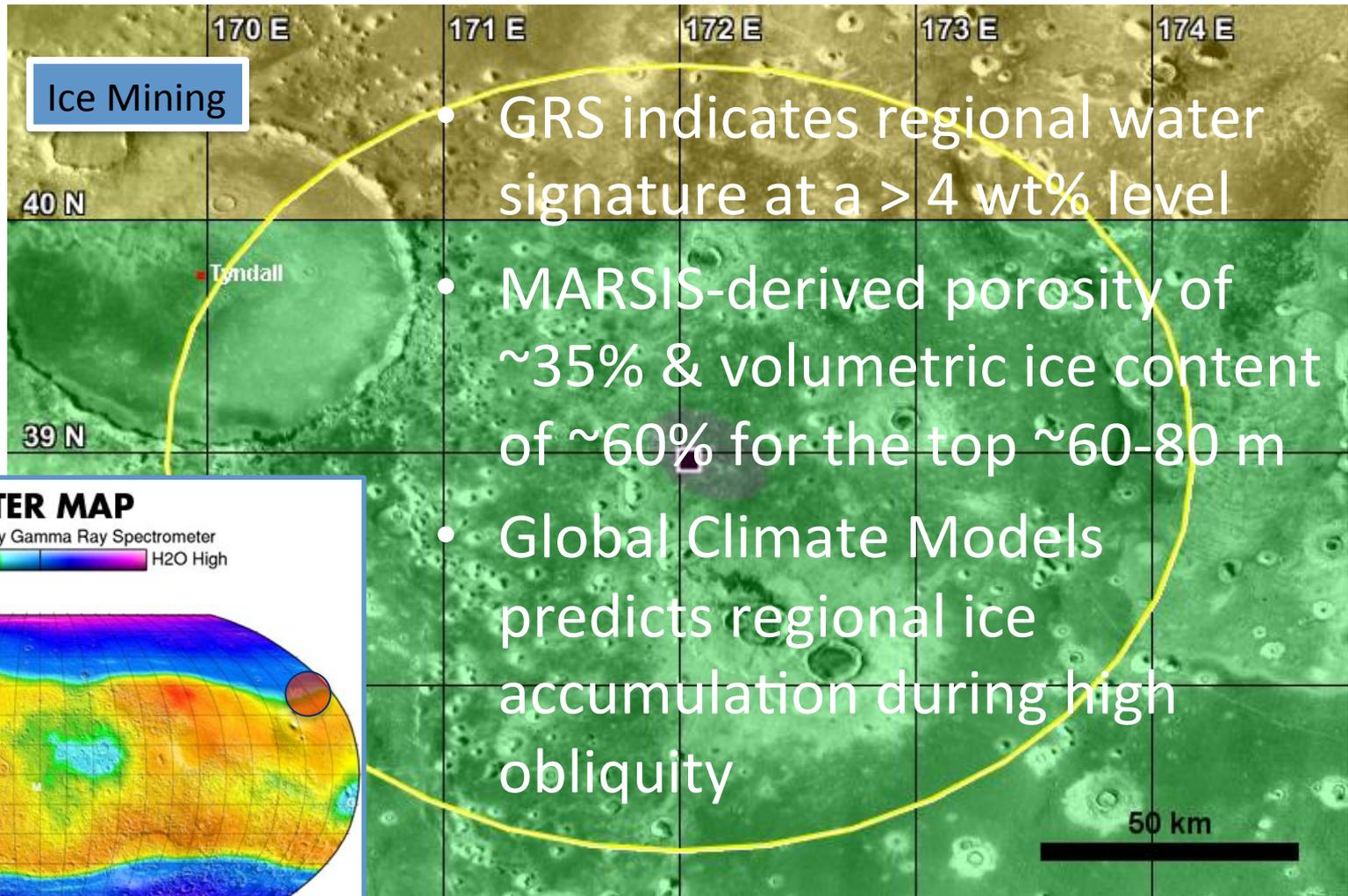
Yet, Many similar arguments can be made for water on the Moon.

Resource ROI 1



Near Surface Ice

GRS over THEMIS

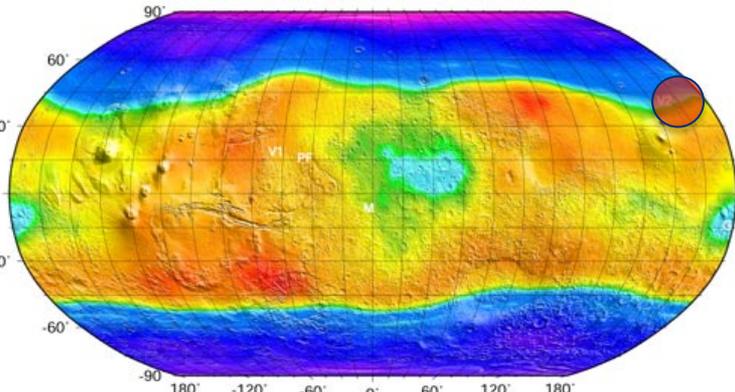


Ice Mining

- GRS indicates regional water signature at a > 4 wt% level
- MARSIS-derived porosity of $\sim 35\%$ & volumetric ice content of $\sim 60\%$ for the top ~ 60 -80 m
- Global Climate Models predicts regional ice accumulation during high obliquity

WATER MAP

2001 Mars Odyssey Gamma Ray Spectrometer
H2O Low H2O High



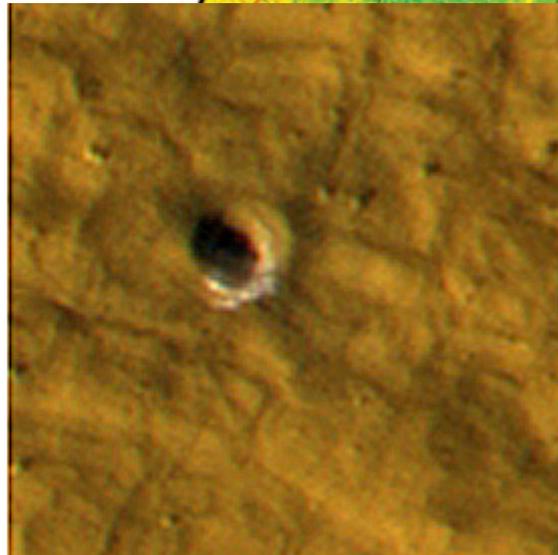
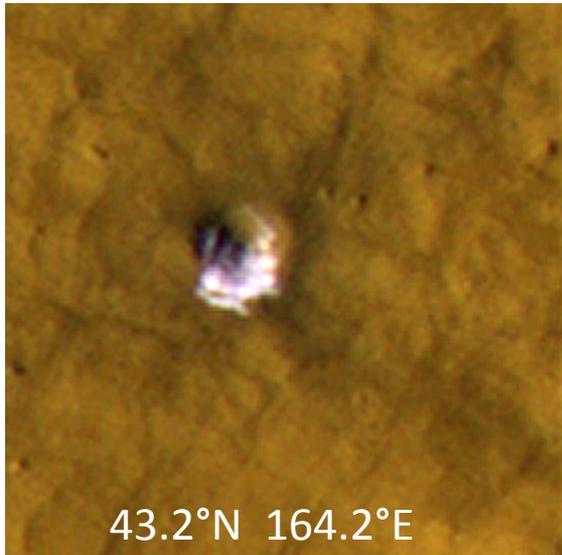
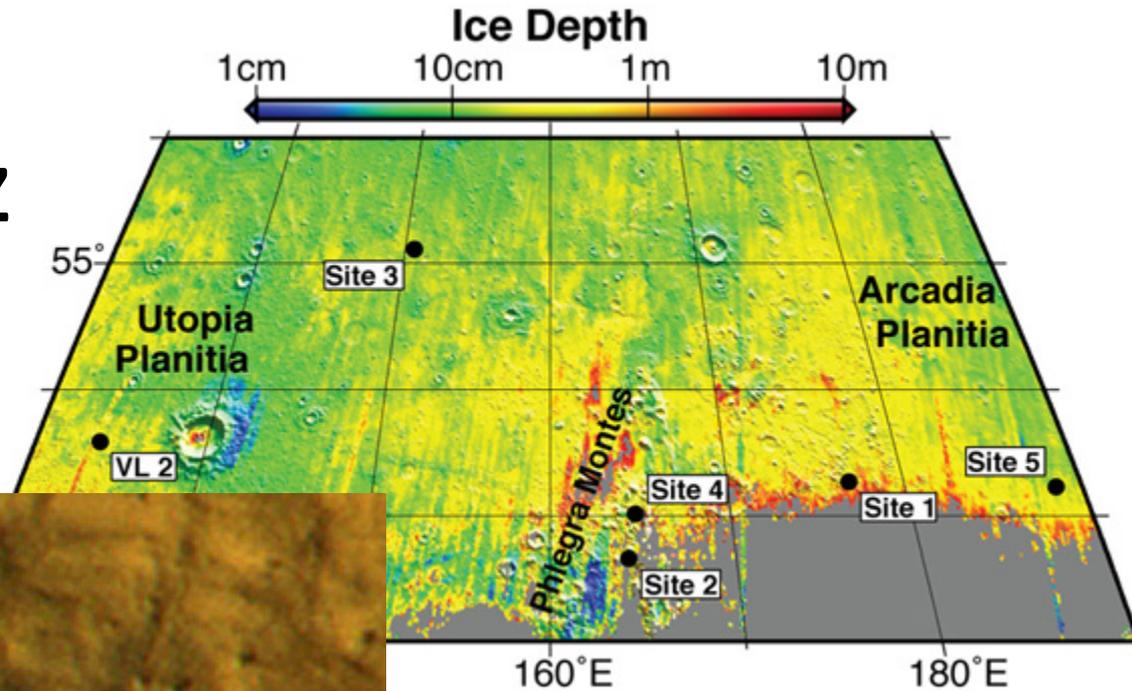
Resource ROI 1

1st EZ Workshop for Human Missions to Mars



Near Surface Ice Observations SE of EZ

Site 2: HiRISE
PSP_010440_2235



6-meter-wide, ~1.33 meter-deep crater Oct. 18, 2008, (left) and on Jan. 14, 2009. Each image is 35 meters across.

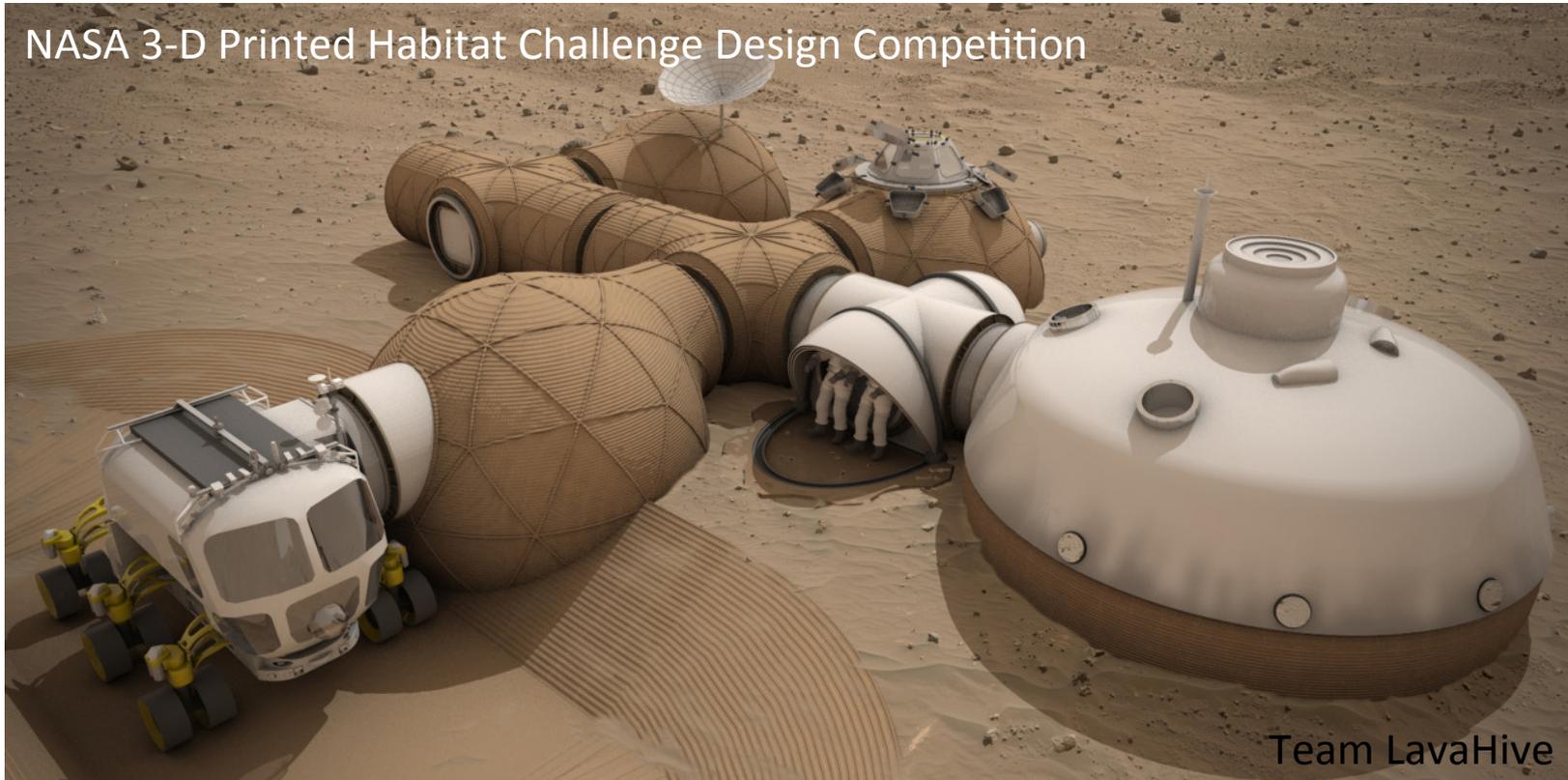


A Few Final Thoughts/Challenges



Next most rapidly useful/available resource (bulk regolith)

1) Use of surface materials for 3D structures/surfaces



Bigger challenges for long term material mining other than water:

1) Processing/Refining & Storage

2) Movement (surfaces, launch, in-space, EDL)



Smelting/Refining/Processing & Storage



Very complex process for most minerals in 1-G:

- Chemical reduction and electrolytic refining processes, reducing agents, acidic solutions, temperatures exceeding 1000°C , etc.
- How do you control and store the materials in off Earth environments (thermal, structural, etc.)?



Mali & Rwanda

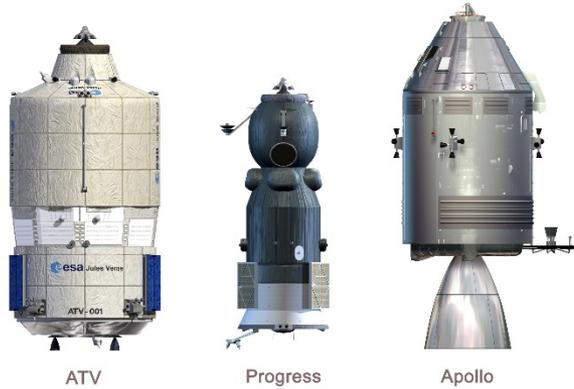
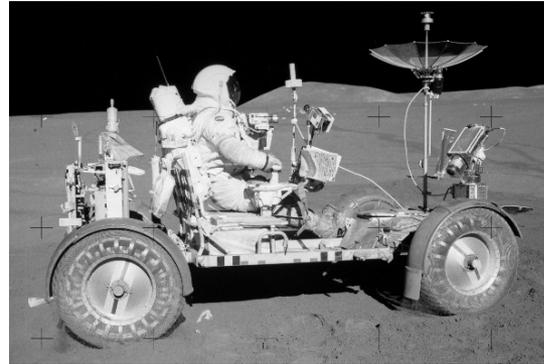




Moving is Difficult



Very time and energy intensive at human scales
(Delta V !!!)

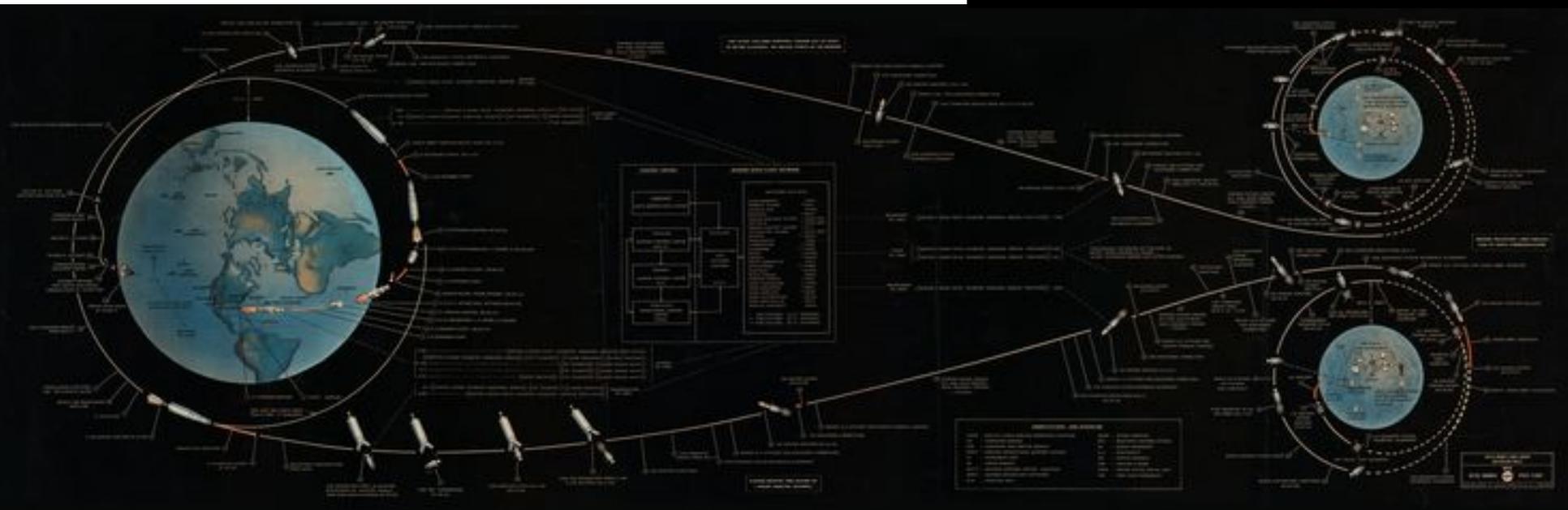
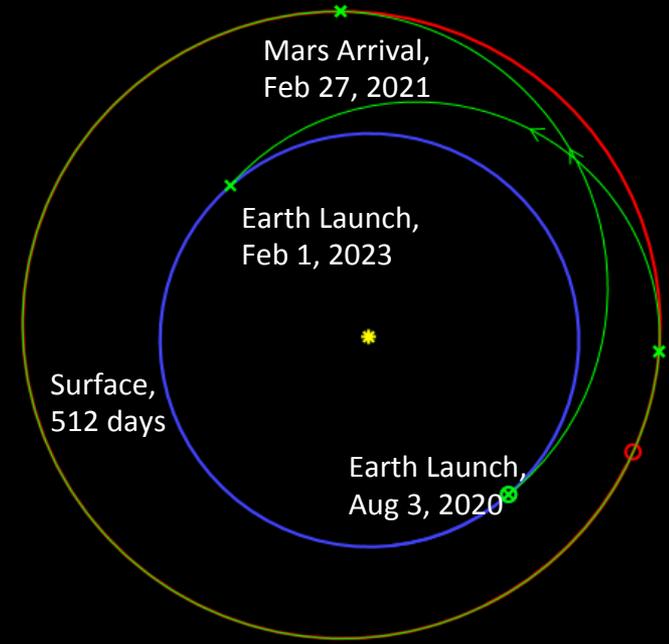


ATV

Progress

Apollo

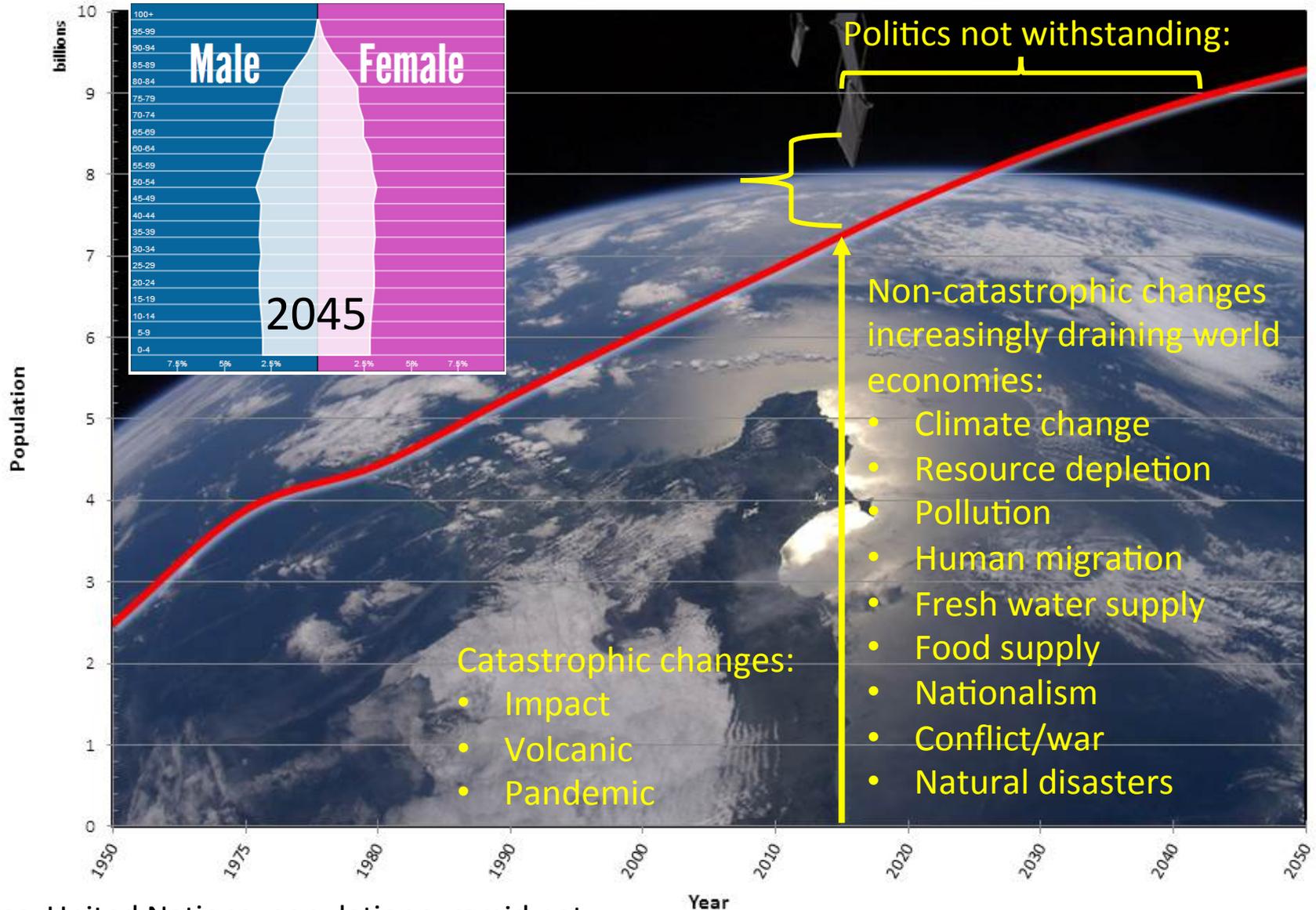
Materials mined off Earth will be used off Earth





A Final Difficulty

Human Occupation of Earth: The Space Age





Take Away



- 1) No “resource” is as important (design driver) and versatile as Water.
- 2) No “resource” other than water on Mars has been identified to a significant level of mining/reclamation confidence.
- 3) Instrument resolution needs to be significantly enhanced.
- 4) Stakeholder community needs to focus its goals, message and build synergy; no more human vs. robotic, science vs. ISRU, etc.
- 5) Stakeholder community needs to determine how to find long term, secure levels of funding independent of government changes.
- 6) At the largest scales, time may not be on our side for many reasons (no rose colored glasses here).
- 7) At the prospecting, mission and hardware design and testing levels, we could lose many of the next best Mars launch opportunities (Sep-2022; Oct-2024; Nov-2026; Dec-2028; Feb-2031; May-2033; Jul-2035; Sep-2037) if objectives and goals are not aligned across all stakeholder communities.